Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

Ireland's National Inventory Report 2018

Greenhouse Gas Emissions 1990-2016

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 2018

GREENHOUSE GAS EMISSIONS 1990 - 2016
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 2018 and refers to the greenhouse gas inventory time-series for the years 1990-2016.

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 2018 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 2018 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 2016, total emissions of greenhouse gases including indirect emissions from solvent use (without *LULUCF*) in Ireland were 61,545.82 kt CO_2 equivalent, which is 10.9 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 61,458.06 kt CO_2 equivalent. The total for 2016 is 12.8 per cent lower than the peak of 70,555.06 kt CO_2 equivalent in 2001 when emissions reached a maximum following a period of unprecedented economic growth. The *Energy* sector accounted for 61.6 per cent of total emissions in 2016, *Agriculture* contributed 31.3 per cent while a further 5.6 per cent emanated from *Industrial Processes and Product Use* and 1.6 per cent was due to *Waste*. Emissions of CO_2 accounted for 64.9 per cent of the national total in 2016, with CH_4 and N_2O contributing 22.3 per cent and 10.8 per cent, respectively. The combined emissions of HFC, PFC, SF_6 and NF_3 accounted for 2.1 per cent of total emissions in 2016.

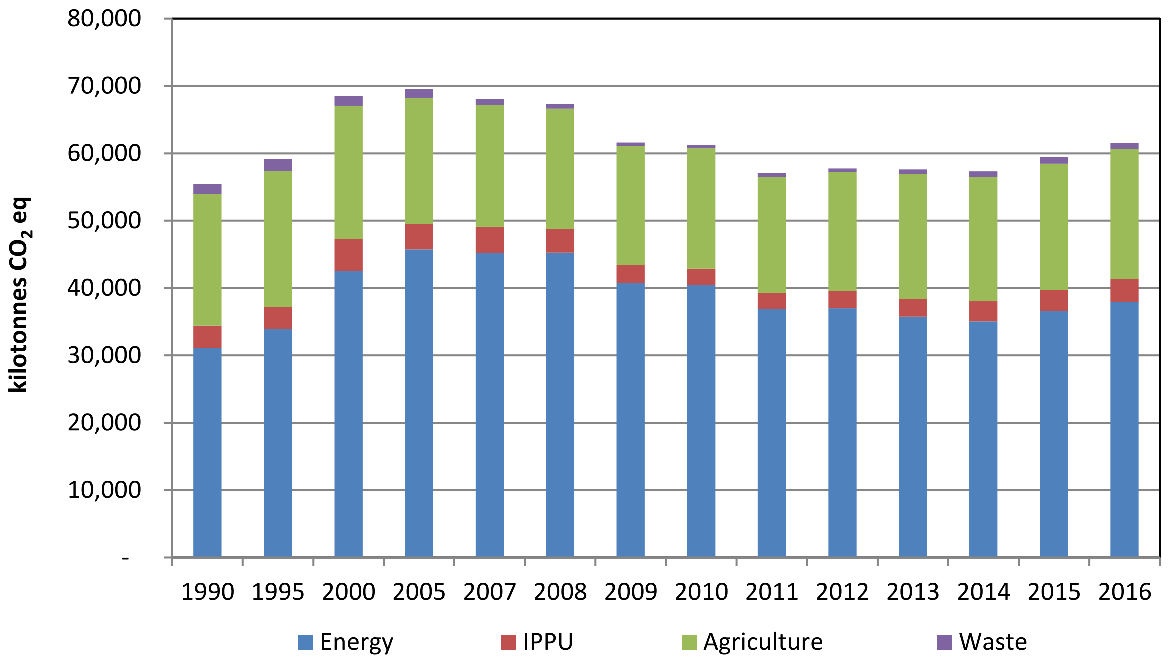

Figure ES.1 National total Greenhouse Gas emissions (excluding LULUCF) 1990-2016

An approach 1 level assessment of emission source categories (ranking on the basis of their contribution to total emissions) identified 27 key categories in 2016 (excluding the *LULUCF* sector). There were 18 key categories of CO_2, accounting for 63.4 per cent of total emissions. There were six key categories of CH_4, two key categories of N_2O and 1 key category of HFC in level assessment, which accounted for 21.0 per cent, 9.1 per cent and 1.7 per cent of total emissions, respectively. The results of the approach 1 key category analysis clearly show the impact of CO_2 emissions from energy consumption on total emissions in Ireland. These combustion sources of CO_2 emissions accounted for 16 out of 27 key categories identified by level assessment in 2016 or 59.8 per cent of total emissions. The top ten key categories contributed 74.9 per cent of total emissions in 2016 with emissions of CO_2 from the combustion of liquid fuels (petrol and diesel) by road traffic being the single largest source, accounting for 18.9 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 3.68 per cent in the 2016 inventory (excluding the LULUCF sector) and a trend uncertainty of 2.28 per cent for the period 1990 to 2016. These values are determined largely by the low uncertainty in the estimates of CO_2 emissions from the energy sector, which is the major source category in Ireland and for which the input data and methodologies are most reliable. The 64.9 per cent of emissions contributed by CO_2 in 2016 are estimated to have an uncertainty of 1.27 per cent. Emissions of CH_4 from 3.A Enteric Fermentation and N_2O from 3.D.1 Direct N_2O Emissions from Managed Soils sectors combined account for majority of the level uncertainty (contributing 89.4 per cent and 94.9 per cent, respectively to each gas uncertainty) in the 2016 inventory. The impact of HFC, PFC, SF_6 and NF_3 on inventory uncertainty in the year 2016 was negligible (0.5 per cent) because they account for only 2.1 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 2016. 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 2018 submission and the latest inventories for the years 1990-2016 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 1990-2016 time-series. The largest increase took place in transport with an increase of 139.3 per cent on 1990 levels, while there were increases of 15.0 per cent from the manufacturing industry and construction sector. Emissions from energy industries, were 11.5 per cent above 1990 levels in 2016. The emissions from Agriculture sector, the other main source category, increased during the 1990s but have decreased to 1.4 per cent below 1990 levels in 2016. As the emissions from energy increased, the contribution of agriculture to total national emissions decreased from 35.1 per cent in 1990 to 31.3 per cent in 2016. This is primarily as a result of falling livestock numbers since 1998 due to reform of the Common Agricultural Policy (CAP). The last two years have seen total national emissions grow by 7.4 per cent as the economy recovers from recession and agricultural output has increased, in particular, in the dairy industry sector.

ES.4 Indirect Greenhouse Gases

The inventory reporting process requires the inclusion of a number of gases whose indirect effects are also relevant to the assessment of human-induced impacts on climate. They include sulphur dioxide (SO_2), nitrogen oxides (NO_X), carbon monoxide (CO) and non-methane volatile organic compounds (NMVOC). Emissions of SO_2 contribute to the formation of aerosols, which may offset the effects of greenhouse gases, while CO, NO_X and NMVOC are precursors of ozone, another naturally occurring greenhouse gas. This NIR does not describe the methods used to estimate emissions of SO_2, NO_X, CO and NMVOC but the annual emissions estimates over the period 1990-2016 are included in the submission.

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

The emissions of most of the indirect gases have decreased substantially in the period 1990-2016 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 2016 in Ireland are of the order of 92.5 per cent in the case of SO_2, 70.8 per cent for CO and 33.9 per cent for NO_X and 24.3 per cent for NMVOC.

PART I

ANNUAL INVENTORY SUBMISSION 2018

1 Introduction

1.1 Background and Context

This report constitutes Ireland's National Inventory Report (NIR), for the years 1990-2016, as required under the United Nations Framework Convention on Climate Change. Ireland's submission under the UNFCCC in 2018 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://erc.epa.ie/ghg]. Such updating is necessary to keep the UNFCCC secretariat and other interested parties informed of the status of Irish greenhouse gas inventories and to document on-going improvements, recalculations and other developments affecting the estimates of emissions. The structure of the report is designed to facilitate year-on-year revision in a manner that allows for systematic and efficient assessment of progress towards the achievement of greenhouse gas emission inventories that meet the guiding principles of transparency, accuracy, completeness, comparability and consistency (TACCC).

1.2.1 Scope of Greenhouse Gas Inventories

1.2.1.1 Greenhouse Gases and Global Warming Potential

The full range of greenhouse gases for which emissions data are required under the Convention is given in Table 5.4.1 of Annex 5.3. It includes carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), the most widely known and most ubiquitous of the anthropogenic greenhouse gases, along with 19 hydrofluorocarbons (HFC), 9 perfluorocarbons (PFC), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3). The global warming potentials (GWPs) of the various greenhouse gases vary greatly, and are as listed in 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_2, CH_4 and N_2O are important because they are normally emitted in large amounts, HFCs, PFCs, SF_6 and NF_3 are included in the inventory process mainly because of their comparatively much larger GWP values.

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

1.2.1.2 Common Reporting Format

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

The 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_2 emissions from NMVOCs from solvent use and food and beverages sectors (category 2.D.3 and 2.H.2 in the IPPU sector) to be consistent with 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 minimization 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 Communications, Climate Action and Environment DCCAE)) 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 Sustainable Production and Consumption Programme (SPCP), compiles the national greenhouse gas emission inventories for submission on behalf of the DCCAE 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 Sustainable Production and Consumption Programme, 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, paragraph 3, 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. A research fellow contracted directly to another office (Office of Evidence and Assessment) within the EPA is responsible for completion of the annual inventory for all other land categories in LULUCF for the annual inventory under the Convention and elected activities under Article 3, paragraph 4, of the Kyoto Protocol (Cropland management and Grazing land management). The deliverables received by OES from DAFM and the research fellow include the completed CRF tables and draft NIR sections for their respective areas of responsibility.

The approval of the completed annual inventory involves sign-off by the QA/QC manager and the inventory manager before it is transmitted to the Board of the EPA via the Programme Manager of the Sustainable Production and Consumption 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.

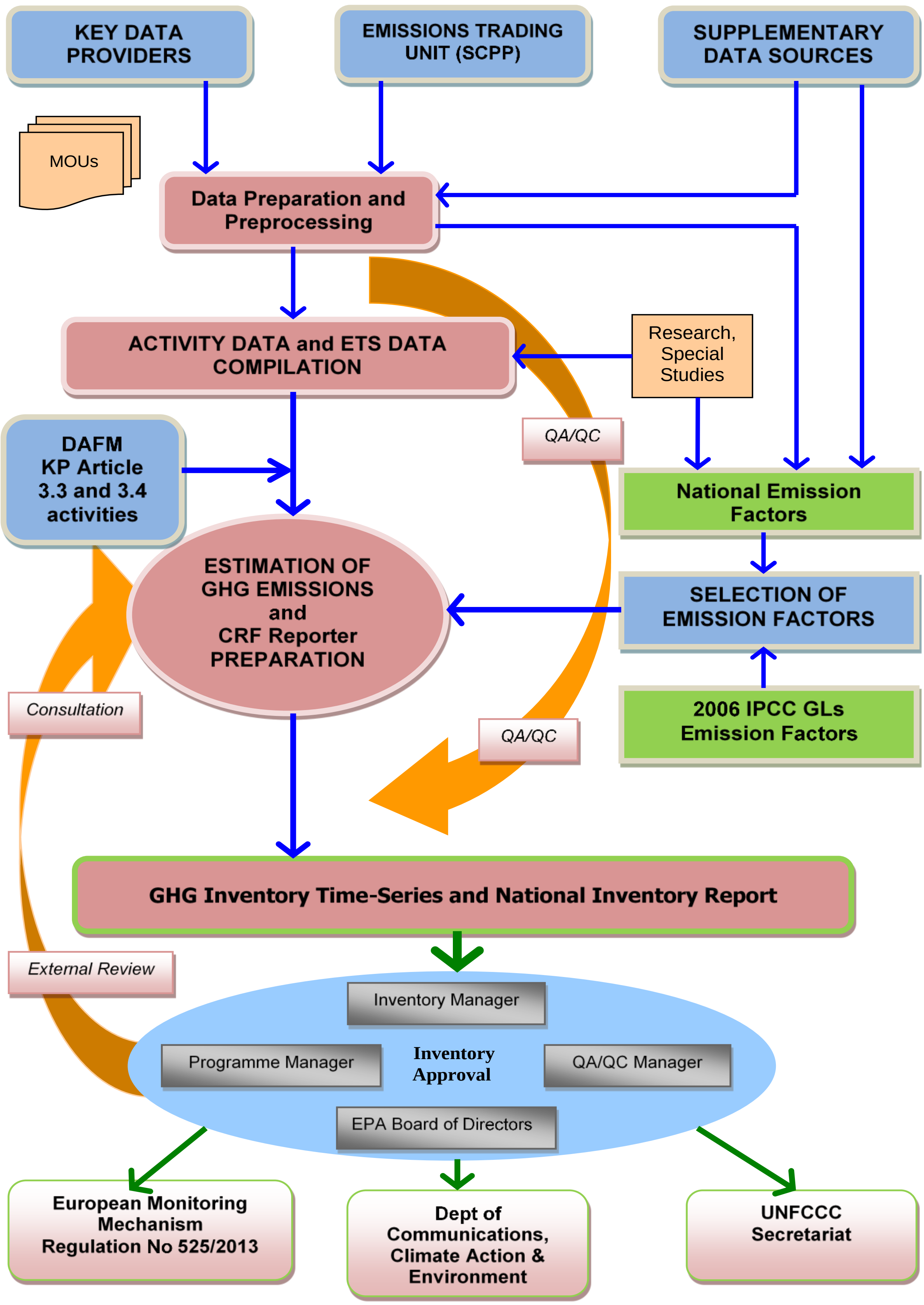

Figure 1.1 National Inventory System Overview

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 15th 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.

The inventory preparation and management process thereafter involves making any revisions subsequent to the receipt of updated or outstanding information nationally. In addition, any observations or amendments following initial assessment at EU level of the 15th January submission by Member States to the European Commission are incorporated into the inventory between 15th January and 15th March.

The complete and final inventory submission, including the National Inventory Report, is submitted to the European Commission by 15th March as required under Regulation (EU) 525/2013. This version of the latest inventory is fixed and retained for submission to the UNFCCC secretariat by 15th April to complete the reporting cycle. Ireland's national system is operating very successfully 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 2018 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 since 2013. 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_2 estimates in a number of sub-categories under *1.A.1 Energy Industries* and *2.A. Mineral Products*. When the allocation to these categories from the ETS raw data is completed, the output is returned to the ETS administrator for final checking against the source data. This ensures the efficient and consistent transfer of the verified ETS emissions estimates into the national inventory. Inventory development continues to benefit from the internal review procedures that are on-going with regard to the EU and its Member States. In 2014, experts from the inventory team attended 2 workshops, in March and June, organised by UBA Germany and the European Commission to facilitate the implementation of the 2006 IPCC guidelines for inventory reporting for the first submission for the second commitment period in 2015.

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

There has been no change in the national inventory arrangements since the previous annual inventory submission in April 2017. The inventory team is part of the Sustainable Consumption and Production Programme within the Office of Environmental Sustainability in the EPA. The Office of Environmental Sustainability is the designated inventory agency as of 1st January 2016. See also section 13.1.

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_2 sequestration by forest biomass, it may be necessary to apply sophisticated models to generate the activity data, the emission factors and or the emissions. The methods recommended by 2006 IPCC Guidelines for national greenhouse gas inventories use a tier system to take account of these issues and other factors, such as data availability, technical expertise, inventory capacity and other circumstances, which may vary considerably across sectors and Parties.

1.4.2 Data Collection, Processing and Storage

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

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

Table 1.1 Key Data Providers and Information covered by MOU

Key Data Provider	Data Supplied	Deadline	Sector in which data are used
Sustainable Energy Authority of Ireland	National Energy Balance; Detailed national energy consumption disaggregated by economic sector and fuel	30 September	Energy, Waste
Department of Agriculture, Food and Marine	**Table 1.1-1.4** Statistical data for cattle compiled under the Animal Identification and Movement (AIM) scheme Fertiliser and lime statistics Poultry statistics Sheep statistics	30 September	Agriculture
Department of Agriculture, Food and Marine (Forest Sector Development Division)	**Table 2.1** GHG emission/removal estimates from all pools for forest lands under the Convention Statistical data on Afforestation, Reforestation, Deforestation and harvesting for forest land lands under Article 3.3 of KP GHG emission/removal estimates from all biomass pools for KP Article 3.3 and elected activities under Article 3, paragraph 4, of the Kyoto Protocol (Cropland management and Grazing land management).	30 September	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_2 estimates and related fuel and production data for installations covered by the EU ETS[1]	30 April	Energy, IPPU
*Department of Communications, Climate Action and the Environment	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	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

[1]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 national model called CARBWARE is used to derive the estimates of emissions and removals for forest lands, which are incorporated in the overall scheme for LULUCF reporting under the Convention following the procedure outlined above. A variety of databases related to land cover, soil type and forest areas are applied for the *LULUCF* inventory under the Convention. These include the National Forest Inventory (NFI), the Forest Inventory and Planning System (FIPS), the Land Parcels Information System (LPIS), Co-ordinated Information on the Environment (CORINE) Land Cover Maps and the General Soil Map of Ireland. These are supported by statistical information from Bord na Móna, CSO and the National Roads Authority.

The static national model, CARBWARE has been extensively developed to a dynamic version to provide the necessary estimates for Article 3, paragraph 3 and paragraph 4, selected activities under the Kyoto Protocol. 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_4 and N_2O. The model processes detailed spatially explicit data on forest species and soil type obtained from the NFI, FIPS, soils maps, supported by the Grants and Premiums Administration System (GPAS) of DAFM, and felling license records. The model uses complex pre-processing functions, growth models, allometric equations and pool allocation and transfers to produce the results required for Article 3, paragraph 3 and paragraph 4, selected activities.

The annual ETS compilation serves as an important source of activity-specific and company-specific data on CO_2 emissions, fuel use and emission factors for major combustion sources and industrial processes. The emissions trading scheme covers 106 installations in Ireland with combined CO_2 emissions of 17,737.02 kt in 2016, accounting for 28.8 per cent of total greenhouse gas emissions (61,545.82 kt CO_2 equivalent). Guidance provided under the associated Decision 2004/156/EC (EP and CEU, 2004) on methodologies for estimating and reporting greenhouse gas emissions to support Directive 2003/87/EC, together with monitoring and verification mechanisms administered by the ETU, consolidates and improves the information in relation to a substantial proportion of CO_2 emissions for the purposes of reporting national GHG inventories under the Convention and the 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 1990-2016. 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_2)

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

The national model used to estimate carbon stock change in the various carbon pools for forest lands in respect of 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_2 in other LULUCF categories and for relevant CH_4 and N_2O emissions in this sector are invariably Tier 1.

1.5.2 Methane (CH_4)

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

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

1.5.3 Nitrous oxide (N_2O)

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

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

1.6 Overview of Key Categories

The 2006 IPCC guidelines defines a key category as one that is prioritised within the national inventory system because its estimate has a significant influence on the Party's total inventory of greenhouse gases in terms of the absolute level of emissions and removals, the trend in emissions and removals or uncertainty in emissions or removals. Information about key categories is considered to be crucial to the choice of methodology for individual sources and to the management and reduction of overall inventory uncertainty. The identification of such categories is recommended in order that inventory agencies can give them priority in the preparation of annual inventories, especially in cases where resources may be limited. Information on key categories is clearly also vital for the development of policies and measures for emissions reduction. The 2006 IPCC guidelines provide two approaches for undertaking the analysis of key categories that can be applied at any appropriate level of source aggregation, depending on the information available. The simplest approach, approach 1, is again used for 2016 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 2019 submission.

1.6.1 Key Categories at IPCC Level 2

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

The results at the IPCC Level 2 source category classification may be readily drawn from the CRF table Summary 2. Those for 1990 and 2016 are shown in Table 1.2 and Table 1.3, respectively. It can be seen that there are seven highly significant key categories of emissions in Ireland in the 1990-2016 trend including; CO_2 combustion sources in *1.A.1 Energy Industries*, *1.A.2 Manufacturing Industries and Construction*, *1.A.3 Transport* and *1.A.4 Other Sectors*, along with the CH_4 emissions from categories *3.A Enteric Fermentation* and *3.B Manure Management* and N_2O emissions from *3.D Agricultural Soils*. These seven categories accounted for 87.9 per cent and 90.3 per cent of total emissions in 1990 and 2016, respectively. In the case of 2016 emissions, three additional Level 2 source categories are needed to reach the cumulative 95 per cent threshold that defines key categories: *2.F.1 Refrigeration and air-conditioning* with HFC emissions, *2.A.1 Cement Production* with CO_2 emissions and *5.A Solid Waste Disposal* with CH_4 emissions. Category *2.F.1* is key in 2016 level analysis and not in 1990, whereas categories *2.B.1* and *2.B.2* are key in 1990 level analysis and not in 2016. The increase in the contribution of CO_2 emissions from category *1.A.3 Transport* from 9.0 per cent in 1990 to 19.7 per cent in 2016 is notable, along with the a reduction in the contribution from *1.A.4* in *Other Sectors Energy* from 18.1 per cent in 1990 to 13.5 per cent in 2016. This simple analysis of key categories continues to prove useful to the formulation of mitigation strategies and for prioritising work on inventories in Ireland.

When LULUCF is accounted for in the Level 2 analysis, CO_2 emissions in three LULUCF categories (*4.A Forest land, 4.C. Grassland, 4.D Wetlands*) become key categories in 1990, and the same three categories and associated gas, are also key categories in 2016.

Table 1.2 Key Categories at IPCC Level 2 in 1990

IPCC Level 2 Source Category		GHG	Emissions in 1990 (kt CO_2 eq)	1990 Level Assessment (%)	Cumulative Total of Level (%)
3.A	Enteric Fermentation	CH_4	11,356.97	20.47	20.47
1.A.1	Energy Industries	CO_2	11,145.01	20.08	40.55
1.A.4	Other Sectors(Comm/Resid/Agric)	CO_2	10,030.94	18.08	58.63
3.D	Agricultural Soils	N_2O	5,853.36	10.55	69.18
1.A.3	Transport	CO_2	5,021.69	9.05	78.23
1.A.2.	Manufacturing Industries and Construction	CO_2	3,942.63	7.11	85.33
3.B	Manure Management	CH_4	1,406.05	2.53	87.87
5.A	Solid Waste Disposal	CH_4	1,318.08	2.38	90.24
2.B.2	Nitric Acid Production	N_2O	995.32	1.79	92.03
2.B.1	Ammonia Production	CO_2	990.23	1.78	93.82
2.A.1	Cement Production	CO_2	884.00	1.59	95.41

* Nitric acid and Ammonia plants ceased operation in 2002 and 2001, respectively

Table 1.3 Key Categories at IPCC Level 2 in 2016

IPCC Level 2 Source Category		GHG	Emissions in 2016 (kt CO_2 eq)	2016 Level Assessment (%)	Cumulative Total of Level (%)
1.A.3	Transport	CO_2	12,368.40	20.10	20.10
1.A.1	Energy Industries	CO_2	12,148.72	19.74	39.84
3.A	Enteric Fermentation	CH_4	11,247.27	18.27	58.11
1.A.4	Other Sectors(Comm/Resid/Agric)	CO_2	8,287.57	13.47	71.58
3.D	Agricultural Soils	N_2O	5,598.85	9.10	80.67
1.A.2	Manufacturing Industries and Construction	CO_2	4,530.43	7.36	88.03
2.A.1	Cement Production	CO_2	1,793.52	2.91	90.95
3.B	Manure Management	CH_4	1,402.22	2.28	93.23
2.F.1	Product Uses as Substitutes for ODS - Refrigeration and air-con (incl. MAC)	HFC	1,021.89	1.66	94.89
5.A	Solid Waste Disposal	CH_4	767.78	1.25	96.13

Table 1.4 Summary of Methods

IPCC SOURCE AND SINK CATEGORIES	CO_2	CH_4	N_2O	HFC	PFC	SF_6	NF_3
1. Energy	**T1,T2,T3**	**T1,T2,T3**	**T1,T2,T3**				
A. Fuel Combustion (Sectoral Approach)	T1,T2,T3	T1,T2,T3	T1,T2,T3				
1. Energy Industries	T1, T3	T1, T2	T1, T2				
2. Manufacturing Industries and Construction	T1, T2, T3	T1	T1				
3. Transport	T2, T3	T1, T2, T3	T1, T2, T3				
4. Other Sectors	T1, T2	T1	T1				
5. Other							
B. Fugitive Emissions from Fuels	NA	T1, T2	NA				
1. Solid Fuels	NA	T1	NA				
2. Oil and Natural Gas	NA	T1, T2	NA				
C. Carbon Dioxide Transport and Storage	NA						
2. Industrial Processes and Product Use	**T1,T3**	**NA**	**D**	**T1, T2, T3**	**T2**	**T2**	**T2**
A. Mineral Industry	T3	NA	NA	NA	NA	NA	NA
B. Chemical Industry	NA	NA	NA				
C. Metal Production	NA	NA	NA				
D. Non-Energy Products from Fuels and Solvent Use	T1	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			T1			T1	
H. Other							
3. Agriculture	**T1**	**T1,T2**	**T1,T2**				
A. Enteric Fermentation		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						
4. Land-Use Land-Use Change Change and Forestry	**T1,T2,T3**	**T1**	**T1**				
A. Forest Land	T1,T2,T3	T1	T1				
B. Cropland							
C. Grassland	T1, T3		T1				
D. Wetlands	T1	T1	T1				
E. Settlements	T1, T3		T1				
F. Other Land	T1, T3						
G. Harvested wood products	T2						
H. Other							
5. Waste	**T1**	**T1,T2**	**T1**				
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							
6. Other							
Article 3.3 Afforestation and Deforestation	T3	T1	T1				
International Bunkers							
Aviation	T1	T1	T1				
Navigation	T1	T1	T1				
Multilateral Operations	NA	NA	NA				
CO_2 Emissions from Biomass	T1	T1	T1				
CO_2 captured	NA	NA	NA				
Long-term storage of C in waste disposal sites	NA	NA	NA				
Indirect N_2O	NA	NA	NA				
Indirect CO_2	T1	NA	NA				

T1: IPCC Tier 1 or equivalent
T2: IPCC Tier 2 or equivalent
T3: IPCC Tier 3 or equivalent

Table 1.5 Summary of Emission Factors

IPCC SOURCE AND SINK CATEGORIES	CO_2	CH_4	N_2O	HFC	PFC	SF_6	NF_3
1. Energy	**CS,D,M,PS**	**CS,D,M**	**D,M**				
A. Fuel Combustion (Sectoral Approach)	CS,D,M,PS	**D,M**	D,M				
1. Energy Industries	CS,D,PS	D	D				
2. Manufacturing Industries and Construction	CS,D,PS	D	D				
3. Transport	CS,M	D,M	D,M				
4. Other Sectors	CS,D	D	D				
5. Other							
B. Fugitive Emissions from Fuels	NA	CS,D	NA				
1. Solid Fuels	NA	D	NA				
2. Oil and Natural Gas	NA	CS,D	NA				
C. Carbon Dioxide Transport and Storage	NA	NA	NA				
2. Industrial Processes and Product Use	**D,PS**	**NA**	**D**	**CS**	**NA**	**NA**	**NA**
A. Mineral Industry	PS						
B. Chemical Industry	NA	NA	NA				
C. Metal Production	NA	NA					
D. Non-Energy Products from Fuels and Solvent Use	D	NA	NA	NA	NA	NA	NA
E. Electronic Industry							
F. Product Uses as Substitutes for ODS				CS	NA	NA	NA
G. Other Product Manufacture and Use			D	NA		NA	
H. Other							
3. Agriculture	**D**	**CS,D**	**CS,D**				
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						
4. Land-Use Land-Use Change and Forestry	**CS,D,OTH**	**D**	**D**				
A. Forest Land	CS	D	D				
B. Cropland							
C. Grassland	CS,D		D				
D. Wetlands	CS,D	D	D				
E. Settlements	CS,D, OTH		D				
F. Other Land	CS						
G. Harvested wood products	D						
H. Other							
5. Waste	**D**	**CS,D**	**D**				
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							
6. Other							
Article 3.3 Afforestation and Deforestation	CS	D	D				
International Bunkers							
Aviation	CS	CR	CR				
Marine	CS	D	D				
Multilateral Operations	NA	NA	NA				
CO_2 Emissions from Biomass	CS, D	D, M, CR	D, M, CR				
CO_2 captured	NA	NA	NA				
Long-term storage of C in waste disposal sites	NA	NA	NA				
Indirect N_2O	NA	NA	NA				
Indirect CO_2	CS, CR, D	NA	NA				

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 2016 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 1990-2016 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 2016 key category analysis are provided in Tables 1.A-D in Annex 1.

The results of the level and trend assessments for 2016 **excluding LULUCF** categories may be summarised as follows:

(i) The **level assessment** identifies 27 key categories, 21 of which are also key categories by trend assessment. Methane emissions in *3.A.1 Enteric Fermentation* – Dairy Cattle; CH_4 emissions in *3.B.1 Manure Management* – Non-Dairy Cattle; CH_4 emissions in *3.B.1 Manure Management* –Dairy Cattle; N_2O emissions in *3.D.2 Agricultural Soils – Indirect Soil Emissions*; CO_2 emissions in *3.G.1 Liming* are key categories by level assessment only.

(ii) There are 18 key categories of CO_2 in level assessment, accounting for 63.4 per cent of total emissions;

(iii) There are six key categories of CH_4, two key categories of N_2O and one category of HFC in level assessment, which account for 21.0 per cent, 9.1 per cent and 1.7 per cent, respectively, of total emissions;

(iv) Energy accounts for 16 key categories, Agriculture for 8, while Industrial Processes and Product Use contributes two and Waste contributes one;

(v) The **trend assessment** identifies 26 key categories, all of which but four (CH_4 emissions in; *1.A.4.b. Residential*– peat fuel and solid fuels; CO_2 emissions in *1.A.2 Manufacturing Industries & Construction* – Non-Renewable waste; CH_4 emissions in *1.B.2.b Fugitive emissions* – Natural gas are key categories for 2016 level assessment;

(vi) There are 18 key categories of CO_2 in trend assessment, accounting for 81.3 per cent of the total trend;

(vii) There are 6 key categories of CH_4, one key category of N_2O and two key categories of HFC in trend assessment, which account for 8.1 per cent, 2.6 per cent and 3.2 per cent, respectively, of the total trend.

The results of the level and trend assessment for 2016 **including LULUCF** categories may be summarised as follows:

(i) The **level assessment** identifies 33 key categories, 22 of these are sources of CO_2 emissions, accounting for 69.0 per cent of total emissions;

(ii) There are six additional categories that are not present in the assessment excluding LULUCF, four of which are LULUCF. The remaining two categories are CH_4 emissions in *3.B.1.3 Manure Management* – Swine and N_2O emissions in *3.B.2.1 Manure Management* – Non-Dairy Cattle.

(iii) The four additional LULUCF categories are: CO_2 emissions from *4.C.1 Grassland Remaining Grassland, 4.A.2 Land Converted to Forest Land, 4.D.1 Wetlands Remaining Wetlands, 4.G Harvested Wood Products*.

(iv) There are seven key categories from sources of CH_4, three key categories of N_2O and one category of HFC, which account for 17.3 per cent, 7.7 per cent and 1.3 per cent, respectively, of total emissions;

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

(vi) The **trend assessment** identifies 32 key categories, six of which were not present in the assessment excluding LULUCF: CO_2 emissions from LULUCF categories: 4*.A.2 Land converted to Forest Land, 4.A.1 Forest land Remaining Forest Land, 4.C.1 Grassland Remaining Grassland, 4.D.1 Wetlands Remaining Wetlands and 4.G Harvested Wood Products*; and HFC emissions from *2.F.4 Product Uses as substitutes for ODS-Aerosols*.

(vii) There are 23 key categories of CO_2 in the trend assessment, accounting for 84.0 per cent of the total trend;

(viii) There are six key categories of CH_4, one key category of N_2O and two key category of HFC in the trend assessment, which account for 6.4 per cent, 2.1 per cent and 2.8 per cent, respectively, of the total trend.

The list of key categories given by level assessment in 2016 is very similar to that for 1990. However, the higher ranking of the main CO_2 emissions from road transport is notable in 2016. Seven out of the top ten key categories in 1990 (excluding LULUCF) were in the top ten in 2016 but in a different order. The remaining three key categories in 2016 are: CO_2 emissions from *1.A.4.b Residential* – Liquid Fuels, *1.A.2. Manufacturing Industries & Construction* - gaseous fuels and *2.A.1 Cement Production*. These sectors replaced 3 key sectors in 1990: CO_2 emissions from *1.A.4.b. Residential* - peat fuel, *1.A.4.b. Residential* - solid fuels and *1.A.2. Manufacturing Industries & Construction* – Liquid Fuels. Those seven key categories contributed 54.0 and 63.3 per cent, of total emissions in 1990 and 2016, respectively. The emissions of CO_2 from the use of petrol and diesel by road traffic (*1.A.3.b*) and CH_4 emissions from *3.A.1. Enteric Fermentation* - Non-Dairy Cattle were the largest source categories of greenhouse gas emissions in Ireland in 2016, accounting for 18.9 and 10.9 per cent of the total, respectively.

The CO_2 emissions/removals in four categories (*4.C. Grassland, 4.A.2 Land converted to Forest Land, 4.D. Wetlands* and *4.G Harvested Wood Products* are key categories in level assessment when the LULUCF sector is included in the detailed analysis. CO_2 emissions in *KP B.3 Grazing Land Management, KP A.1 Afforestation/Reforestation and KP B.1 Forest Management* are also key categories in 2016 when Article 3, paragraph 3 and paragraph 4, activities are included in the analysis.

1.6.3 Use of Key Category Analysis

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

This is well shown by the results of key category determination for Ireland, based on approach 1 level assessment, in Table 1.9. The results including LULUCF indicate that 22 of the 33 key categories in 2016 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 1.9 (excluding LULUCF) clearly show the impact of CO_2 emissions from energy consumption on total emissions in Ireland. These emissions account for 17 of the key categories listed in Table 1.10 (trend, excluding LULUCF) and for 60.1 per cent of total emissions in 2016. While key categories determined by CO_2 emissions from energy consumption have a major bearing on total emissions in Ireland, the remaining potential for significant reduction in the uncertainties associated with these sources is rather limited. The activity data and CO_2 emission factors for Energy source categories in general are among the most reliable items of input data in the inventory and there is consequently little scope for improving the accuracy of the emission estimates. The application of a robust Tier 2 methodology for emissions of CH_4 from enteric fermentation in cattle (non-dairy) and the use of verified estimates for CO_2 emissions from cement production means that the contributions from these two additional key categories (ranked 17 and 15 in Table 1.10, respectively), making up a further 13.8 per cent of the total, are also known with probably the highest certainty now achievable. The HFC emissions from *2.F.1 Refrigeration and air-conditioning*, N_2O emissions from *3.D.1 Agricultural Soils* – direct soil emissions and CH_4 emissions from both *3.A.2 Enteric fermentation in sheep* and *5.A Solid Waste Disposal* account for most of the remaining important key categories in Table 1.10. 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.

1.7 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 2016 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 2016 data is presented in Table 1.12 (excluding LULUCF) and Table 1.13 (including LULUCF), using emissions on a GWP basis and a level of source category disaggregation that corresponds in general to the level used for emissions calculation and for key category analysis. This disaggregation level limits the likely dependency and correlation between source categories.

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

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

The Agriculture sector is the second most important sector in Ireland's GHG inventory and has a major influence on overall uncertainty due to its large contribution in terms of CH_4 and N_2O emissions. Ireland has long-established and robust statistical data collection procedures in place for agriculture in general, which guides the selection of 1 per cent as the activity data uncertainty for all agriculture sub-categories. The 2006 IPCC guidelines indicate that the emission factor estimates for the Tier 2 method to determine CH_4 emissions from enteric fermentation in cattle are likely to have an uncertainty of 20 per cent. Following the opinion of national agriculture experts, a value of 15 per cent has been adopted for these emissions to take into account Ireland's detailed Tier 2 method and use of reliable data. In some of the other important emissions sources in Agriculture (such as manure management and agricultural soils) the activity data or emission factors ultimately used are determined by several specific component inputs, which are individually subject to varying degrees of uncertainty. In this submission, 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 2016 in order to include the revised EF uncertainty associated with cattle dung and urine deposited by grazing cattle in category 3.D.1.3 to account for new country specific EFs in this submission.

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

Category 5.A Solid Waste is the principal source of CH_4 emissions outside Agriculture. Under the methodology used, the component uncertainties for both activity data and emission factor for CH_4 generation are derived using equations 3.1 and 3.2 in chapter 3 of the 2006 IPCC guidelines Volume 1 as shown in the footnotes to Table 1.12. These are combined with uncertainties of 30 per cent and 10 per cent for flaring and utilisation respectively to obtain the overall uncertainty using equation 3.2.

Equations 3.1 and 3.2 are both applied as appropriate in a hierarchical approach to derive uncertainty for LULUCF under the Convention 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 2016 inventory under the Convention gives an overall uncertainty of 3.68 per cent in total emissions and a trend uncertainty of 2.28 per cent for the period 1990 to 2016. This equates to both a decrease on level and in trend as compared to the values reported in the 2017 submission (for 1990 to 2015) of 10.01 and 2.76 per cent, respectively.

The reason for the overall decrease from 2015 to 2016 is primarily due to the finer level of disaggregation used in approach 1 for agricultural categories this year and reductions in EF uncertainty associated with category 3.D.1.3, urine and dung deposited by grazing animals.

The reason for the trend decrease from 2015 to 2016 is mainly due to increasing emissions from agricultural categories; enteric fermentation, manure management and agricultural soils which are more in line with emission levels for those categories in 1990.

Relatively low estimates are determined largely by the low uncertainties in the estimate of CO_2 emissions, which account for 64.9 per cent of total national emissions in 2016 and which are estimated to have a level uncertainty of 1.27 per cent (excluding LULUCF). When CH_4 is included, bringing the proportion of total emissions up to 87.2 per cent, the total uncertainty estimate is 2.02 per cent (excluding LULUCF), even though there are large uncertainties assigned to the CH_4 emission factors in some source categories. However, it is the influence of N_2O that leads to a higher uncertainty in total emissions bringing it to 3.68 per cent. The impact of HFCs, PFCs, SF_6 and NF_3 on inventory uncertainty remains negligible because these gases account for only 2.1 per cent of total emissions in Ireland.

The approach 1 uncertainty analysis (including LULUCF) for Ireland's 2016 inventory under the Convention (Table 1.13) gives an overall level uncertainty of 4.19 per cent in total emissions and a trend uncertainty of 10.21 per cent for the period 1990 to 2016.

The overall level uncertainly (including LULUCF) of the 2016 inventory is a decrease on the last submission. The corresponding value in 2016 submission (2015 data) was 9.63 per cent. The reason for the decrease from 2015 to 2016 is as described above in the uncertainty analysis excluding LULUCF.

1.8 Completeness and Time-Series Consistency

Table 1.14 gives an overview of the level of completeness of the 2016 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, 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 Sub-category	Emission Source / Activity	Direct GHG	1990 Emissions exclud. LULUCF (kt CO_2 eq)	1990 Level assessment exclud. LULUCF (%)	Cumulative Total (%)
1	3.A.1	Enteric Fermentation - Non-Dairy Cattle	CH_4	6,702.59	12.08	12.08
2	3.D.1	Agricultural Soils - Direct Soil Emissions	N_2O	5,296.13	9.54	21.62
3	1.A.1	Energy Industries - Solid Fuels	CO_2	4,844.66	8.73	30.35
4	1.A.3.b	Road Transport - Liquid Fuels	CO_2	4,690.42	8.45	38.81
5	3.A.1	Enteric Fermentation - Dairy Cattle	CH_4	3,398.80	6.13	44.93
6	1.A.1	Energy Industries - Peat Fuel	CO_2	3,164.78	5.70	50.63
7	1.A.4.b	Residential - Peat Fuel	CO_2	3,123.37	5.63	56.26
8	1.A.4.b	Residential - Solid Fuels	CO_2	2,483.42	4.48	60.74
9	1.A.2	Manufacturing Industries & Construction - Liquid Fuels	CO_2	2,198.38	3.96	64.70
10	1.A.1	Energy Industries - Gaseous Fuels	CO_2	1,880.66	3.39	68.09
11	1.A.4.a	Commercial/Institutional - Liquid Fuels	CO_2	1,870.07	3.37	71.46
12	5.A	Solid Waste Disposal	CH_4	1,318.08	2.38	73.84
13	1.A.1	Energy Industries - Liquid Fuels	CO_2	1,254.90	2.26	76.10
14	3.A.2	Enteric Fermentation - Sheep	CH_4	1,176.34	2.12	78.22
15	1.A.4.b	Residential - Liquid Fuels	CO_2	1,175.34	2.12	80.33
16	2.B.2	Chemical Industry - Nitric Acid Production	N_2O	995.32	1.79	82.13
17	2.B.1	Chemical Industry - Ammonia Production	CO_2	990.23	1.78	83.91
18	2.A.1	Cement Production	CO_2	884.00	1.59	85.51
19	1.A.2	Manufacturing Industries & Construction - Gaseous Fuels	CO_2	873.02	1.57	87.08
20	1.A.2	Manufacturing Industries & Construction - Solid Fuels	CO_2	871.24	1.57	88.65
21	1.A.4.c	Agriculture/Fishing - Liquid Fuels	CO_2	747.23	1.35	90.00
22	3.B.1.1	Manure Management - Non-Dairy Cattle	CH_4	684.58	1.23	91.23
23	3.D.2	Agricultural Soils - Indirect Soil Emissions	N_2O	557.23	1.00	92.23
24	3.G.1	Liming - Limestone CaCO3	CO_2	355.04	0.64	92.87
25	3.B.1.1	Manure Management - Dairy Cattle	CH_4	354.22	0.64	93.51
26	1.A.4.b	Residential - Gaseous Fuels	CO_2	269.73	0.49	94.00
27	1.A.4.b	Residential - Peat Fuel	CH_4	227.65	0.41	94.41
28	1.A.4.a	Commercial/Institutional - Gaseous Fuels	CO_2	223.49	0.40	94.81
29	2.A.2	Lime Production	CO_2	214.08	0.39	95.20

Table 1.7 Key Category Analysis Level Assessment 2016 (excluding LULUCF)

Ranking	IPCC Sub-category	Emission Source / Activity	Direct GHG	2016 Emissions exclud. LULUCF (kt CO_2 eq)	2016 Level assessment exclud. LULUCF (%)	Cumulative Total (%)
1	1.A.3.b	Road Transport - Liquid Fuels	CO_2	11,623.55	18.89	18.89
2	3.A.1	Enteric Fermentation - Non-Dairy Cattle	CH_4	6,697.92	10.88	29.77
3	3.D.1	Agricultural Soils - Direct Soil Emissions	N_2O	5,062.89	8.23	38.00
4	1.A.1	Energy Industries - Gaseous Fuels	CO_2	4,896.48	7.96	45.95
5	1.A.1	Energy Industries - Solid Fuels	CO_2	4,281.83	6.96	52.91
6	3.A.1	Enteric Fermentation - Dairy Cattle	CH_4	3,780.92	6.14	59.05
7	1.A.4.b	Residential - Liquid Fuels	CO_2	3,008.64	4.89	63.94
8	1.A.1	Energy Industries - Peat Fuel	CO_2	2,600.14	4.22	68.16
9	1.A.2	Manufacturing Industries & Construction - Gaseous Fuels	CO_2	2,372.52	3.85	72.02
10	2.A.1	Cement Production	CO_2	1,793.52	2.91	74.93
11	1.A.2	Manufacturing Industries & Construction - Liquid Fuels	CO_2	1,556.14	2.53	77.46
12	1.A.4.b	Residential - Gaseous Fuels	CO_2	1,316.51	2.14	79.60
13	1.A.4.a	Commercial/Institutional - Gaseous Fuels	CO_2	1,094.85	1.78	81.38
14	2.F.1	Product Uses as Substitutes for ODS -Refrigeration and air-con (incl. MAC)	HFC	1,021.89	1.66	83.04
15	1.A.4.b	Residential - Peat Fuel	CO_2	842.41	1.37	84.41
16	5.A	Solid Waste Disposal	CH_4	767.78	1.25	85.66
17	1.A.4.a	Commercial/Institutional - Liquid Fuels	CO_2	756.06	1.23	86.88
18	1.A.4.b	Residential - Solid Fuels	CO_2	721.27	1.17	88.06
19	3.A.2	Enteric Fermentation - Sheep	CH_4	670.59	1.09	89.15
20	3.B.1.1	Manure Management - Non-Dairy Cattle	CH_4	640.79	1.04	90.19
21	1.A.4.c	Agriculture/Fishing - Liquid Fuels	CO_2	547.83	0.89	91.08
22	3.D.2	Agricultural Soils - Indirect Soil Emissions	N_2O	535.95	0.87	91.95
23	1.A.1	Energy Industries - Liquid Fuels	CO_2	503.82	0.82	92.77
24	1.A.2	Manufacturing Industries & Construction - Solid Fuels	CO_2	436.33	0.71	93.48
25	3.G.1	Liming - Limestone CaCO3	CO_2	425.60	0.69	94.17
26	3.B.1.1	Manure Management - Dairy Cattle	CH_4	344.28	0.56	94.73
27	1.A.3.d	Navigation - Liquid Fuels	CO_2	263.69	0.43	95.16

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

Ranking	IPCC Sub-category	Emission Source / Activity	Direct GHG	1990 Emissions exclud. LULUCF (kt CO_2 eq)	1990 Emissions for LULUCF (kt CO_2 eq)	Absolute Values (kt CO_2 eq)	1990 Level assessment includ. LULUCF (%)	Cumulative Total (%)
1	4.C	LULUCF - Grassland	CO_2	0.00	7,343.33	7,343.33	10.77	10.77
2	3.A.1	Enteric Fermentation - Non-Dairy Cattle	CH_4	6,702.59	0.00	6,702.59	9.83	20.60
3	3.D.1	Agricultural Soils - Direct Soil Emissions	N_2O	5,296.13	0.00	5,296.13	7.77	28.37
4	1.A.1	Energy Industries - Solid Fuels	CO_2	4,844.66	0.00	4,844.66	7.11	35.47
5	1.A.3.b	Road Transport - Liquid Fuels	CO_2	4,690.42	0.00	4,690.42	6.88	42.35
6	3.A.1	Enteric Fermentation - Dairy Cattle	CH_4	3,398.80	0.00	3,398.80	4.98	47.33
7	1.A.1	Energy Industries - Peat Fuel	CO_2	3,164.78	0.00	3,164.78	4.64	51.98
8	1.A.4.b	Residential - Peat Fuel	CO_2	3,123.37	0.00	3,123.37	4.58	56.56
9	4.A.1	LULUCF - Forest land Remaining Forest Land	CO_2	0.00	-2,719.66	2,719.66	3.99	60.55
10	1.A.4.b	Residential - Solid Fuels	CO_2	2,483.42	0.00	2,483.42	3.64	64.19
11	1.A.2	Manufacturing Industries & Construction - Liquid Fuels	CO_2	2,198.38	0.00	2,198.38	3.22	67.41
12	1.A.1	Energy Industries - Gaseous Fuels	CO_2	1,880.66	0.00	1,880.66	2.76	70.17
13	1.A.4.a	Commercial/Institutional - Liquid Fuels	CO_2	1,870.07	0.00	1,870.07	2.74	72.91
14	4.D	LULUCF - Wetlands	CO_2	0.00	1,487.42	1,487.42	2.18	75.09
15	5.A	Solid Waste Disposal	CH_4	1,318.08	0.00	1,318.08	1.93	77.03
16	1.A.1	Energy Industries - Liquid Fuels	CO_2	1,254.90	0.00	1,254.90	1.84	78.87
17	3.A.2	Enteric Fermentation - Sheep	CH_4	1,176.34	0.00	1,176.34	1.73	80.59
18	1.A.4.b	Residential - Liquid Fuels	CO_2	1,175.34	0.00	1,175.34	1.72	82.32
19	2.B.2	Chemical Industry - Nitric Acid Production	N_2O	995.32	0.00	995.32	1.46	83.78
20	2.B.1	Chemical Industry - Ammonia Production	CO_2	990.23	0.00	990.23	1.45	85.23
21	2.A.1	Cement Production	CO_2	884.00	0.00	884.00	1.30	86.52
22	1.A.2	Manufacturing Industries & Construction - Gaseous Fuels	CO_2	873.02	0.00	873.02	1.28	87.80
23	1.A.2	Manufacturing Industries & Construction - Solid Fuels	CO_2	871.24	0.00	871.24	1.28	89.08
24	1.A.4.c	Agriculture/Fishing - Liquid Fuels	CO_2	747.23	0.00	747.23	1.10	90.18
25	3.B.1.1	Manure Management - Non-Dairy Cattle	CH_4	684.58	0.00	684.58	1.00	91.18
26	3.D.2	Agricultural Soils - Indirect Soil Emissions	N_2O	557.23	0.00	557.23	0.82	92.00
27	4.G	LULUCF - Harvested wood products	CO_2	0.00	-413.04	413.04	0.61	92.61
28	3.G.1	Liming - Limestone CaCO3	CO_2	355.04	0.00	355.04	0.52	93.13
29	3.B.1.1	Manure Management - Dairy Cattle	CH_4	354.22	0.00	354.22	0.52	93.65
30	1.A.4.b	Residential - Gaseous Fuels	CO_2	269.73	0.00	269.73	0.40	94.04
31	4.C	LULUCF - Grassland	CH_4	0.00	267.95	267.95	0.39	94.43
32	1.A.4.b	Residential - Peat Fuel	CH_4	227.65	0.00	227.65	0.33	94.77
33	1.A.4.a	Commercial/Institutional - Gaseous Fuels	CO_2	223.49	0.00	223.49	0.33	95.10

Table 1.9 Key Category Analysis Level Assessment 2016(including LULUCF)

Ranking	IPCC Sub-category	Emission Source / Activity	Direct GHG	2016 Emissions exclud. LULUCF (kt CO_2 eq)	2016 Emissions for LULUCF (kt CO_2 eq)	Absolute Values (kt CO_2 eq)	2016 Level assessment includ. LULUCF (%)	Cumulative Total (%)
1	1.A.3.b	Road Transport - Liquid Fuels	CO_2	11,623.55	0.00	11,623.55	15.27	15.27
2	4.C	LULUCF - Grassland	CO_2	0.00	6,889.15	6,889.15	9.05	24.33
3	3.A.1	Enteric Fermentation - Non-Dairy Cattle	CH_4	6,697.92	0.00	6,697.92	8.80	33.13
4	3.D.1	Agricultural Soils - Direct Soil Emissions	N_2O	5,062.89	0.00	5,062.89	6.65	39.78
5	1.A.1	Energy Industries - Gaseous Fuels	CO_2	4,896.48	0.00	4,896.48	6.43	46.21
6	1.A.1	Energy Industries - Solid Fuels	CO_2	4,281.83	0.00	4,281.83	5.63	51.84
7	3.A.1	Enteric Fermentation - Dairy Cattle	CH_4	3,780.92	0.00	3,780.92	4.97	56.81
8	4.A.2	LULUCF - Land Converted to Forest Land	CO_2	0.00	-3,692.46	3,692.46	4.85	61.66
9	1.A.4.b	Residential - Liquid Fuels	CO_2	3,008.64	0.00	3,008.64	3.95	65.61
10	1.A.1	Energy Industries - Peat Fuel	CO_2	2,600.14	0.00	2,600.14	3.42	69.03
11	1.A.2	Manufacturing Industries & Construction - Gaseous Fuels	CO_2	2,372.52	0.00	2,372.52	3.12	72.15
12	4.D	LULUCF - Wetlands	CO_2	0.00	2,061.28	2,061.28	2.71	74.85
13	2.A.1	Cement Production	CO_2	1,793.52	0.00	1,793.52	2.36	77.21
14	1.A.2	Manufacturing Industries & Construction - Liquid Fuels	CO_2	1,556.14	0.00	1,556.14	2.04	79.26
15	1.A.4.b	Residential - Gaseous Fuels	CO_2	1,316.51	0.00	1,316.51	1.73	80.99
16	1.A.4.a	Commercial/Institutional - Gaseous Fuels	CO_2	1,094.85	0.00	1,094.85	1.44	82.42
17	2.F.1	Product Uses as Substitutes for ODS -Refrigeration and air-con (incl. MAC)	HFC	1,021.89	0.00	1,021.89	1.34	83.77
18	1.A.4.b	Residential - Peat Fuel	CO_2	842.41	0.00	842.41	1.11	84.87
19	4.G	LULUCF - Harvested wood products	CO_2	0.00	-799.52	799.52	1.05	85.92
20	5.A	Solid Waste Disposal	CH_4	767.78	0.00	767.78	1.01	86.93
21	1.A.4.a	Commercial/Institutional - Liquid Fuels	CO_2	756.06	0.00	756.06	0.99	87.93
22	1.A.4.b	Residential - Solid Fuels	CO_2	721.27	0.00	721.27	0.95	88.87
23	3.A.2	Enteric Fermentation - Sheep	CH_4	670.59	0.00	670.59	0.88	89.76
24	3.B.1.1	Manure Management - Non-Dairy Cattle	CH_4	640.79	0.00	640.79	0.84	90.60
25	1.A.4.c	Agriculture/Fishing - Liquid Fuels	CO_2	547.83	0.00	547.83	0.72	91.32
26	3.D.2	Agricultural Soils - Indirect Soil Emissions	N_2O	535.95	0.00	535.95	0.70	92.02
27	1.A.1	Energy Industries - Liquid Fuels	CO_2	503.82	0.00	503.82	0.66	92.68
28	1.A.2	Manufacturing Industries & Construction - Solid Fuels	CO_2	436.33	0.00	436.33	0.57	93.26
29	3.G.1	Liming - Limestone CaCO3	CO_2	425.60	0.00	425.60	0.56	93.82
30	3.B.1.1	Manure Management - Dairy Cattle	CH_4	344.28	0.00	344.28	0.45	94.27
31	1.A.3.d	Navigation - Liquid Fuels	CO_2	263.69	0.00	263.69	0.35	94.62
32	3.B.1.3	Manure Management - Swine	CH_4	260.35	0.00	260.35	0.34	94.96
33	3.B.2.1	Manure Management - Non-Dairy Cattle	N_2O	240.61	0.00	240.61	0.32	95.27

Table 1.10 Key Category Analysis Trend Assessment 1990-2016 (excluding LULUCF)

Ranking	IPCC Sub-category	Emission Source / Activity	Direct GHG	1990 Emissions exclud. LULUCF (kt CO_2 eq)	2016 Emissions exclud. LULUCF (kt CO_2 eq)	2016 Level assessment exclud. LULUCF (%)	2016 Trend assessment exclud. LULUCF (%)	Contribution to Trend (%)	Cumulative Total (%)
1	1.A.3.b	Road Transport - Liquid Fuels	CO_2	4690.42	11623.55	18.89	9.41	20.16	20.16
2	1.A.1	Energy Industries - Gaseous Fuels	CO_2	1880.66	4896.48	7.96	4.12	8.82	28.99
3	1.A.4.b	Residential - Peat Fuel	CO_2	3123.37	842.41	1.37	3.84	8.23	37.22
4	1.A.4.b	Residential - Solid Fuels	CO_2	2483.42	721.27	1.17	2.98	6.38	43.60
5	1.A.4.b	Residential - Liquid Fuels	CO_2	1175.34	3008.64	4.89	2.50	5.35	48.96
6	1.A.2	Manufacturing Industries & Construction - Gaseous Fuels	CO_2	873.02	2372.52	3.85	2.06	4.41	53.36
7	1.A.4.a	Commercial/Institutional - Liquid Fuels	CO_2	1870.07	756.06	1.23	1.93	4.14	57.50
8	1.A.1	Energy Industries - Solid Fuels	CO_2	4844.66	4281.83	6.96	1.60	3.43	60.93
9	2.F.1	Product Uses as Substitutes for ODS -Refrigeration and air-con (incl. MAC)	HFC	0.00	1021.89	1.66	1.50	3.21	64.14
10	1.A.4.b	Residential - Gaseous Fuels	CO_2	269.73	1316.51	2.14	1.49	3.19	67.33
11	1.A.1	Energy Industries - Peat Fuel	CO_2	3164.78	2600.14	4.22	1.33	2.86	70.19
12	1.A.1	Energy Industries - Liquid Fuels	CO_2	1254.90	503.82	0.82	1.30	2.79	72.98
13	1.A.2	Manufacturing Industries & Construction - Liquid Fuels	CO_2	2198.38	1556.14	2.53	1.29	2.77	75.75
14	1.A.4.a	Commercial/Institutional - Gaseous Fuels	CO_2	223.49	1094.85	1.78	1.24	2.66	78.41
15	2.A.1	Cement Production	CO_2	884.00	1793.52	2.91	1.19	2.55	80.96
16	3.D.1	Agricultural Soils - Direct Soil Emissions	N_2O	5296.13	5062.89	8.23	1.19	2.55	83.51
17	3.A.1	Enteric Fermentation - Non-Dairy Cattle	CH_4	6702.59	6697.92	10.88	1.08	2.31	85.82
18	5.A	Solid Waste Disposal	CH_4	1318.08	767.78	1.25	1.02	2.18	88.00
19	3.A.2	Enteric Fermentation - Sheep	CH_4	1176.34	670.59	1.09	0.93	1.99	89.99
20	1.A.2	Manufacturing Industries & Construction - Solid Fuels	CO_2	871.24	436.33	0.71	0.78	1.66	91.65
21	1.A.4.c	Agriculture/Fishing - Liquid Fuels	CO_2	747.23	547.83	0.89	0.41	0.88	92.54
22	1.A.4.b	Residential - Peat Fuel	CH_4	227.65	61.82	0.10	0.28	0.60	93.13
23	1.A.3.d	Navigation - Liquid Fuels	CO_2	84.90	263.69	0.43	0.25	0.53	93.67
24	1.A.2	Manufacturing Industries & Construction - Non-Renewable waste	CO_2	0.00	161.96	0.26	0.24	0.51	94.17
25	1.A.4.b	Residential - Solid Fuels	CH_4	196.51	56.14	0.09	0.24	0.51	94.68
26	1.B.2.b	Fugitive emissions - Natural gas	CH_4	156.05	20.04	0.03	0.22	0.48	95.16

Table 1.11 Key Category Analysis Trend Assessment 2016 (including LULUCF)

Ranking	IPCC Sub-category	Emission Source / Activity	Direct GHG	1990 Emissions includ. LULUCF (kt CO_2 eq)	2016 Emissions includ. LULUCF (kt CO_2 eq)	2016 Level assessment includ. LULUCF (%)	2016 Trend assessment includ. LULUCF (%)	Contribution to Trend (%)	Cumulative Total (%)
1	1.A.3.b	Road Transport - Liquid Fuels	CO_2	4690.42	11623.55	15.27	7.52	15.54	15.54
2	4.A.2	LULUCF - Land Converted to Forest Land	CO_2	27.26	3692.46	4.85	4.31	8.91	24.45
3	4.A.1	LULUCF - Forest land Remaining Forest Land	CO_2	2719.66	183.46	0.24	3.36	6.94	31.39
4	1.A.1	Energy Industries - Gaseous Fuels	CO_2	1880.66	4896.48	6.43	3.29	6.80	38.19
5	1.A.4.b	Residential - Peat Fuel	CO_2	3123.37	842.41	1.11	3.11	6.43	44.62
6	1.A.4.b	Residential - Solid Fuels	CO_2	2483.42	721.27	0.95	2.41	4.99	49.61
7	1.A.4.b	Residential - Liquid Fuels	CO_2	1175.34	3008.64	3.95	2.00	4.13	53.74
8	1.A.2	Manufacturing Industries & Construction - Gaseous Fuels	CO_2	873.02	2372.52	3.12	1.65	3.40	57.14
9	1.A.4.a	Commercial/Institutional - Liquid Fuels	CO_2	1870.07	756.06	0.99	1.57	3.24	60.38
10	4.C	LULUCF - Grassland	CO_2	7343.33	6889.15	9.05	1.54	3.18	63.56
11	1.A.1	Energy Industries - Solid Fuels	CO_2	4844.66	4281.83	5.63	1.32	2.74	66.29
12	2.F.1	Product Uses as Substitutes for ODS -Refrigeration and air-con (incl. MAC)	HFC	0.00	1021.89	1.34	1.20	2.49	68.78
13	1.A.4.b	Residential - Gaseous Fuels	CO_2	269.73	1316.51	1.73	1.20	2.47	71.25
14	1.A.1	Energy Industries - Peat Fuel	CO_2	3164.78	2600.14	3.42	1.10	2.27	73.52
15	1.A.2	Manufacturing Industries & Construction - Liquid Fuels	CO_2	2198.38	1556.14	2.04	1.06	2.18	75.70
16	1.A.1	Energy Industries - Liquid Fuels	CO_2	1254.90	503.82	0.66	1.06	2.18	77.88
17	3.D.1	Agricultural Soils - Direct Soil Emissions	N_2O	5296.13	5062.89	6.65	1.00	2.06	79.95
18	1.A.4.a	Commercial/Institutional - Gaseous Fuels	CO_2	223.49	1094.85	1.44	1.00	2.06	82.00
19	2.A.1	Cement Production	CO_2	884.00	1793.52	2.36	0.95	1.96	83.97
20	3.A.1	Enteric Fermentation - Non-Dairy Cattle	CH_4	6702.59	6697.92	8.80	0.92	1.90	85.87
21	5.A	Solid Waste Disposal	CH_4	1318.08	767.78	1.01	0.83	1.71	87.58
22	3.A.2	Enteric Fermentation - Sheep	CH_4	1176.34	670.59	0.88	0.76	1.56	89.14
23	1.A.2	Manufacturing Industries & Construction - Solid Fuels	CO_2	871.24	436.33	0.57	0.63	1.30	90.45
24	4.D	LULUCF - Wetlands	CO_2	1487.42	2061.28	2.71	0.47	0.98	91.42
25	4.G	LULUCF - Harvested wood products	CO_2	413.04	799.52	1.05	0.40	0.82	92.25
26	1.A.4.c	Agriculture/Fishing - Liquid Fuels	CO_2	747.23	547.83	0.72	0.34	0.70	92.94
27	1.A.4.b	Residential - Peat Fuel	CH_4	227.65	61.82	0.08	0.23	0.47	93.41
28	1.A.3.d	Navigation - Liquid Fuels	CO_2	84.90	263.69	0.35	0.20	0.41	93.82
29	1.A.4.b	Residential - Solid Fuels	CH_4	196.51	56.14	0.07	0.19	0.40	94.22
30	1.A.2	Manufacturing Industries & Construction - Non-Renewable waste	CO_2	0.00	161.96	0.21	0.19	0.39	94.61
31	1.B.2.b	Fugitive emissions - Natural gas	CH_4	156.05	20.04	0.03	0.18	0.37	94.99
32	2.F.4	Product Uses as Substitutes for ODS -Aerosols (incl. MDIs)	HFC	0.64	133.61	0.18	0.16	0.32	95.31

Table 1.12 Tier 1 Uncertainty Estimates 2016 excluding LULUCF (continued on following pages)

	KEY CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (kt CO_2eq)	Emissions in 2016 (kt CO_2eq)	Activity Data (AD) Uncertainty (%)	Emission Factor (EF) Uncertainty (%)	Combined Uncertainty (%)	Contribution to Variance by Category in Year 20164	Combined Emissions Uncertainty Squared	Uncertainty in Trend in Total Emissions due to AD (%)	Uncertainty in Trend in Total Emissions due to EF (%)	Combined Uncertainty in Trend in Total Emissions (%)	Combined Trend Uncertainty Squared
1	1.A.1 Fuel combustion - Energy Industries - Gaseous Fuels	CO2	1880.66	4896.48	1.00	2.50	2.69	0.05	0.00	0.12	0.13	0.18	0.03
2	1.A.1 Fuel combustion - Energy Industries - Liquid Fuels	CO2	1254.90	503.82	1.00	2.50	2.69	0.00	0.00	0.01	-0.04	0.04	0.00
3	1.A.1 Fuel combustion - Energy Industries - Other Fossil Fuels	CO2	0.00	86.12	1.00	5.00	5.10	0.00	0.00	0.00	0.01	0.01	0.00
4	1.A.1 Fuel combustion - Energy Industries - Peat	CO2	3164.78	2600.14	1.00	5.00	5.10	0.05	0.00	0.07	-0.08	0.11	0.01
5	1.A.1 Fuel combustion - Energy Industries - Solid Fuels	CO2	4844.66	4281.83	1.00	5.00	5.10	0.13	0.02	0.11	-0.10	0.15	0.02
6	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	CO2	873.02	2372.52	7.00	3.00	7.62	0.09	0.01	0.42	0.08	0.43	0.18
7	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	CO2	2198.38	1556.14	10.00	2.50	10.31	0.07	0.00	0.40	-0.04	0.40	0.16
8	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Other Fossil Fuels	CO2	0.00	161.96	1.00	5.00	5.10	0.00	0.00	0.00	0.01	0.02	0.00
9	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Peat	CO2	0.00	3.48	2.00	5.00	5.39	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	436.33	2.00	5.00	5.39	0.00	0.00	0.02	-0.05	0.05	0.00
11	1.A.3.a Domestic Aviation	CO2	51.13	9.66	1.00	2.50	2.69	0.00	0.00	0.00	0.00	0.00	0.00
12	1.A.3.b Road Transportation	CO2	4690.42	11623.55	1.25	3.00	3.25	0.38	0.14	0.37	0.35	0.51	0.26
13	1.A.3.c Railways	CO2	133.19	111.93	1.00	1.00	1.41	0.00	0.00	0.00	0.00	0.00	0.00
14	1.A.3.d Domestic Navigation - Liquid Fuels	CO2	84.90	263.69	1.00	2.00	2.24	0.00	0.00	0.01	0.01	0.01	0.00
15	1.A.3.e Other Transportation	CO2	62.04	139.90	1.00	2.50	2.69	0.00	0.00	0.00	0.00	0.00	0.00
16	1.A.4 Other Sectors - Gaseous Fuels	CO2	493.22	2411.36	2.50	2.50	3.54	0.02	0.00	0.15	0.08	0.18	0.03
17	1.A.4 Other Sectors - Liquid Fuels	CO2	3792.64	4312.53	10.00	5.00	11.18	0.61	0.38	1.10	0.01	1.10	1.21
18	1.A.4 Other Sectors - Peat	CO2	3259.11	842.41	10.00	20.00	22.36	0.09	0.01	0.21	-1.00	1.02	1.04
19	1.A.4 Other Sectors - Solid Fuels	CO2	2485.97	721.27	5.00	10.00	11.18	0.02	0.00	0.09	-0.37	0.38	0.14
20	2.A.1 Cement Production	CO2	884.00	1793.52	1.50	1.50	2.12	0.00	0.00	0.07	0.02	0.07	0.01
21	2.A.2 Lime Production	CO2	214.08	173.90	5.00	5.00	7.07	0.00	0.00	0.02	-0.01	0.02	0.00
22	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
23	2.A.4 Other Process Uses of Carbonates	CO2	5.32	0.98	5.00	2.50	5.59	0.00	0.00	0.00	0.00	0.00	0.00
24	2.B.1 Ammonia Production	CO2	990.23	0.00	1.00	5.00	5.10	0.00	0.00	0.00	-0.10	0.10	0.01
25	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
26	2.D Non-energy Products from Fuels and Solvent Use	CO2	114.48	138.94	30.00	5.00	30.41	0.00	0.00	0.11	0.00	0.11	0.01
27	3.G Liming	CO2	355.04	425.60	5.00	50.00	50.25	0.12	0.01	0.05	0.03	0.06	0.00
28	3.H Urea Application	CO2	44.47	35.80	5.00	50.00	50.25	0.00	0.00	0.00	-0.01	0.01	0.00
29	5.C Incineration and Open Burning of Waste	CO2	90.61	22.64	10.00	5.00	11.18	0.00	0.00	0.01	-0.01	0.01	0.00
	Total CO_2		**32877.91**	**39926.51**				**1.63**					**3.13**
						Level uncertainty, CO_2		**1.27**			**Trend uncertainty, CO_2**		**1.77**

	KEY CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (kt CO_2eq)	Emissions in 2016 (kt CO_2eq)	Activity Data (AD) Uncertainty (%)	Emission Factor (EF) Uncertainty (%)	Combined Uncertainty (%)	Contribution to Variance by Category in Year 2016	Combined Emissions Uncertainty Squared	Uncertainty in Trend in Total Emissions due to AD (%)	Uncertainty in Trend in Total Emissions due to EF (%)	Combined Uncertainty in Trend in Total Emissions (%)	Combined Trend Uncertainty Squared
1	1.A.1 Fuel combustion - Energy Industries - Biomass	CH4	0.00	1.85	1.00	66.00	66.01	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	2.29	1.00	70.00	70.01	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	0.15	1.00	66.00	66.01	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	0.77	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00
5	1.A.1 Fuel combustion - Energy Industries - Peat	CH4	1.90	1.65	1.00	50.00	50.01	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	0.81	1.00	50.00	50.01	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	5.40	10.00	50.00	50.99	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	1.06	2.50	50.00	50.06	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	2.06	1.28	10.00	50.00	50.99	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	0.13	1.00	50.00	50.01	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
12	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Solid Fuels	CH4	2.30	1.15	2.00	50.00	50.04	0.00	0.00	0.00	0.00	0.00	0.00
13	1.A.3.a Domestic Aviation	CH4	0.02	0.01	1.00	66.00	66.01	0.00	0.00	0.00	0.00	0.00	0.00
14	1.A.3.b Road Transportation	CH4	48.13	13.23	1.25	71.00	71.01	0.00	0.00	0.00	-0.05	0.05	0.00
15	1.A.3.c Railways	CH4	0.19	0.16	1.00	60.00	60.01	0.00	0.00	0.00	0.00	0.00	0.00
16	1.A.3.d Domestic Navigation - Liquid Fuels	CH4	0.20	0.63	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00
17	1.A.3.e Other Transportation	CH4	0.14	0.31	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00
18	1.A.4 Other Sectors - Biomass	CH4	14.08	18.31	10.00	50.00	50.99	0.00	0.00	0.00	0.00	0.01	0.00
19	1.A.4 Other Sectors - Gaseous Fuels	CH4	1.12	5.40	2.50	50.00	50.06	0.00	0.00	0.00	0.00	0.00	0.00
20	1.A.4 Other Sectors - Liquid Fuels	CH4	11.27	13.79	10.00	66.00	66.75	0.00	0.00	0.00	0.00	0.00	0.00
21	1.A.4 Other Sectors - Peat	CH4	227.98	61.82	10.00	50.00	50.99	0.00	0.00	0.02	-0.17	0.17	0.03
22	1.A.4 Other Sectors - Solid Fuels	CH4	196.51	56.14	5.00	50.00	50.25	0.00	0.00	0.01	-0.15	0.15	0.02
23	1.B.1 Fugitive emissions from Solid Fuels	CH4	55.56	19.24	10.00	50.00	50.99	0.00	0.00	0.00	-0.04	0.04	0.00
24	1.B.2.a Fugitive Emissions from Fuels - Oil and Natural Gas - Oil	CH4	0.21	0.38	10.00	50.00	50.99	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	156.08	21.66	10.00	50.00	50.99	0.00	0.00	0.01	-0.14	0.14	0.02
26	3.A.1 Enteric Fermentation-Dairy Cattle	CH4	3398.80	3780.92	1.00	15.00	15.03	0.85	0.73	0.10	0.00	0.10	0.01
27	3.A.1 Enteric Fermentation-Non-Dairy Cattle	CH4	6702.59	6697.92	1.00	15.00	15.03	2.68	7.16	0.17	-0.20	0.26	0.07
28	3.A.2 Enteric Fermentation-Sheep	CH4	1176.34	670.59	1.00	30.00	30.02	0.11	0.01	0.02	-0.34	0.34	0.12
29	3.A.3 Enteric Fermentation-Swine	CH4	41.37	52.21	1.00	30.00	30.02	0.00	0.00	0.00	0.00	0.00	0.00
30	3.A.4 Enteric Fermentation-Other Animals	CH4	37.87	45.63	1.00	30.00	30.02	0.00	0.00	0.00	0.00	0.00	0.00
31	3.B.1.1 Manure Management-Dairy Cattle	CH4	354.22	344.28	1.00	15.00	15.03	0.01	0.00	0.01	-0.01	0.02	0.00
32	3.B.1.1 Manure Management-Non-Dairy Cattle	CH4	684.58	640.79	1.00	15.00	15.03	0.02	0.00	0.02	-0.03	0.04	0.00
33	3.B.1.2 Manure Management-Sheep	CH4	99.19	59.52	1.00	30.00	30.02	0.00	0.00	0.00	-0.03	0.03	0.00
34	3.B.1.3 Manure Management-Swine	CH4	206.49	260.35	1.00	30.00	30.02	0.02	0.00	0.01	0.02	0.02	0.00
35	3.B.1.4 Manure Management-Other Animals	CH4	61.58	97.29	1.00	30.00	30.02	0.00	0.00	0.00	0.02	0.02	0.00
36	5.A Solid Waste Disposal	CH4	1318.08	767.78	34.64	34.64	48.99	0.37	0.14	0.68	-0.43	0.80	0.65
37	5.B Biological treatment of solid waste: Composting	CH4	0.00	11.58	10.00	30.00	31.62	0.00	0.00	0.00	0.01	0.01	0.00
38	5.C Incineration and Open Burning of Waste	CH4	0.83	0.07	10.00	30.00	31.62	0.00	0.00	0.00	0.00	0.00	0.00
39	5.D Wastewater Treatment and Discharge	CH4	61.10	50.43	10.00	30.00	31.62	0.00	0.00	0.01	-0.01	0.02	0.00
	Total CH_4		**14867.83**	**13706.98**				**4.07**					**0.92**
						Level uncertainty, CH_4		**2.02**			**Trend uncertainty, CH_4**		**0.96**
	Combined CO_2 and CH_4		**47745.73**	**53633.49**				**5.69**					**4.05**
					Level uncertainty, CO_2 and CH_4			**2.39**			**Trend uncertainty, CO_2 & CH_4**		**2.01**

	KEY CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (kt CO_2eq)	Emissions in 2016 (kt CO_2eq)	Activity Data (AD) Uncertainty (%)	Emission Factor (EF) Uncertainty (%)	Combined Uncertainty (%)	Contribution to Variance by Category in Year 2014	Combined Emissions Uncertainty Squared	Uncertainty in Trend in Total Emissions due to AD (%)	Uncertainty in Trend in Total Emissions due to EF (%)	Combined Uncertainty in Trend in Total Emissions (%)	Combined Trend Uncertainty Squared
1	1.A.1 Fuel combustion - Energy Industries - Biomass	N2O	0.00	8.78	1.00	63.00	63.01	0.00	0.00	0.00	0.01	0.01	0.00
2	1.A.1 Fuel combustion - Energy Industries - Gaseous Fuels	N2O	10.21	77.09	1.00	50.00	50.01	0.00	0.00	0.00	0.06	0.06	0.00
3	1.A.1 Fuel combustion - Energy Industries - Liquid Fuels	N2O	1.47	0.37	1.00	50.00	50.01	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	1.22	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00
5	1.A.1 Fuel combustion - Energy Industries - Peat	N2O	52.07	45.18	1.00	50.00	50.01	0.00	0.00	0.00	-0.01	0.01	0.00
6	1.A.1 Fuel combustion - Energy Industries - Solid Fuels	N2O	7.74	6.87	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00
7	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Biomass	N2O	3.04	8.57	10.00	50.00	50.99	0.00	0.00	0.00	0.00	0.01	0.00
8	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	N2O	0.47	1.27	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00
9	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	N2O	4.83	2.92	10.00	50.00	50.99	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	0.31	1.00	20.00	20.02	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	0.02	2.00	50.00	50.04	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	2.06	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00
13	1.A.3.a Domestic Aviation	N2O	0.55	0.13	1.00	66.00	66.01	0.00	0.00	0.00	0.00	0.00	0.00
14	1.A.3.b Road Transportation	N2O	48.95	114.11	1.25	68.00	68.01	0.02	0.00	0.00	0.07	0.07	0.01
15	1.A.3.c Railways	N2O	15.49	13.01	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00
16	1.A.3.d Domestic Navigation - Liquid Fuels	N2O	0.67	2.14	1.00	90.00	90.01	0.00	0.00	0.00	0.00	0.00	0.00
17	1.A.3.e Other Transportation	N2O	0.67	1.49	1.00	25.00	25.02	0.00	0.00	0.00	0.00	0.00	0.00
18	1.A.4 Other Sectors - Biomass	N2O	2.23	2.90	10.00	50.00	50.99	0.00	0.00	0.00	0.00	0.00	0.00
19	1.A.4 Other Sectors - Gaseous Fuels	N2O	0.27	1.29	2.50	50.00	50.06	0.00	0.00	0.00	0.00	0.00	0.00
20	1.A.4 Other Sectors - Liquid Fuels	N2O	76.92	60.81	10.00	50.00	50.99	0.00	0.00	0.02	-0.02	0.03	0.00
21	1.A.4 Other Sectors - Peat	N2O	13.22	3.44	5.00	50.00	50.25	0.00	0.00	0.00	-0.01	0.01	0.00
22	1.A.4 Other Sectors - Solid Fuels	N2O	11.72	3.35	5.00	50.00	50.25	0.00	0.00	0.00	-0.01	0.01	0.00
23	2.B.2 Nitric Acid Production	N2O	995.32	0.00	1.00	10.00	10.05	0.00	0.00	0.00	-0.20	0.20	0.04
24	2.G Other Product Manufacture and Use	N2O	31.34	42.57	5.00	5.00	7.07	0.00	0.00	0.01	0.00	0.01	0.00
25	3.B.2.1 Manure Management -Dairy Cattle	N2O	51.18	48.29	11.22	50.00	51.24	0.00	0.00	0.01	-0.01	0.02	0.00
26	3.B.2.1 Manure Management -Non-Dairy Cattle	N2O	212.61	240.61	11.22	50.00	51.24	0.04	0.00	0.07	0.00	0.07	0.00
27	3.B.2.2 Manure Management -Sheep	N2O	22.67	14.83	11.22	50.00	51.24	0.00	0.00	0.00	-0.01	0.01	0.00
28	3.B.2.3 Manure Management -Swine	N2O	10.08	12.25	11.22	50.00	51.24	0.00	0.00	0.00	0.00	0.00	0.00
29	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
30	3.B.2.4 Manure Management -Goats	N2O	0.65	0.37	11.22	50.00	51.24	0.00	0.00	0.00	0.00	0.00	0.00
31	3.B.2.4 Manure Management -Horses	N2O	3.44	5.15	11.22	50.00	51.24	0.00	0.00	0.00	0.00	0.00	0.00
32	3.B.2.4 Manure Management -Mules & Asses	N2O	0.32	0.35	11.22	50.00	51.24	0.00	0.00	0.00	0.00	0.00	0.00
33	3.B.2.4 Manure Management -Poultry	N2O	3.81	5.25	11.22	50.00	51.24	0.00	0.00	0.00	0.00	0.00	0.00
34	3.B.2.4 Manure Management -Fur Animals	N2O	2.72	1.97	50.00	50.00	70.71	0.00	0.00	0.00	0.00	0.00	0.00
35	3.B.2.5 Indirect N2O emissions	N2O	190.76	211.97	11.22	100.00	100.63	0.12	0.01	0.06	0.00	0.06	0.00
36	3.D.1.1 Inorganic N Fertilizer	N2O	2158.39	1951.23	1.00	50.00	50.01	2.51	6.32	0.05	-0.40	0.40	0.16
37	3.D.1.2 Organic N Fertilizers	N2O	683.59	753.14	11.22	100.00	100.63	1.52	2.30	0.22	-0.01	0.22	0.05
38	3.D.1.3 Urine and Dung Deposited by Grazing Animals	N2O	1310.12	1284.31	11.18	50.00	51.23	1.14	1.31	0.37	-0.15	0.40	0.16
39	3.D.1.4 Crop Residues	N2O	374.15	194.34	10.00	100.00	100.50	0.10	0.01	0.05	-0.40	0.40	0.16
40	3.D.1.5 Mineralization/Immobilization Associated with Loss/Gain of Soil Organic Matter	N2O	20.03	21.78	22.57	100.00	102.52	0.00	0.00	0.01	0.00	0.01	0.00
41	3.D.1.6 Cultivation of Organic Soils	N2O	749.85	858.09	12.22	100.00	100.74	1.97	3.89	0.27	0.05	0.27	0.07
42	3.D.2 Indirect N2O Emissions From Managed Soils	N2O	557.23	535.95	11.18	50.00	51.23	0.20	0.04	0.15	-0.07	0.17	0.03
43	5.B Biological treatment of solid waste: Composting	N2O	0.00	8.28	10.00	10.00	14.14	0.00	0.00	0.00	0.00	0.00	0.00
44	5.C Incineration and Open Burning of Waste	N2O	1.04	0.24	10.00	10.00	14.14	0.00	0.00	0.00	0.00	0.00	0.00
45	5.D Wastewater Treatment and Discharge	N2O	75.14	96.69	10.00	10.00	14.14	0.00	0.00	0.02	0.00	0.02	0.00
	Total N_2O		**7709.33**	**6645.04**				**7.63**					**0.69**
							Level uncertainty, N_2O	**2.76**			**Trend uncertainty, N_2O**		**0.83**
	Combined CO_2, CH_4 and N_2O		**55455.06**	**60278.52**				**13.33**					**4.73**
							Level uncertainty, CO_2, CH_4 & N_2O	**3.65**		**Trend uncertainty, CO_2, CH_4 & N_2O**			**2.18**

	KEY CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (kt CO₂eq)	Emissions in 2016 (kt CO₂eq)	Activity Data (AD) Uncertainty (%)	Emission Factor (EF) Uncertainty (%)	Combined Uncertainty (%)	Contribution to Variance by Category in Year 2016	Combined Emissions Uncertainty Squared	Uncertainty in Trend in Total Emissions due to AD (%)	Uncertainty in Trend in Total Emissions due to EF (%)	Combined Uncertainty in Trend in Total Emissions (%)	Combined Trend Uncertainty Squared
1	2.E Electronics Industry & 2.F Product Uses and Substitutes for ODS	Aggregate F-gases	1.81	1244.99	20.00	10.00	22.36	0.20	0.04	0.63	0.22	0.67	0.45
2	2.G Other Product Manufacture and Use	Aggregate F-gases	33.42	22.30	10.00	0.00	10.00	0.00	0.00	0.01	0.00	0.01	0.00
	Total F-gases		**35.23**	**1267.30**				**0.20**					**0.45**
					Level uncertainty, F-gases			**0.45**	**Trend uncertainty, F-gases**				**0.67**
	TOTAL for all gases		**55490.29**	**61545.82**				**13.53**					**5.19**
					Total level uncertainty for all GHGs			**3.68**	**Total trend uncertainty for all GHGs**				**2.28**

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

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

Where:

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

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

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

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

Where:

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

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

Table 1.13 Tier 1 Uncertainty Estimates 2016 including LULUCF (continued on following pages)

	KEY CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (kt CO_2eq)	Emissions in 2016 (kt CO_2eq)	Activity Data (AD) Uncertainty (%)	Emission Factor (EF) Uncertainty (%)	Combined Uncertainty (%)	Contribution to Variance by Category in Year 2016	Combined Emissions Uncertainty Squared	Uncertainty in Trend in Total Emissions due to AD (%)	Uncertainty in Trend in Total Emissions due to EF (%)	Combined Uncertainty in Trend in Total Emissions (%)	Combined Trend Uncertainty Squared
1	1.A.1 Fuel combustion - Energy Industries - Gaseous Fuels	CO_2	1880.66	4896.48	1.00	2.50	2.69	0.04	0.00	0.12	0.13	0.18	0.03
2	1.A.1 Fuel combustion - Energy Industries - Liquid Fuels	CO_2	1254.90	503.82	1.00	2.50	2.69	0.00	0.00	0.01	-0.04	0.04	0.00
3	1.A.1 Fuel combustion - Energy Industries - Other Fossil Fuels	CO_2	0.00	86.12	1.00	5.00	5.10	0.00	0.00	0.00	0.01	0.01	0.00
4	1.A.1 Fuel combustion - Energy Industries - Peat	CO_2	3164.78	2600.14	1.00	5.00	5.10	0.04	0.00	0.07	-0.08	0.11	0.01
5	1.A.1 Fuel combustion - Energy Industries - Solid Fuels	CO_2	4844.66	4281.83	1.00	5.00	5.10	0.11	0.01	0.11	-0.10	0.15	0.02
6	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	CO_2	873.02	2372.52	7.00	3.00	7.62	0.07	0.01	0.42	0.08	0.43	0.18
7	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	CO_2	2198.38	1556.14	10.00	2.50	10.31	0.06	0.00	0.40	-0.04	0.40	0.16
8	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Other Fossil Fuels	CO_2	0.00	161.96	1.00	5.00	5.10	0.00	0.00	0.00	0.01	0.02	0.00
9	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Peat	CO_2	0.00	3.48	2.00	5.00	5.39	0.00	0.00	0.00	0.00	0.00	0.00
10	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Solid Fuels	CO_2	871.24	436.33	2.00	5.00	5.39	0.00	0.00	0.02	-0.05	0.05	0.00
11	1.A.3.a Domestic Aviation	CO_2	51.13	9.66	1.00	2.50	2.69	0.00	0.00	0.00	0.00	0.00	0.00
12	1.A.3.b Road Transportation	CO_2	4690.42	11623.55	1.25	3.00	3.25	0.32	0.10	0.37	0.35	0.51	0.26
13	1.A.3.c Railways	CO_2	133.19	111.93	1.00	1.00	1.41	0.00	0.00	0.00	0.00	0.00	0.00
14	1.A.3.d Domestic Navigation - Liquid Fuels	CO_2	84.90	263.69	1.00	2.00	2.24	0.00	0.00	0.01	0.01	0.01	0.00
15	1.A.3.e Other Transportation	CO_2	62.04	139.90	1.00	2.50	2.69	0.00	0.00	0.00	0.00	0.00	0.00
16	1.A.4 Other Sectors - Gaseous Fuels	CO_2	493.22	2411.36	2.50	2.50	3.54	0.02	0.00	0.15	0.08	0.18	0.03
17	1.A.4 Other Sectors - Liquid Fuels	CO_2	3792.64	4312.53	10.00	5.00	11.18	0.53	0.28	1.10	0.01	1.10	1.21
18	1.A.4 Other Sectors - Peat	CO_2	3259.11	842.41	10.00	20.00	22.36	0.08	0.01	0.21	-1.00	1.02	1.04
19	1.A.4 Other Sectors - Solid Fuels	CO_2	2485.97	721.27	5.00	10.00	11.18	0.01	0.00	0.09	-0.37	0.38	0.14
20	2.A.1 Cement Production	CO_2	884.00	1793.52	1.50	1.50	2.12	0.00	0.00	0.07	0.02	0.07	0.01
21	2.A.2 Lime Production	CO_2	214.08	173.90	5.00	5.00	7.07	0.00	0.00	0.02	-0.01	0.02	0.00
22	2.A.3 Glass Production	CO_2	13.33	0.00	5.00	2.50	5.59	0.00	0.00	0.00	0.00	0.00	0.00
23	2.A.4 Other Process Uses of Carbonates	CO_2	5.32	0.98	5.00	2.50	5.59	0.00	0.00	0.00	0.00	0.00	0.00
24	2.B.1 Ammonia Production	CO_2	990.23	0.00	1.00	5.00	5.10	0.00	0.00	0.00	-0.10	0.10	0.01
25	2.C Metal Production	CO_2	26.08	0.00	5.00	2.50	5.59	0.00	0.00	0.00	0.00	0.00	0.00
26	2.D Non-energy Products from Fuels and Solvent Use	CO_2	114.48	138.94	30.00	5.00	30.41	0.00	0.00	0.11	0.00	0.11	0.01
27	3.G Liming	CO_2	355.04	425.60	5.00	50.00	50.25	0.10	0.01	0.05	0.03	0.06	0.00
28	3.H Urea Application	CO_2	44.47	35.80	5.00	50.00	50.25	0.00	0.00	0.00	-0.01	0.01	0.00
29	4.A.1 Forest Land Remaining Forest Land	CO_2	-2719.66	-183.46	51.00	114.00	124.89	-0.34	0.12	-0.21	5.05	5.05	25.51
30	4.A.2 Land Converted to Forest Land	CO_2	27.26	-3692.46	51.00	114.00	124.89	-6.94	48.10	-4.30	-6.86	8.09	65.51
31	4.B.1 Cropland Remaining Cropland	CO_2	-16.23	-131.93	20.59	69.15	72.15	-0.14	0.02	-0.06	-0.13	0.14	0.02
32	4.C. Grassland	CO_2	7343.33	6889.15	12.22	90.00	90.83	9.41	88.56	1.92	-1.45	2.41	5.81
33	4.C.2 Land Converted to Grassland	CO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
34	4.D. Wetlands	CO_2	1487.42	2061.28	21.49	101.45	103.70	3.21	10.34	1.01	0.76	1.27	1.60
35	4.D.2 Land Converted to Wetlands	CO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
36	4.E.2 Land Converted to Settlements	CO_2	80.46	91.06	39.97	81.83	91.07	0.12	0.02	0.08	0.01	0.08	0.01
37	4.F.2 Land Converted to Other Land	CO_2	0.55	15.21	51.93	75.00	91.23	0.02	0.00	0.02	0.02	0.03	0.00
38	4.G Harvested Wood Products	CO_2	-413.04	-799.52	25.00	26.92	36.74	-0.44	0.20	-0.46	-0.15	0.48	0.23
39	5.C Incineration and Open Burning of Waste	CO_2	90.61	22.64	10.00	5.00	11.18	0.00	0.00	0.01	-0.01	0.01	0.00
	Total CO_2		**38667.99**	**44175.85**				**6.30**					**101.82**
							Level uncertainty, CO_2	**2.51**				**Trend uncertainty, CO_2**	**10.09**

	KEY CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (kt CO_2 eq)	Emissions in 2016 (kt CO_2eq)	Activity Data (AD) Uncertainty (%)	Emission Factor (EF) Uncertainty (%)	Combined Uncertainty (%)	Contribution to Variance by Category in Year 2016	Combined Emissions Uncertainty Squared	Uncertainty in Trend in Total Emissions due to AD (%)	Uncertainty in Trend in Total Emissions due to EF (%)	Combined Uncertainty in Trend in Total Emissions (%)	Combined Trend Uncertainty Squared
1	1.A.1 Fuel combustion - Energy Industries - Biomass	CH_4	0.00	1.85	1.00	66.00	66.01	0.00	0.00	0.00	0.00	0.00	0.00
2	1.A.1 Fuel combustion - Energy Industries - Gaseous Fuels	CH_4	3.43	2.29	1.00	70.00	70.01	0.00	0.00	0.00	0.00	0.00	0.00
3	1.A.1 Fuel combustion - Energy Industries - Liquid Fuels	CH_4	0.39	0.15	1.00	66.00	66.01	0.00	0.00	0.00	0.00	0.00	0.00
4	1.A.1 Fuel combustion - Energy Industries - Other Fossil Fuels	CH_4	0.00	0.77	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00
5	1.A.1 Fuel combustion - Energy Industries - Peat	CH_4	1.90	1.65	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00
6	1.A.1 Fuel combustion - Energy Industries - Solid Fuels	CH_4	0.91	0.81	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00
7	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Biomass	CH_4	1.91	5.40	10.00	50.00	50.99	0.00	0.00	0.00	0.00	0.00	0.00
8	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	CH_4	0.40	1.06	2.50	50.00	50.06	0.00	0.00	0.00	0.00	0.00	0.00
9	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	CH_4	2.06	1.28	10.00	50.00	50.99	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	CH_4	0.00	0.13	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00
11	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Peat	CH_4	0.00	0.00	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00
12	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Solid Fuels	CH_4	2.30	1.15	2.00	50.00	50.04	0.00	0.00	0.00	0.00	0.00	0.00
13	1.A.3.a Domestic Aviation	CH_4	0.02	0.01	1.00	66.00	66.01	0.00	0.00	0.00	0.00	0.00	0.00
14	1.A.3.b Road Transportation	CH_4	48.13	13.23	1.25	71.00	71.01	0.00	0.00	0.00	-0.05	0.05	0.00
15	1.A.3.c Railways	CH_4	0.19	0.16	1.00	60.00	60.01	0.00	0.00	0.00	0.00	0.00	0.00
16	1.A.3.d Domestic Navigation - Liquid Fuels	CH_4	0.20	0.63	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00
17	1.A.3.e Other Transportation	CH_4	0.14	0.31	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00
18	1.A.4 Other Sectors - Biomass	CH_4	14.08	18.31	10.00	50.00	50.99	0.00	0.00	0.00	0.00	0.01	0.00
19	1.A.4 Other Sectors - Gaseous Fuels	CH_4	1.12	5.40	2.50	50.00	50.06	0.00	0.00	0.00	0.00	0.00	0.00
20	1.A.4 Other Sectors - Liquid Fuels	CH_4	11.27	13.79	10.00	66.00	66.75	0.00	0.00	0.00	0.00	0.00	0.00
21	1.A.4 Other Sectors - Peat	CH_4	227.98	61.82	10.00	50.00	50.99	0.00	0.00	0.02	-0.17	0.17	0.03
22	1.A.4 Other Sectors - Solid Fuels	CH_4	196.51	56.14	5.00	50.00	50.25	0.00	0.00	0.01	-0.15	0.15	0.02
23	1.B.1 Fugitive emissions from Solid Fuels	CH_4	55.56	19.24	10.00	50.00	50.99	0.00	0.00	0.00	-0.04	0.04	0.00
24	1.B.2.a Fugitive Emissions from Fuels - Oil and Natural Gas - Oil	CH_4	0.21	0.38	10.00	50.00	50.99	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	CH_4	156.08	21.66	10.00	50.00	50.99	0.00	0.00	0.01	-0.14	0.14	0.02
26	3A1 Enteric Fermentation-Dairy Cattle	CH_4	3398.80	3780.92	1.00	15.00	15.03	0.73	0.53	0.10	0.00	0.10	0.01
27	3A1 Enteric Fermentation-Non-Dairy Cattle	CH_4	6702.59	6697.92	1.00	15.00	15.03	2.29	5.26	0.17	-0.20	0.26	0.07
28	3A2 Enteric Fermentation-Sheep	CH_4	1176.34	670.59	1.00	30.00	30.02	0.09	0.01	0.02	-0.34	0.34	0.12
29	3A3 Enteric Fermentation-Swine	CH_4	41.37	52.21	1.00	30.00	30.02	0.00	0.00	0.00	0.00	0.00	0.00
30	3A4 Enteric Fermentation-Other Animals	CH_4	37.87	45.63	1.00	30.00	30.02	0.00	0.00	0.00	0.00	0.00	0.00
31	3B1.1 Manure Management-Dairy Cattle	CH_4	354.22	344.28	1.00	15.00	15.03	0.01	0.00	0.01	-0.01	0.02	0.00
32	3B1.1 Manure Management-Non-Dairy Cattle	CH_4	684.58	640.79	1.00	15.00	15.03	0.02	0.00	0.02	-0.03	0.04	0.00
33	3B1.2 Manure Management-Sheep	CH_4	99.19	59.52	1.00	30.00	30.02	0.00	0.00	0.00	-0.03	0.03	0.00
34	3B1.3 Manure Management-Swine	CH_4	206.49	260.35	1.00	30.00	30.02	0.01	0.00	0.01	0.02	0.02	0.00
35	3B1.4 Manure Management-Other Animals	CH_4	61.58	97.29	1.00	30.00	30.02	0.00	0.00	0.00	0.02	0.02	0.00
36	4.A LULUCF - Forest Land	CH_4	58.58	69.88	30.00	100.00	104.40	0.11	0.01	0.05	0.01	0.05	0.00
37	4.B LULUCF - Cropland	CH_4	0.04	0.00	100.00	39.10	107.37	0.00	0.00	0.00	0.00	0.00	0.00
38	4.C LULUCF - Grassland	CH_4	267.95	240.02	96.40	91.20	132.70	0.48	0.23	0.53	-0.07	0.53	0.28
39	4.D LULUCF - Wetlands	CH_4	135.62	64.97	86.00	66.50	108.71	0.11	0.01	0.13	-0.09	0.15	0.02
40	5.A Solid Waste Disposal	CH_4	1318.08	767.78	34.64	34.64	48.99	0.32	0.10	0.68	-0.43	0.80	0.65
41	5.B Biological treatment of solid waste: Composting	CH_4	0.00	11.58	10.00	30.00	31.62	0.00	0.00	0.00	0.01	0.01	0.00
42	5.C Incineration and Open Burning of Waste	CH_4	0.83	0.07	10.00	30.00	31.62	0.00	0.00	0.00	0.00	0.00	0.00
43	5.D Wastewater Treatment and Discharge	CH_4	61.10	50.43	10.00	30.00	31.62	0.00	0.00	0.01	-0.01	0.02	0.00
	Total CH_4		**15330.02**	**14081.85**				**4.18**					**1.23**
						Level uncertainty, CH_4		**2.04**			**Trend uncertainty, CH_4**		**1.11**
	Combined CO_2 and CH_4		**53998.02**	**58257.70**				**10.48**					**103.05**
					Level uncertainty, CO_2 and CH_4			**3.24**			**Trend uncertainty, CO_2 & CH_4**		**10.15**

	KEY CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (kt CO_2eq)	Emissions in 2016 (kt CO_2eq)	Activity Data (AD) Uncertainty (%)	Emission Factor (EF) Uncertainty (%)	Combined Uncertainty (%)	Contribution to Variance by Category in Year 2016	Combined Emissions Uncertainty Squared	Uncertainty in Trend in Total Emissions due to AD (%)	Uncertainty in Trend in Total Emissions due to EF (%)	Combined Uncertainty in Trend in Total Emissions (%)	Combined Trend Uncertainty Squared
1	1.A.1 Fuel combustion - Energy Industries - Biomass	N_2O	0.00	8.78	1.00	63.00	63.01	0.00	0.00	0.00	0.01	0.01	0.00
2	1.A.1 Fuel combustion - Energy Industries - Gaseous Fuels	N_2O	10.21	77.09	1.00	50.00	50.01	0.00	0.00	0.00	0.06	0.06	0.00
3	1.A.1 Fuel combustion - Energy Industries - Liquid Fuels	N_2O	1.47	0.37	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00
4	1.A.1 Fuel combustion - Energy Industries - Other Fossil Fuels	N_2O	0.00	1.22	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00
5	1.A.1 Fuel combustion - Energy Industries - Peat	N_2O	52.07	45.18	1.00	50.00	50.01	0.00	0.00	0.00	-0.01	0.01	0.00
6	1.A.1 Fuel combustion - Energy Industries - Solid Fuels	N_2O	7.74	6.87	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00
7	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Biomass	N_2O	3.04	8.57	10.00	50.00	50.99	0.00	0.00	0.00	0.00	0.01	0.00
8	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	N_2O	0.47	1.27	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00
9	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	N_2O	4.83	2.92	10.00	50.00	50.99	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	N_2O	0.00	0.31	1.00	20.00	20.02	0.00	0.00	0.00	0.00	0.00	0.00
11	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Peat	N_2O	0.00	0.02	2.00	50.00	50.04	0.00	0.00	0.00	0.00	0.00	0.00
12	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Solid Fuels	N_2O	4.12	2.06	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00
13	1.A.3.a Domestic Aviation	N_2O	0.55	0.13	1.00	66.00	66.01	0.00	0.00	0.00	0.00	0.00	0.00
14	1.A.3.b Road Transportation	N_2O	48.95	114.11	1.25	68.00	68.01	0.01	0.00	0.00	0.07	0.07	0.01
15	1.A.3.c Railways	N_2O	15.49	13.01	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00
16	1.A.3.d Domestic Navigation - Liquid Fuels	N_2O	0.67	2.14	1.00	90.00	90.01	0.00	0.00	0.00	0.00	0.00	0.00
17	1.A.3.e Other Transportation	N_2O	0.67	1.49	1.00	25.00	25.02	0.00	0.00	0.00	0.00	0.00	0.00
18	1.A.4 Other Sectors - Biomass	N_2O	2.23	2.90	10.00	50.00	50.99	0.00	0.00	0.00	0.00	0.00	0.00
19	1.A.4 Other Sectors - Gaseous Fuels	N_2O	0.27	1.29	2.50	50.00	50.06	0.00	0.00	0.00	0.00	0.00	0.00
20	1.A.4 Other Sectors - Liquid Fuels	N_2O	76.92	60.81	10.00	50.00	50.99	0.00	0.00	0.02	-0.02	0.03	0.00
21	1.A.4 Other Sectors - Peat	N_2O	13.22	3.44	5.00	50.00	50.25	0.00	0.00	0.00	-0.01	0.01	0.00
22	1.A.4 Other Sectors - Solid Fuels	N_2O	11.72	3.35	5.00	50.00	50.25	0.00	0.00	0.00	-0.01	0.01	0.00
23	2.B.2 Nitric Acid Production	N_2O	995.32	0.00	1.00	10.00	10.05	0.00	0.00	0.00	-0.20	0.20	0.04
24	2.G Other Product Manufacture and Use	N_2O	31.34	42.57	5.00	5.00	7.07	0.00	0.00	0.01	0.00	0.01	0.00
25	3.B.2.1 Manure Management -Dairy Cattle	N_2O	51.18	48.29	11.22	50.00	51.24	0.00	0.00	0.01	-0.01	0.02	0.00
26	3.B.2.1 Manure Management -Non-Dairy Cattle	N_2O	212.61	240.61	11.22	50.00	51.24	0.03	0.00	0.07	0.00	0.07	0.00
27	3.B.2.2 Manure Management -Sheep	N_2O	22.67	14.83	11.22	50.00	51.24	0.00	0.00	0.00	-0.01	0.01	0.00
28	3.B.2.3 Manure Management -Swine	N_2O	10.08	12.25	11.22	50.00	51.24	0.00	0.00	0.00	0.00	0.00	0.00
29	3.B.2.4 Manure Management -Deer	N_2O	0.24	0.02	11.22	50.00	51.24	0.00	0.00	0.00	0.00	0.00	0.00
30	3.B.2.4 Manure Management -Goats	N_2O	0.65	0.37	11.22	50.00	51.24	0.00	0.00	0.00	0.00	0.00	0.00
31	3.B.2.4 Manure Management -Horses	N_2O	3.44	5.15	11.22	50.00	51.24	0.00	0.00	0.00	0.00	0.00	0.00
32	3.B.2.4 Manure Management -Mules & Asses	N_2O	0.32	0.35	11.22	50.00	51.24	0.00	0.00	0.00	0.00	0.00	0.00
33	3.B.2.4 Manure Management -Poultry	N_2O	3.81	5.25	11.22	50.00	51.24	0.00	0.00	0.00	0.00	0.00	0.00
34	3.B.2.4 Manure Management -Fur Animals	N_2O	2.72	1.97	50.00	50.00	70.71	0.00	0.00	0.00	0.00	0.00	0.00
35	3.B.2.5 Indirect N2O emissions	N_2O	190.76	211.97	11.22	100.00	100.63	0.10	0.01	0.06	0.00	0.06	0.00
36	3.D.1.1 Inorganic N Fertilizer	N_2O	2158.39	1951.23	1.00	50.00	50.01	2.15	4.64	0.05	-0.40	0.40	0.16
37	3.D.1.2 Organic N Fertilizers	N_2O	683.59	753.14	11.22	100.00	100.63	1.30	1.69	0.22	-0.01	0.22	0.05
38	3.D.1.3 Urine and Dung Deposited by Grazing Animals	N_2O	1310.12	1284.31	11.18	50.00	51.23	0.98	0.96	0.37	-0.15	0.40	0.16
39	3.D.1.4 Crop Residues	N_2O	374.15	194.34	10.00	100.00	100.50	0.09	0.01	0.05	-0.40	0.40	0.16
40	3.D.1.5 Mineralization/Immobilization Associated with Loss/Gain of Soil Organic Matter	N_2O	20.03	21.78	22.57	100.00	102.52	0.00	0.00	0.01	0.00	0.01	0.00
41	3.D.1.6 Cultivation of Organic Soils	N_2O	749.85	858.09	12.22	100.00	100.74	1.69	2.86	0.27	0.05	0.27	0.07
42	3.D.2 Indirect N2O Emissions From Managed Soils	N_2O	557.23	535.95	11.18	50.00	51.23	0.17	0.03	0.15	-0.07	0.17	0.03
43	4.A LULUCF - Forest Land	N_2O	92.86	175.88	30.00	100.00	104.40	0.28	0.08	0.12	0.12	0.17	0.03
44	4.B.1 LULUCF - Cropland remaining Cropland	N_2O	0.01	0.00	100.00	100.00	141.42	0.00	0.00	0.00	0.00	0.00	0.00
45	4.C.1 LULUCF - Grassland Remaining Grassland	N_2O	15.67	5.77	91.02	100.00	135.22	0.01	0.00	0.01	-0.02	0.02	0.00
46	4.C.2 LULUCF - Land converted to Grassland	N_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
47	4.D.1 LULUCF - Wetlands remaining Wetlands	N_2O	31.25	10.98	86.00	100.00	131.89	0.02	0.00	0.02	-0.04	0.04	0.00

48	4.D.2 LULUCF - Land converted to Wetlands	N_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
49	4.E.1. LULUCF-Settlements remaining settlements	N_2O	6.29	72.65	45.24	54.69	70.98	0.08	0.01	0.08	0.06	0.10	0.01
50	4.E.2 LULUCF - Land Converted to Settlements	N_2O	6.29	72.65	45.24	54.69	70.98	0.08	0.01	0.08	0.06	0.10	0.01
51	4.F.2 LULUCF - Land Converted to Other Land	N_2O	0.08	50.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
52	5.B Biological treatment of solid waste: Composting	N_2O	0.00	8.28	10.00	10.00	14.14	0.00	0.00	0.00	0.00	0.00	0.00
53	5.C Incineration and Open Burning of Waste	N_2O	1.04	0.24	10.00	10.00	14.14	0.00	0.00	0.00	0.00	0.00	0.00
54	5.D Wastewater Treatment and Discharge	N_2O	75.14	96.69	10.00	10.00	14.14	0.00	0.00	0.02	0.00	0.02	0.00
	Total N_2O		**7855.49**	**6964.98**				**6.93**					**0.73**
							Level uncertainty, N_2O	**2.63**				**Trend uncertainty, N_2O**	**0.85**
	Combined CO_2, CH_4 and N_2O		**61853.51**	**65222.68**				**17.41**					**103.78**
							Level uncertainty, CO_2, CH_4 & N_2O	**4.17**				**Trend uncertainty, CO_2, CH_4 & N_2O**	**10.19**

	KEY CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (kt CO2eq)	Emissions in 2016 (kt CO2eq)	Activity Data (AD) Uncertainty (%)	Emission Factor (EF) Uncertainty (%)	Combined Uncertainty (%)	Contribution to Variance by Category in Year 2016	Combined Emissions Uncertainty Squared	Uncertainty in Trend in Total Emissions due to AD (%)	Uncertainty in Trend in Total Emissions due to EF (%)	Combined Uncertainty in Trend in Total Emissions (%)	Combined Trend Uncertainty Squared
1	2.E Electronics Industry & 2.F Product Uses and Substitutes for ODS	Aggregate F-gases	1.81	1244.99	20.00	10.00	22.36	0.18	0.03	0.63	0.22	0.67	0.45
2	2.G Other Product Manufacture and Use	Aggregate F-gases	33.42	22.30	10.00	0.00	10.00	0.00	0.00	0.01	0.00	0.01	0.00
	Total F-gases		**35.23**	**1267.30**				**0.18**					**0.45**
							Level uncertainty, F-gases	**0.42**			**Trend uncertainty, F-gases**		**0.67**
	TOTAL for all gases		**61888.74**	**66489.97**				**17.59**					**104.23**
					Total level uncertainty for all GHGs			**4.19**		**Total trend uncertainty for all GHGs**			**10.21**

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

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

Where:

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

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

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

Where:

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

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

Table 1.14 Summary of Completeness

IPCC SOURCE AND SINK CATEGORIES	CO_2	CH_4	N_2O	HFC	PFC	SF_6	NF_3
1. Energy							
A. Fuel Combustion (Sectoral Approach)	All	All	All	NA	NA	NA	NA
1. Energy Industries	All	All	All	NA	NA	NA	NA
2. Manufacturing Industries and Construction	All	All	All	NA	NA	NA	NA
3. Transport	All	All	All	NA	NA	NA	NA
4. Other Sectors	All	All	All	NA	NA	NA	NA
5. Other	NO	NO	NO	NA	NA	NA	NA
B. Fugitive Emissions from Fuels							
1. Solid Fuels	NO	All	NO	NA	NA	NA	NA
2. Oil and Natural Gas	All	All	Part	NA	NA	NA	NA
C. Carbon Dioxide Transport and Storage	NO	NO	NO	NA	NA	NA	NA
2. Industrial Processes and Product Use							
A. Mineral Industry	All	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
3. Agriculture							
A. Enteric Fermentation	NA	All	NA	NA	NA	NA	NA
B. Manure Management	NA	All	All	NA	NA	NA	NA
C. Rice Cultivation	NA	NO	NA	NA	NA	NA	NA
D. Agricultural Soils	NA	NE	All	NA	NA	NA	NA
E. Prescribed Burning of Savannas	NO	NO	NO	NA	NA	NA	NA
F. Field Burning of Agricultural Residues	NO	NO	NO	NA	NA	NA	NA
G. Liming	NO	NO	NO	NA	NA	NA	NA
H. Urea Application	All	NO	NO	NA	NA	NA	NA
I. Other	All	NO	NO	NA	NA	NA	NA
4. Land-Use Land-Use Change and Forestry							
A. Forest Land	All	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
5. Waste							
A. Solid Waste Disposal	NO	All	NA	NA	NA	NA	NA
B. Biological Treatment of Solid Waste	NA	All	All	NA	NA	NA	NA
C. Waste Incineration and Open Burning of Waste	All	All	All	NA	NA	NA	NA
D. Wastewater Treatment and Discharge	NO	All	All	NA	NA	NA	NA
E. Other	NO	NO	NO	NA	NA	NA	NA
6. Other	NO	NO	NO	NA	NA	NA	NA
Article 3.3 Afforestation and Deforestation	All	All	All	NA	NA	NA	NA
Memo Items:							
International Bunkers							
Aviation	All	All	All	NA	NA	NA	NA
Navigation	All	All	All	NA	NA	NA	NA
Multilateral Operations	NO	NO	NO	NA	NA	NA	NA
CO_2 Emissions from Biomass	All	NA	NA	NA	NA	NA	NA
CO_2 captured	NO	NO	NO	NA	NA	NA	NA
Long-term storage of C in waste disposal sites	NE	NO	NO	NA	NA	NA	NA
Indirect N_2O	NO	NO	NE	NA	NA	NA	NA
Indirect CO_2	Part	NO	NO	NA	NA	NA	NA

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

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 1990-2016 are shown in Figure 2.1 and Table 2.1. The estimates reported here show some changes on those reported in the 2017 submission, which reflect recalculations that are fully described in subsequent chapters. The trends in the principal emission components, shown as CO_2 equivalents, within the five IPCC sectors are shown on Figure 2.4 through Figure 2.11.

Total emissions of the seven greenhouse gases in Ireland (including indirect CO_2 emissions without land use, land use change and forestry) increased steadily from 55,490.3 kt CO_2 eq in 1990 to 70,555.1 kt CO_2 eq in 2001, which is the highest level of GHG emissions ever reported in Ireland. Emissions then plateaued until 2008 with estimates ranging from 67,341.2 kt CO_2 eq to 69,542.7 kt CO_2 eq. There was then a sharp decrease from 67,341.2 kt CO_2 eq in 2008 to 57,106.3 kt CO_2 eq in 2011. Emissions then plateaued again between 2011 and 2014. There was a rise in emissions between 2014 and 2015 of 3.7 per cent to 59,426.5 kt CO_2 eq, and there was a further increase between 2015 and 2016 of 3.6 per cent to 61,545.8 kt CO_2 eq which is the third largest annual growth rate ever reported in Ireland.

The largest annual change occurred from 2008 to 2009 when emissions decreased by 5,740.0 kt CO_2 eq from 67,341.2 kt CO_2 eq to 62,601.2 kt CO_2 eq a reduction of 8.5 per cent. Total emissions in 2016 were 10.9 per cent higher than in 1990 and 12.8 per cent lower than the peak level in 2001. Inter annual changes to national total emission estimates are shown in Figure 2.2.

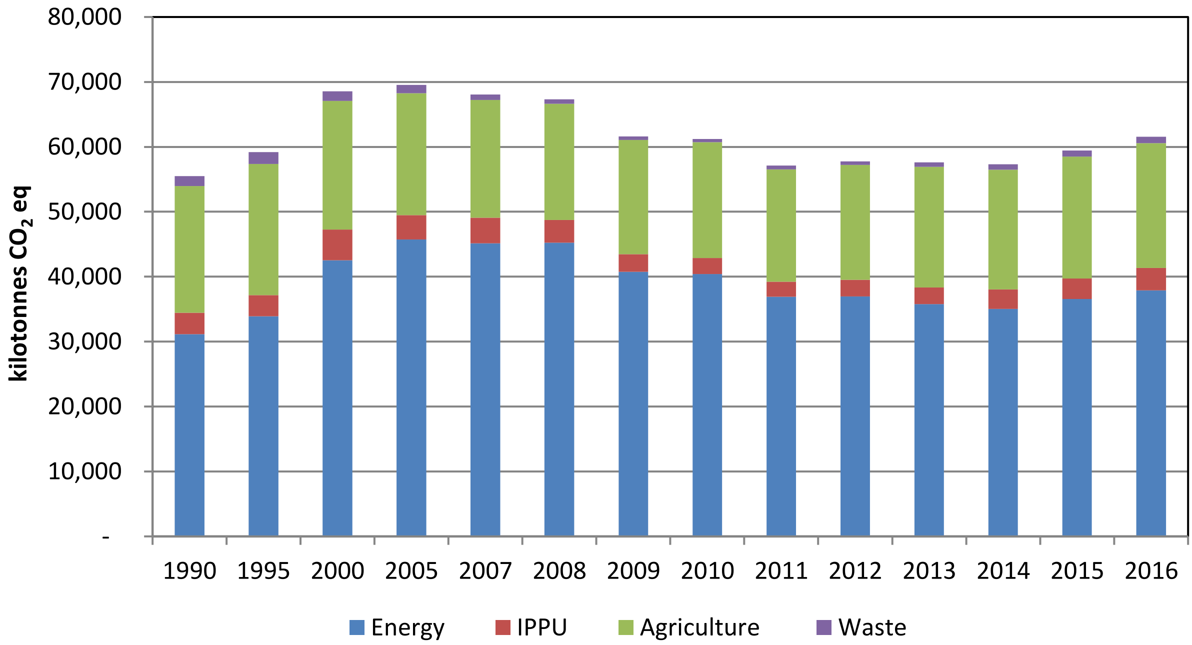

Figure 2.1 National total Greenhouse Gas emissions (excluding LULUCF) 1990-2016

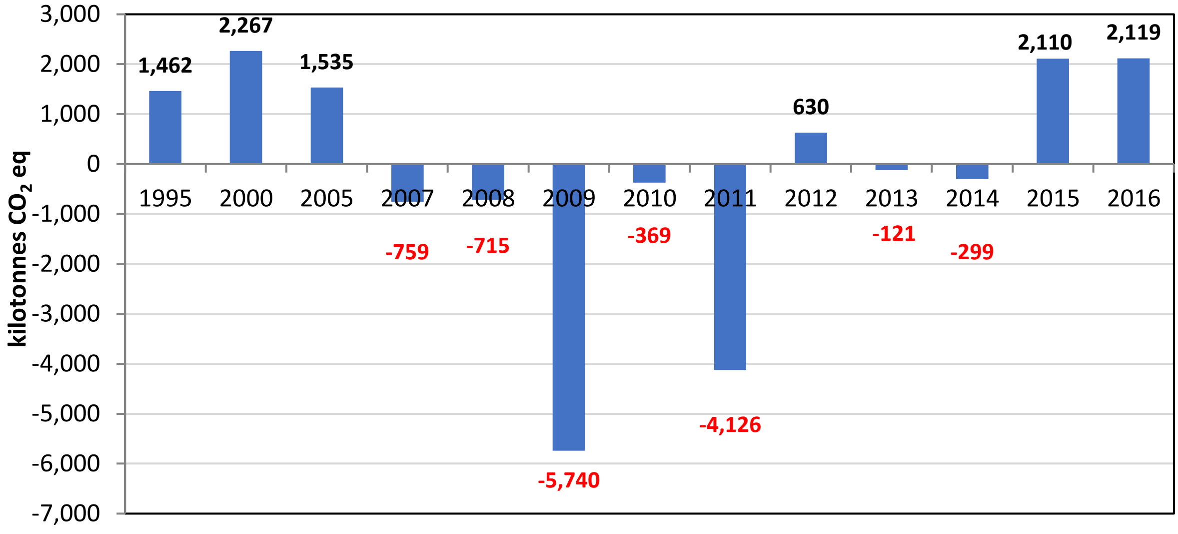

Figure 2.2 Inter annual changes

In 2016, the total Energy sector accounted for 61.6 per cent of total emissions, Agriculture contributed 31.3 per cent while a further 5.6 per cent emanated from Industrial Processes and Product Use and 1.6 per cent was due to Waste.

The Energy sector accounted for the bulk of the CO_2 emissions in 2016 (93.5 per cent), IPPU and Agriculture sectors contributed further 5.3 per cent and 1.2 per cent, respectively and Waste contributed the remainder 0.1 per cent. CH_4 emissions are produced mainly in the Agriculture sector (92.3 per cent) and Waste sector (6.1 per cent), the Energy sector contributed the remainder 1.6 per cent. Most of the N_2O emissions are generated in Agriculture (92.4 per cent) and Energy (5.4 per cent) with Waste and IPPU contributing a further 1.6 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_2 emissions from energy use. CO_2 from the Energy sector increased its share of national total emissions from 54.3 per cent in 1990 to 62.1 per cent share in 2001. The bulk of this increase occurred in the years between 1994 and 2001, during which Ireland experienced a period of unprecedented economic growth with energy CO_2 emissions increasing by an average of 4.4 per cent annually.

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

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

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

The increase seen in 2015, continued in 2016, and was due to increased emissions from almost all IPCC sectors. The most significant contributors were energy use categories, including road transport, and emissions from enteric fermentation.

Table 2.1. Greenhouse Gas Emissions 1990-2016 (kt CO_2 equivalent)

(a) Emissions by Gas

Greenhouse Gas Emissions	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Percentage change (1990-2016)
CO_2 emissions without net CO_2 from LULUCF	32,877.9	35,794.4	45,194.0	48,104.6	47,622.9	47,300.1	42,108.5	41,679.5	38,009.3	38,194.8	37,182.8	36,681.6	38,443.6	39,928.1	21.4%
CO_2 emissions with net CO_2 from LULUCF	38,668.0	41,418.5	50,873.5	53,455.6	52,204.4	50,977.5	45,309.4	45,802.2	42,177.3	43,132.8	41,569.4	41,213.1	42,775.3	44,177.5	14.2%
CH_4 emissions without CH_4 from LULUCF	14,867.8	15,076.9	14,386.8	13,601.9	12,882.6	12,675.6	12,299.3	12,048.9	12,012.2	12,309.5	12,640.7	12,943.4	13,323.0	13,705.4	-7.8%
CH_4 emissions with CH_4 from LULUCF	15,330.0	15,539.3	14,820.4	14,108.8	13,298.8	13,063.7	12,688.6	12,602.2	12,437.5	12,679.6	13,050.8	13,346.1	13,722.5	14,080.2	-8.2%
N_2O emissions without N_2O from LULUCF	7,709.3	8,029.1	8,018.5	6,816.3	6,375.9	6,328.8	6,155.5	6,492.4	6,068.3	6,235.7	6,668.5	6,508.4	6,517.8	6,645.0	-13.8%
N_2O emissions with N_2O from LULUCF	7,855.5	8,221.7	8,216.7	7,107.6	6,661.9	6,650.8	6,477.9	6,848.9	6,398.3	6,564.2	7,003.1	6,836.8	6,857.0	6,965.0	-11.3%
HFCs	1.2	103.2	456.7	678.3	905.8	845.8	915.1	932.0	955.2	948.6	1,070.0	1,140.9	1,076.1	1,189.7	96301.4%
PFCs	0.1	97.6	397.8	216.4	168.1	136.1	83.6	46.6	15.9	9.6	8.3	3.6	20.5	37.4	31090.6%
SF_6	33.9	79.1	51.8	96.8	62.9	54.7	39.2	33.1	45.5	37.4	43.5	37.4	44.5	39.3	16.0%
NF_3	NO	4.4	49.2	28.4	37.7	NO	NO	NO	NO	0.8	0.9	1.0	1.0	1.0	-
Total (without LULUCF)	**55,490.3**	**59,184.7**	**68,554.7**	**69,542.7**	**68,056.0**	**67,341.2**	**61,601.2**	**61,232.5**	**57,106.3**	**57,736.3**	**57,614.9**	**57,316.3**	**59,426.5**	**61,545.8**	**10.9%**
Total (with LULUCF)	**61,888.7**	**65,463.7**	**74,866.0**	**75,691.8**	**73,339.5**	**71,728.6**	**65,513.7**	**66,265.0**	**62,029.6**	**63,373.0**	**62,746.1**	**62,578.9**	**64,496.9**	**66,490.0**	**7.4%**
Total (without LULUCF, with indirect)	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**-**
Total (with LULUCF, with indirect)	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**-**

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

Greenhouse Gas Source and Sink Categories	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Percentage change (1990-2016)
1. Energy	31,119.7	33,896.2	42,529.2	45,713.9	45,147.5	45,246.7	40,765.1	40,392.1	36,897.8	36,982.9	35,761.9	35,030.1	36,584.1	37,920.1	21.9%
2. Industrial Processes	3,309.4	3,274.8	4,743.8	3,784.4	3,944.9	3,508.5	2,696.5	2,476.3	2,351.3	2,557.6	2,600.2	3,003.2	3,149.2	3,417.2	3.3%
3. Agriculture	19,514.4	20,190.6	19,792.6	18,753.7	18,115.1	17,898.6	17,624.4	17,865.3	17,267.2	17,681.2	18,581.7	18,430.1	18,743.9	19,250.8	-1.4%
4. LULUCF	6,398.5	6,279.0	6,311.3	6,149.1	5,283.5	4,387.5	3,912.6	5,032.4	4,923.3	5,636.7	5,131.3	5,262.6	5,070.4	4,944.2	-22.7%
5. Waste	1,546.8	1,823.0	1,489.1	1,290.7	848.5	687.4	515.2	498.9	589.9	514.6	671.0	853.0	949.3	957.7	-38.1%
6. Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	-
Total (including LULUCF)	**61,888.7**	**65,463.7**	**74,866.0**	**75,691.8**	**73,339.5**	**71,728.6**	**65,513.7**	**66,265.0**	**62,029.6**	**63,373.0**	**62,746.1**	**62,578.9**	**64,496.9**	**66,490.0**	**7.4%**

2.2 Trends by Gas

Emissions of CO_2 accounted for 64.9 per cent of the total (excluding LULUCF) of 61,545.8 kt CO_2 equivalent in 2016, with CH_4 and N_2O contributing 22.3 per cent and 10.8 per cent, respectively. The combined emissions of HFC, PFC, SF_6 and NF_3 accounted for 2.1 per cent of total emissions in 2016. In 1990 emissions of CO_2, CH_4, N_2O and the combined emissions of HFCs, PFCs, SF_6 and NF_3 accounted for 59.2, 26.8, 13.9 and less than 0.1 per cent, respectively of total emissions of 55,490.3 kt CO_2 equivalent as presented in Figure 2.3.

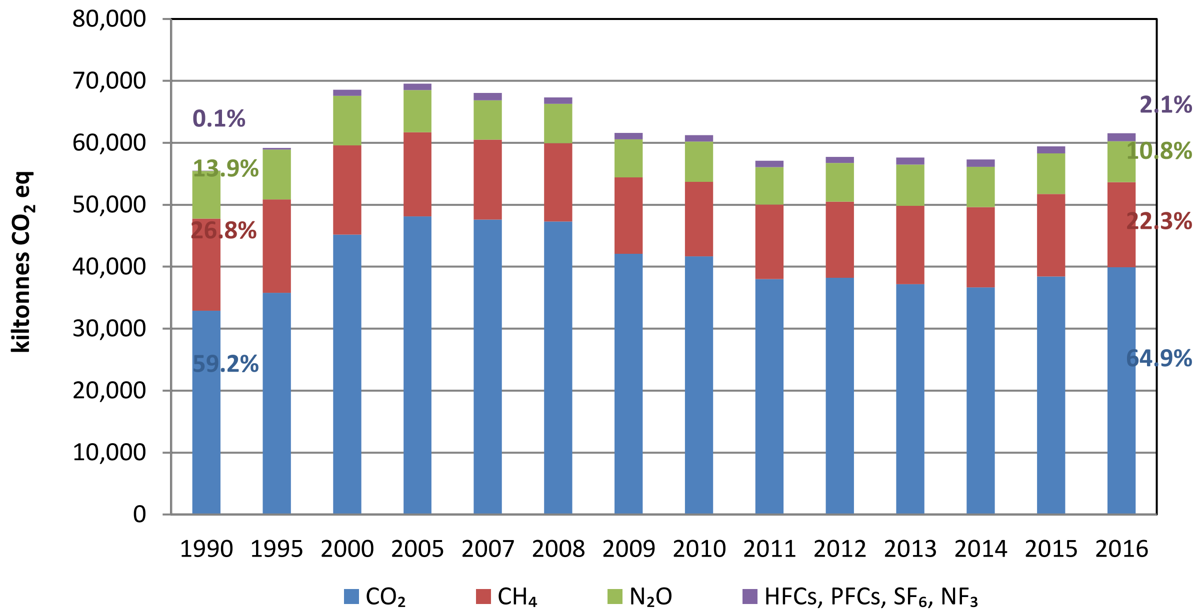

Figure 2.3 Greenhouse Gas emissions-by Gas (excluding LULUCF) 1990-2016

2.2.1 Trends in Carbon Dioxide

CO_2 is the most significant contributor to the greenhouse gas emissions with 1.A.1 Energy Industries and 1.A.3 Transport sectors responsible for 31.0 per cent and 30.4 per cent of total CO_2 emissions (excluding LULUCF) in 2016, respectively. 1.A.4 Other Sectors represents a share of 20.8 per cent, 1.A.2 Manufacturing Industries and Construction has an 11.3 per cent share and the remainder of CO_2 emissions (6.5 per cent share) fall into other categories.

Emissions of CO_2 increased from 32,877.9 kt in 1990 to 39,928.1 kt in 2016, which equates to an increase of 21.4 per cent. The main driver behind this increase in emissions is primarily fuel combustion in Transport followed by Energy Industries. Over the period 1990-2016, emissions of CO_2 from transport, predominantly road traffic in Ireland, increased by 141.9 per cent. This trend is exaggerated somewhat in later years by so-called fuel-tourism. In 2016 it is estimated that 1.0 per cent of petrol and 13.0 per cent of diesel sold in Ireland was used in vehicles in the UK and other countries.

Over the time-series, emissions of CO_2 from 1.A.1 Energy Industries increased in the first decade by 54.7 per cent until they peaked in 2001 and decreased by 28.3 per cent to 2016, showing an overall increase of 11.0 per cent CO_2 over the 1990-2016 period. In addition, even though Ireland has only a small number of energy intensive industries, CO_2 emissions from combustion in the industrial sector 1.A.2 Manufacturing Industries and Construction increased by 14.9 per cent between 1990 and 2016.

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 2016 emissions of CH_4 were 13,705.4 CO_2 equivalent, indicating a decrease of 7.8 per cent on the 1990 level of 14,867.8 kt CO_2 equivalent. Emissions of CH_4 increased progressively from 1990, reaching a peak in 1998 of 15,497.5 kt CO_2 equivalent, which reflects an increase in livestock numbers and therefore increased emissions from source categories 3.A Enteric Fermentation and 3.B Manure Management.

Between 1998 and 2011 CH_4 emissions decreased as a result of falling livestock numbers due to reform of the Common Agricultural Policy (CAP). However, total CH_4 emissions in the period 2001-2014 fluctuated to some extent on a yearly basis. This trend is a direct result of fluctuating CH_4 emissions from 1.A.4 Other Sectors and 1.B Fugitive Emissions from Fuels. The main contributor to the CH_4 trend has been Agriculture and in 2016 the sector accounted for 92.3 per cent of the total methane emissions (compared to 85.8 per cent share in 1990 when emissions from Waste had a larger share in the methane trend). The sectoral methane emissions from Agriculture decreased by 0.9 per cent between 1990 (12,763.0 kt CO_2 equivalent) and 2016 (12,649.5 kt CO_2 equivalent).

Another significant source of methane emissions is Waste sector, especially from landfill gas in category 5.A Solid Waste Disposal on Land. CH_4 emissions from Waste decreased from 8.9 per cent share of total methane emissions (1,318.1 kt CO_2 equivalent) in 1990 to 6.1 per cent share (767.8 kt CO_2 equivalent) in 2016. 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 13.8 per cent from their 1990 level of 7,709.3 kt CO_2 equivalent in 1990 to 6,645.0 kt CO_2 equivalent in 2016. Similar to CH_4, emissions of N_2O increased during the 1990s to reach peak level of 8,464.5 kt CO_2 equivalent in 1998 reflecting increased use of synthetic fertilisers and increased amounts of animal manures associated with increasing animal numbers over that period. Emissions of N_2O subsequently show a clear downward trend following reductions in synthetic fertiliser use and organic nitrogen applications on land as a result of the effect of the CAP reform on animal numbers as well the closure of Ireland's only nitric acid plant in 2002.

The largest contributor to the trend is the Agriculture sector with 92.4 per cent share of the total N_2O emissions (6,139.9 kt CO_2 equivalent) in 2016. This reflects an increase from 82.4 per cent share (6,351.8 kt CO_2 equivalent) in 1990 despite being a lower absolute number. Emissions from IPPU in chemical industry used to be the second largest contributor to the trend contributing 12.9 per cent to total N_2O emissions in 1990 and an average of 10.2 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 9.6 per cent and 2.7 per cent, respectively to total N_2O emissions in 2016.

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

Emissions of F-gases (HFCs, PFCs, SF_6 and NF_3) were 1,267.3 kt CO_2 equivalent in 2016 compared to 35.2 kt CO_2 equivalent in 1990, a 35 fold increase over the time series. However, F-gas emissions only account for 2.1 per cent of the national total in 2016. 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 1.2 kt CO_2 equivalent in 1990 to 1,189.7 kt CO_2 in 2016.

Emissions of PFCs increased from 0.12 kt CO_2 equivalent in 1990 up to their peak of 397.8 kt CO_2 equivalent 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 2016 (37.4 kt CO_2 equivalent in 2016).

SF_6 is used in a diverse number or products and processes and is therefore included in a number of IPCC source sub-categories including 2.E.1 Semiconductor Manufacture, 2.G.1 Electrical Equipment and four subcategories under 2.G.2 Other. Emissions of SF_6 were 33.9 kt CO_2 equivalent and 39.3 kt CO_2 equivalent in 1990 and 2016, respectively. However, total emissions of SF_6 across the time series vary considerably, primarily because the two largest sources (Semiconductor Manufacture and Electrical Equipment) vary considerably from year to year. Emissions of SF_6 grew steadily from 1990, peaking at 126.1 kt CO_2 equivalent in 1997. The increase over the period 1990-1997 was largely due to increased use of SF_6 in Semiconductor Manufacture. Emissions from both Semiconductor Manufacture and Electrical Equipment then show a steady decline across the time series (although there are peaks in 2003 and 2005 due to elevated emissions from Semiconductor Manufacture). Similar to PFCs, semiconductor manufacturers have undertaken to reduce the use of SF_6 through gas substitution and new process technologies. In 2.E.1 Electrical Equipment, where SF_6 is used for electrical insulation, arc quenching and current interruption, a leak reduction programme has been in place since 1997, when peak emissions are observed.

NF_3 are solely released from 2.E.1 Semiconductor Manufacture. Emissions of NF_3 were reported since 1995 (4.37 kt CO_2 eq.) when use of this gas commenced in the industry and peaked in 2000 (49.2 kt CO_2 eq.), followed by fluctuations until 2008 when NF_3 was phased out from Semiconductor Manufacture for four consecutive years. Since 2012 small amounts of NF_3 were used again in Semiconductor Manufacture resulting in low emission levels averaging 0.91 kt CO_2 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). It can be seen that the largest contribution is from the Energy sector, which in 2016 contributes 61.6 per cent of total greenhouse gas emissions (excluding LULUCF). The second largest sector is Agriculture, which accounted for 31.3 per cent of total greenhouse gas emissions in 2016. Emissions from Industrial Processes and Product Use accounted for 5.6 per cent and Waste accounted for 1.6 per cent of total emissions in 2016. 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 21.9 per cent from 31,119.7 kt CO_2 eq in 1990 to 37,920.1 kt CO_2 eq in 2016. 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 45,713.9 kt CO_2 eq. A major decrease occurred between 2008 and 2009 when the sectoral emissions fell by 9.9 per cent. A further reduction of 7.0 per cent has occurred between 2009 and 2016.

Energy Industries (1.A.1) accounted for 20.2 per cent and 20.3 per cent of total national greenhouse gas emissions excluding LULUCF in 1990 and 2016, respectively. Total greenhouse gas emissions from this sub-sector increased by 54.5 per cent from 11,223.13 CO_2 equivalent in 1990 to 17,334.22 CO_2 equivalent 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 15,335.43 kt CO_2 equivalent in 2004. Emissions subsequently increased in 2005 to 15,828.51 kt CO_2 equivalent 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 15,076.62 kt CO_2 equivalent 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_2 equivalent) are largely a result of the displacement of oil by natural gas. In 2008, emissions increased by 0.8 per cent or 123.49 kt CO_2 equivalent to 14,706.49 kt CO_2 equivalent, then decreased in 2009 by 10.8 per cent to 13,117.52 kt CO_2 equivalent reflecting the impact of the economic recession in Ireland. There was a slight increase in emissions (2.0 per cent) in 2010 to reach 13,378.89 kt CO_2 equivalent which reflects a reduction in the share of renewables in gross electricity consumption from 14.3 per cent in 2009 to 13.0 per cent in 2010. Wind and hydro resources were less in 2010 which resulted in more electricity generation from coal and gas-fired power stations. By 2012, wind and hydro energy generation had grown substantially, resulting in a renewables contribution to gross electricity consumption of 19.1 per cent. However, these changes combined with increased consumption of coal and reduction of natural gas resulted in an increase in emissions from the Energy industries sector of 7.0 per cent between 2011 and 2012, from 11,977.73 kt CO_2 equivalent to 12,815.21 kt CO_2 equivalent, respectively. In 2013 emissions from this sector decreased by 11.0 per cent on 2012 levels to reach 11,408.64 kt CO_2 equivalent, 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 11,185.04 kt CO_2 equivalent (2.0 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 11,801.52 kt CO_2 equivalent, the main driver of which was a 18.8 per cent increase in the combustion of coal in Ireland’s only coal fired electricity generation plant. Emissions in 2016 were 12,515.42 kt CO_2 equivalent, 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. Overall drivers and trends in emissions from the Energy sector are presented in Figure 2.4 and Figure 2.5.

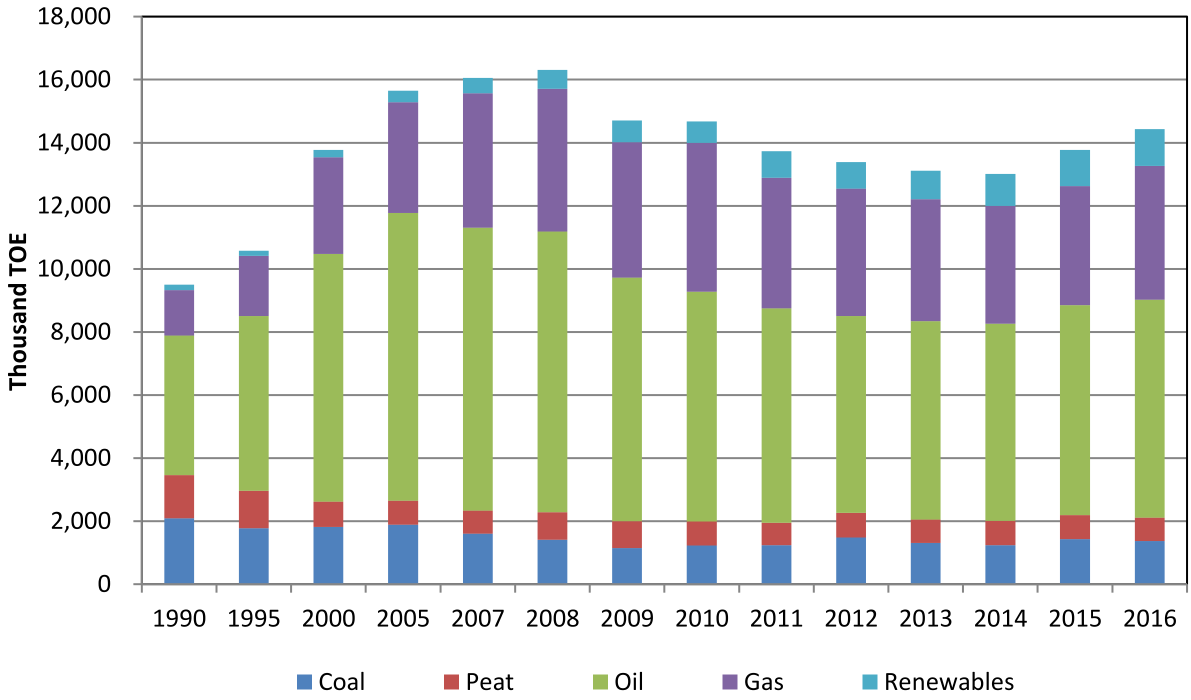

Figure 2.4 Total Primary Energy Requirement (TPER) 1990-2016

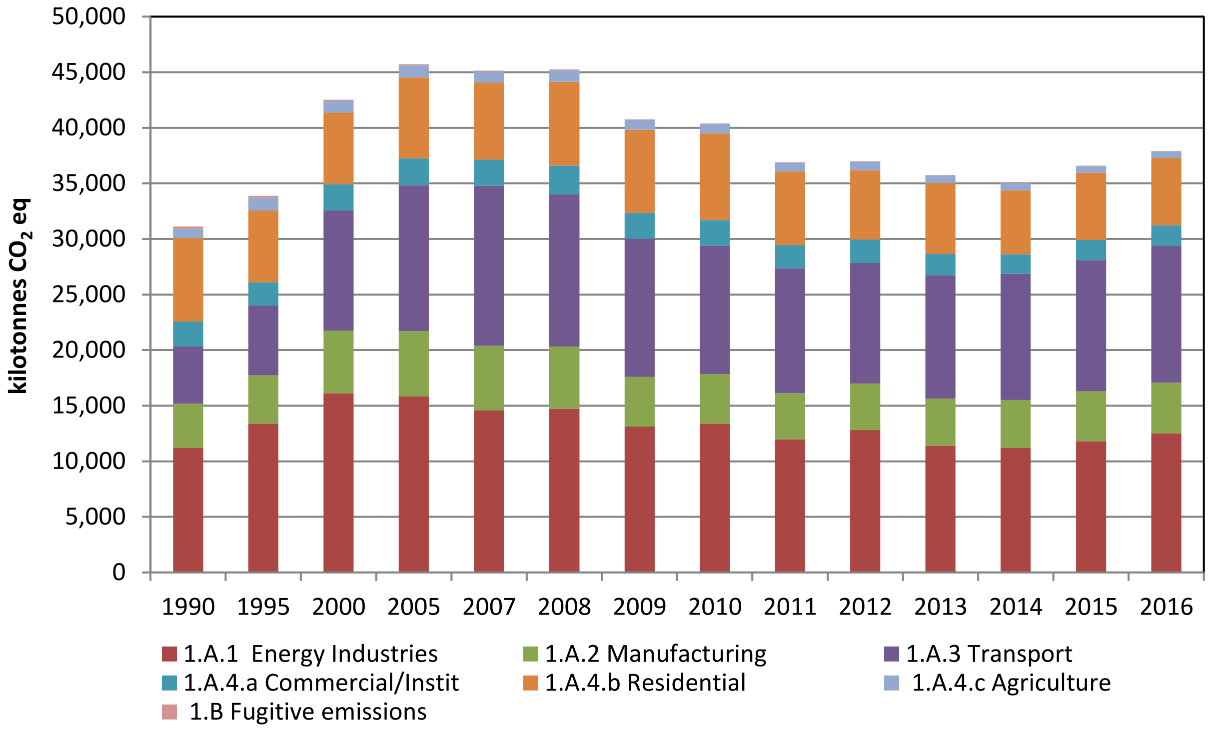

Figure 2.5 Trend in Emissions from Energy 1990-2016

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 7.1 per cent (3,961.8 kt CO_2 equivalent) and 7.4 per cent (4,554.61 kt CO_2 equivalent) of total national greenhouse gas emissions in 1990 and 2016, respectively. The trend shows an increase of 15.0 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 years 2000 and 2008 with their peak at 5,870.42 kt CO_2 equivalent in 2005. Following an economic downturn, emissions sharply declined by 20.4 per cent between 2008 and 2009, from 5,629.34 kt CO_2 equivalent to 4,480.28 kt CO_2 equivalent, respectively and continued to decline until 2012 (4,176.49 kt CO_2 equivalent), followed by a small increases in 2013 and 2014, by 1.4 per cent, and 3.5 per cent as compared to 2012 levels when manufacturing industry started to recover from recession. Emissions in 2016 were 9.1 per cent above those in 2012 and 1.6 per cent above those in 2015. 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 9.3 per cent and 20.0 per cent of total national greenhouse gas emissions in 1990 and 2016, respectively. The overall sector's emissions increased by 139.3 per cent from 5,136.71 kt CO_2 equivalent in 1990 to 12,293.95 kt CO_2 equivalent in 2016. This is largely accounted for by a 145.4 per cent increase in road transport emissions over the same period, due to sustained growth in the use of passenger cars and goods vehicles. The trend is however, somewhat exaggerated by so-called fuel tourism whereby a proportion of the automotive fuel sold in the Republic of Ireland is used in vehicles in the UK and other countries. Fuel tourism is estimated to have accounted for 1.0 per cent of petrol and 13.2 per cent of diesel sales in 2016. 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 2,097.07 kt CO_2 equivalent lower in 2016 than in 2007. This represents a decrease of 14.6 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. There is some evidence of the return to economic growth as emissions have increased on average by 3.1 per cent per year since 2012. Emissions from domestic aviation decreased by 81.1 per cent between 1990 (51.7 kt CO_2 equivalent) and 2016 (9.80 kt CO_2 equivalent), having peaked in 2006 at 77.3 kt CO_2 equivalent. However, their overall effect on transport emission trends is negligible.

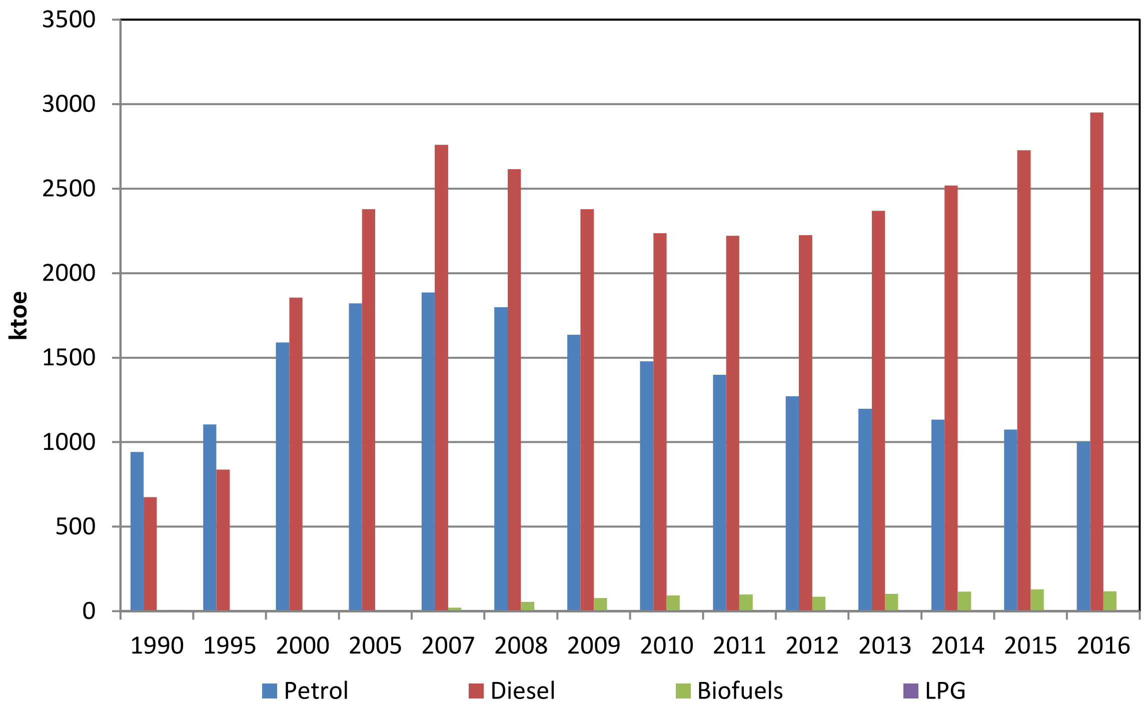

Figure 2.6 Fuel use in Road Transport 1990-2016

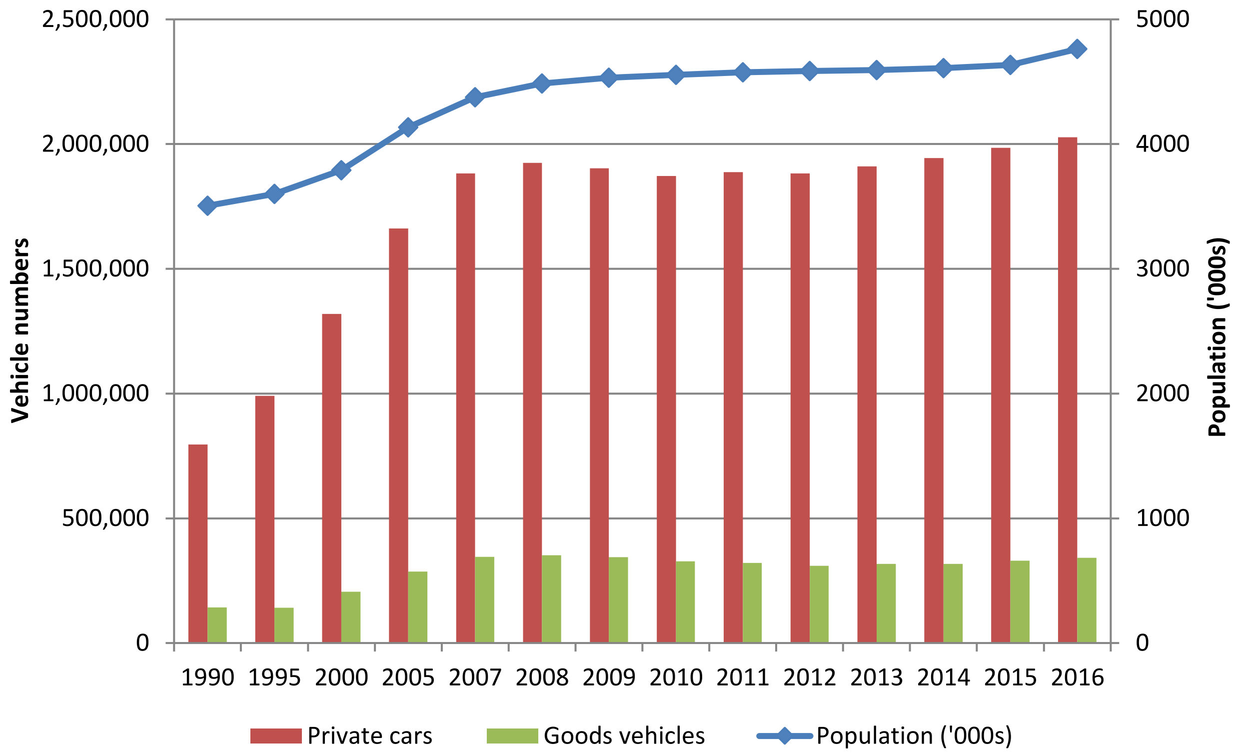

Figure 2.7 Vehicle numbers and Census of Population 1990-2016

Emissions from category 1.A.4 Other Sectors decreased by 20.0 per cent from 10,586.27 kt CO_2 equivalent in 1990 to 8,514.82 kt CO_2 equivalent in 2016. Emissions from the Commercial (1.A.4.a), Residential (1.A.4.b) and Agriculture/Fishing (1.A.4.c) sub-categories decreased by 16.8, 19.6 and 26.6 per cent, respectively between 1990 and 2016. The emissions of CO_2 from coal and peat use in the residential sector decreased by 73.0 per cent and 71.0 per cent, respectively between 1990 and 2016 while those from oil and natural gas increased by 199.3 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 6.0 per cent of total greenhouse gases in 1990 and 5.6 per cent in 2016. Total emissions from the sector were 3,309.41 kt CO_2 equivalent in 1990 and 3,417.20 kt CO_2 equivalent in 2016. This is an increase of 3.3 per cent in emissions over the time series. Overall trends in emissions from IPPU are presented in Figure 2.8.

In the early 1990's (1990 to 1994) the contribution of 2.B Chemical Industry to overall sectoral emissions was on average 59.4 per cent. By the late 1990's (1995 to 1999) this proportion had fallen to 48.1 per cent on average of total emissions from the sector. In 1990 emissions from 2.B. Chemical Industry were 1,985.55 kt CO_2 equivalent, however by 2000 they had reduced by 16.2 per cent to 1,663.30 kt CO_2 equivalent 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_2 to 1,700.9 kt CO_2. Economic growth was sustained into the early years of the new millennium with associated increases in emissions from the sector, during which two new cement production plants were commissioned, with one opening in 2000 and the other in 2003. This resulted in further growth in emissions from the cement sector to reach peak of 2,374.1 kt CO_2 in 2007 (an increase of 168.6 per cent from 1990). Due to the economic recession, emissions from sector 2.A.1 decreased by 59.3 per cent between 2007 and 2011 to reach 966.27 kt CO_2. Emissions have subsequently risen to 1,793.52 kt CO_2 in 2016 (and increase of 86.0 per cent between 2011 and 2016), reflecting economic recovery.

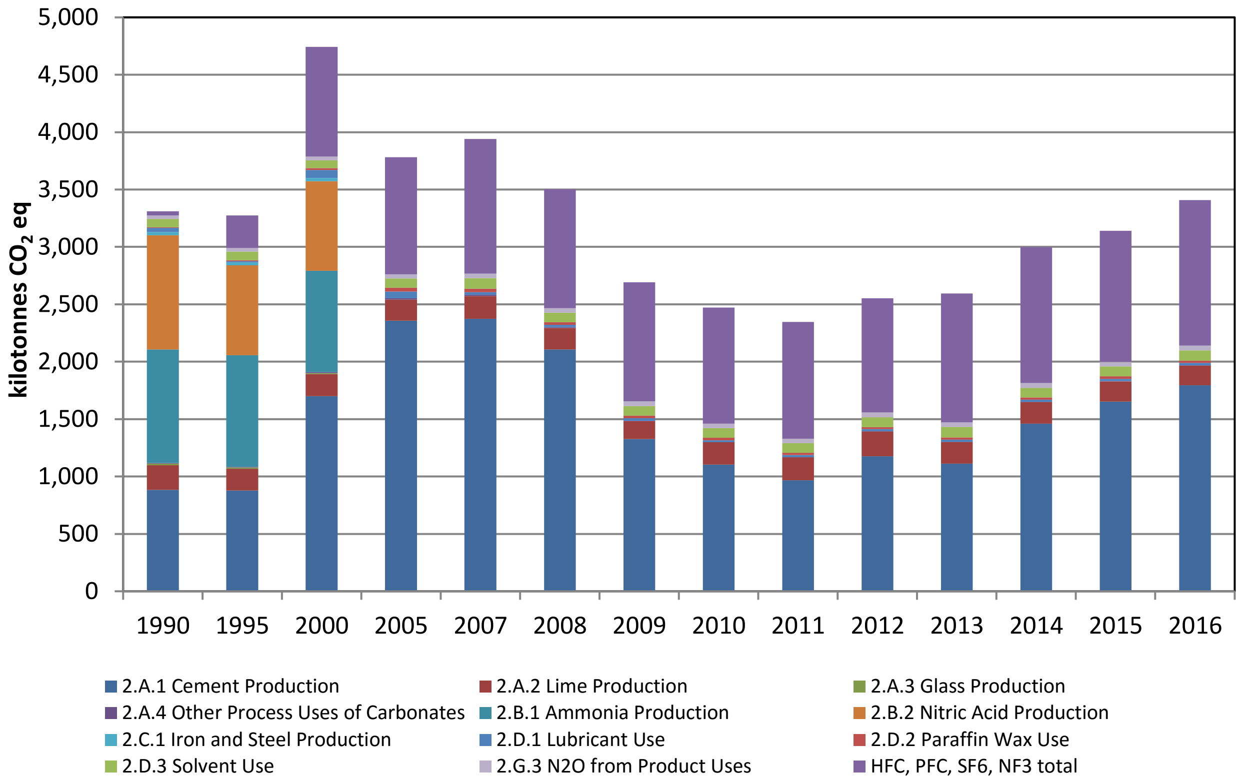

Figure 2.8 Trend in Emissions from Industrial Processes and Product Use 1990-2016

The closure of Ireland's nitric acid and ammonia plants in 2002 and 2003, respectively, significantly changed the level of process emissions in Ireland. As a result CO_2 emissions from cement production (2.A.1) became the single major component of sector emissions and these emissions increased steadily during the period of economic growth up to 2007, the year when they reached a peak of 2,374.1 kt CO_2 equivalent (and 60.2 per cent share of the IPPU sector). Emissions from cement manufacture then decreased in line with the economic downturn, accounting for 60.0 per cent of total emissions from IPPU sector in 2008, falling to a 41.1 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, 2015 and 2016. The contribution from cement manufacture to emissions from IPPU sector in 2016 is now 52.5 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 5.1 per cent of total IPPU sector emissions in 2016. The emissions from these sub-categories are small and their effect on overall trends is negligible.

The Non-Energy Products from Fuels and Solvent Use sector 2.D includes emissions from 2.D.1 Lubricant use, 2.D.2 Paraffin Wax use and indirect CO_2 emissions from 2.D.3 Solvent use. In 2016 sector 2.D accounted for 4.1 per cent of IPPU sector, having increased by 21.4 per cent from 114.48 kt CO_2 equivalent in 1990 to 138.94 kt CO_2 equivalent in 2016. However, the largest contributing sector in 2D, Non-Energy Products from Fuels and Solvent Use sector with 0.2 per cent share of total national greenhouse gas emissions in 2016 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 1,187.95 kt CO_2 equivalent in 2016, compared to 0.64 kt CO_2 equivalent 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 144.18 kt CO_2 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 (152.0 kt CO_2 equivalent) and started declining again until 2016 at a level of 133.61 kt CO_2 equivalent. 2.F.1 Refrigeration and Air Conditioning was reported first in 1993 having an emissions level of 0.51 kt CO_2 equivalent which increased sharply to 1,021.89 kt CO_2 equivalent in 2016. 2.F.3 Fire Protection was reported first in 1996 and showed a slow increase from 1.5 kt CO_2 equivalent to 32.45 kt CO_2 equivalent from 1990 to 2016.

2.3.3 Trends in Agriculture (IPCC Sector 3)

The trend in emissions from the Agriculture sector is presented in Figure 2.9. Emissions of greenhouse gases from the Agriculture sector amounted to 19,514.36 kt CO_2 equivalent in 1990 and 19,250.82 kt CO_2 equivalent in 2016, a reduction of 1.4 per cent. Between 1990 and 1998, the total emissions from the Agriculture sector increased by 7.8 per cent, reflecting an increase in animal numbers and increased synthetic nitrogen use on farms. Following this peak in emission levels of 21,027.17 kt CO_2 equivalent in 1998, emissions from the sector decreased by 18.0 per cent to 17,267.22 kt CO_2 equivalent 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 2016 were 19,250.82 kt CO_2 equivalent, representing a 11.5 per cent increase on the total emissions in 2011. This was primarily driven by an increase in cattle number of 11.6 per cent between 2011 and 2016.

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 92.3 per cent of total methane emissions in 2016. The combined total of emissions of CH_4 from enteric fermentation and manure management was 12,763.02 kt CO_2 equivalent in 1990. This increased by 7.3 per cent to reach 13,693.28 kt CO_2 equivalent in 1998 and subsequently decreased by 7.6 per cent to 12,649.50 kt CO_2 equivalent in 2016. Cattle account for 90.6 per cent of CH_4 emissions in Irish agriculture in 2016.

The emissions of N_2O from the Agriculture sector follow similar trends to those of CH_4 because cattle also largely determine the amount of nitrogen inputs to agricultural soils from synthetic fertiliser (sector 3.D) and animal manures (sector 3.B), which combined produce the bulk of N_2O emissions (92.4 per cent of total N_2O emissions in 2016). Nitrous oxide emissions in Agriculture increased from 6,351.83 kt CO_2 equivalent in 1990 by 1.2 per cent yearly in the period 1990-1998 with emissions in

1998 totalling 6,984.44 kt CO_2 equivalent. Nitrous oxide emissions totalling 6,139.92 kt CO_2 equivalent in 2016 represent a reduction of 12.1 per cent on the 1998 level and 3.3 per cent on the 1990 level. Crops contribute very little to N_2O emissions in Ireland and the amount fluctuates annually in response to varying production of the relevant crops.

Carbon dioxide emissions were 461.4 kt CO_2 equivalent in 2016 compared to 399.5 kt CO_2 equivalent in 1990, a 15.5 per cent increase over the time series. 3.G Liming and 3.H Urea Application are the two subsectors responsible for CO_2 emissions from Agriculture sector accounting for 1.2 per cent share of total CO_2 emissions in 2016.

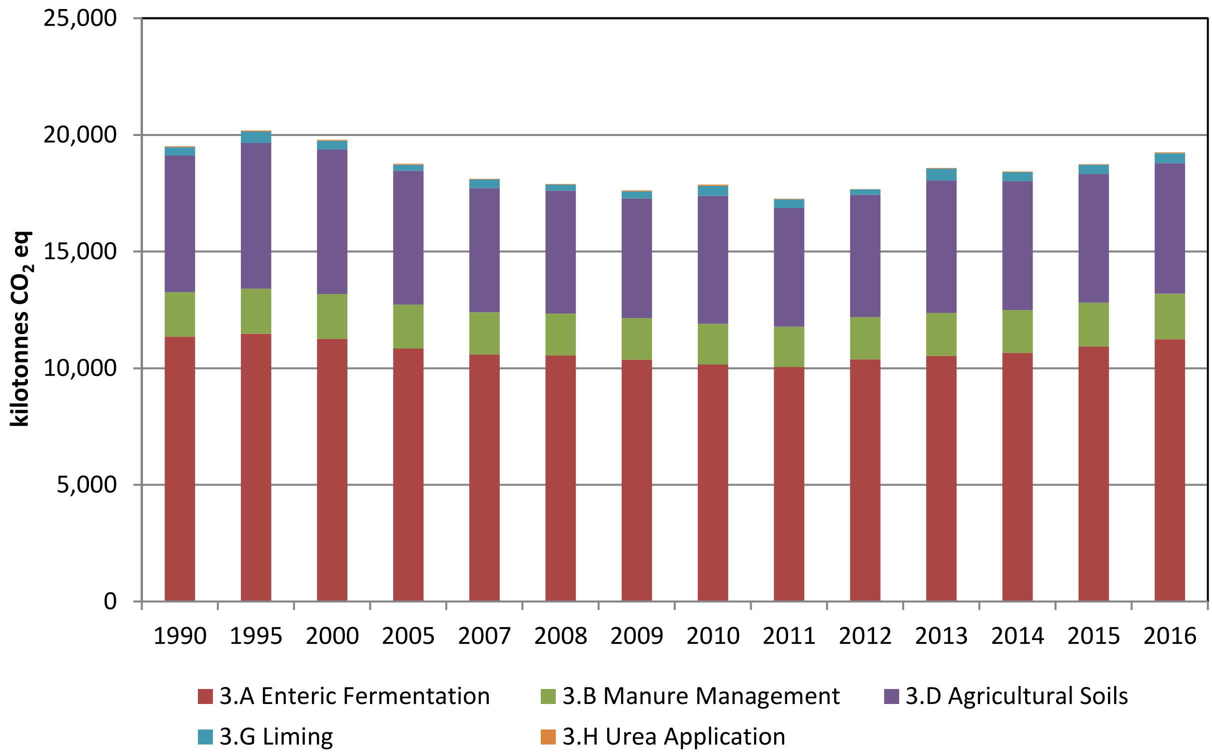

Figure 2.9 Trend in Emissions from Agriculture 1990-2016

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 a number of land-use categories that are important in terms of either emissions or removals of CO_2. This sector is a net source of carbon in all years (Table 2.1 and Figure 2.10). This result is determined largely by the CO_2 emissions from 4.A Forest Land, which is a major carbon sink, and 4.C Grasslands and 4.D Wetlands which are major sources of emissions due to drainage of organic soils, Harvested Wood Products are a sink of carbon for all years. The complex dynamics of land-use changes between categories and the relative contributions from biomass and soils lead to highly fluctuating estimates of sectoral emissions and removals over the period 1990- 2016.

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

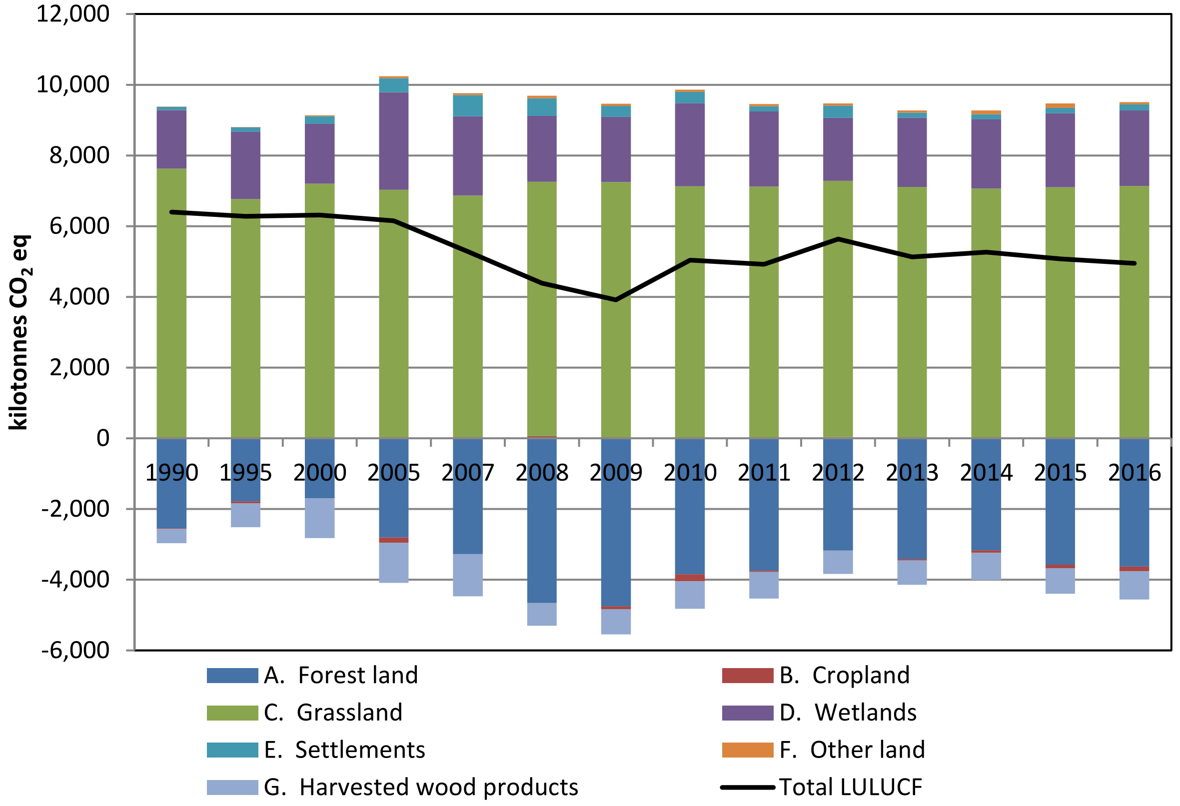

Figure 2.10 Trend in Emissions and Removals from Land Use Land-Use Change and Forestry 1990-2016

2.3.5 Trends in Waste (IPCC Sector 5)

The Waste sector remains an important source of CH_4 emissions (Figure 2.11) due to the continued dominance of landfills as a means of solid waste disposal in Ireland. Emissions from the waste sector increased by 14.0 per cent from 1,546.5 kt CO_2 equivalent in 1990 to 1,763.1 CO_2 equivalent in 2003 (peak) and then decreased by 45.7 per cent to 957.7 kt CO_2 equivalent in 2016. Overall, emissions in the Waste sector have decreased by 38.1 per cent from 1990 to 2016. The main contributor to trends in the Waste sector is the CH_4 emissions from municipal solid wastes (MSW) disposed of in solid waste landfills (5.A Solid Waste Disposal on Land) responsible for 80.2 per cent share of Waste emissions in 2016. 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 (2.1 per cent share of Waste emissions in 2016) is a growing source of emissions in Ireland since it commenced in 2001 with emission levels of 3.8 kt CO_2 equivalent, increasing to 19.9 kt CO_2 equivalent in 2016. 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 tonne in 2008 to 0.8 million tonne in 2016 due to lower personal consumption and increased recycling rates. Total MSW disposed to landfill decreased by 63.2 per cent between 2007 and 2016. The proportion of organic materials (food and garden waste) in MSW has decreased from 39.3 per cent in 1990 to 20.5 per cent in 2016. The proportions of paper and textiles changed from 29.5 per cent and 9.8 per cent, respectively in 1990 to 19.1 per cent and 22.6 per cent, respectively in 2016, reflecting a significant diversion of paper products from landfills. This reduces CH_4 potential, as paper products are the main source of degradable organic carbon in landfills. A major increase in the use of flares as a means of odour control in landfills in recent years offsets a large proportion of the CH_4 generated. This offset from flares and utilisation was 59.8 per cent in 2016, hence there was a 7 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 92.5 kt CO_2 equivalent in 1990 and 22.95 kt CO_2 equivalent in 2016 a decrease of 75.2 per cent which equates to 6.0 and 2.4 per cent of total emissions from the waste sector, respectively in 1990 and 2016. 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 1990-2016. The contribution of this sub-category to the overall sectoral trend is negligible.

Emissions of CH_4 and N_2O from 5.D Wastewater Treatment and Discharge accounted for 136.24 kt CO_2 equivalent in 1990 and 147.12 kt CO_2 equivalent in 2016 (8.0 per cent increase on 1990), which equates to 8.8 and 15.4 per cent of total emissions from the waste sector, respectively. The contribution of this sub-category to overall sectoral trends is negligible.

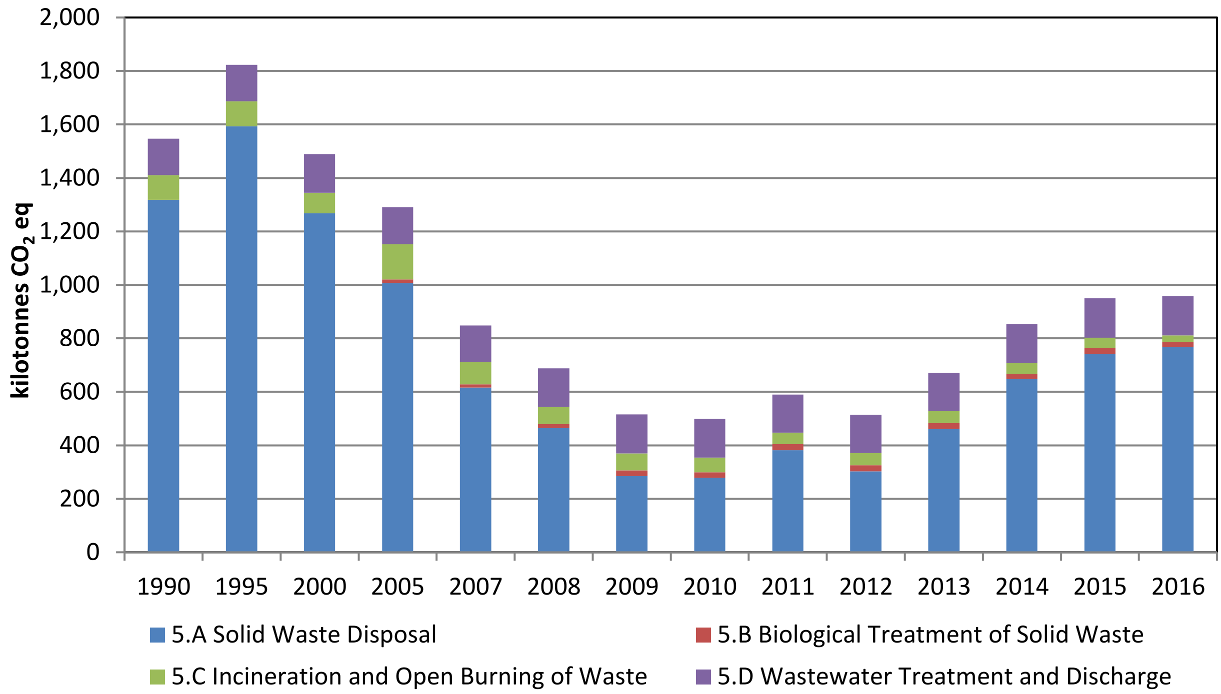

Figure 2.11 Trend in Emissions from Waste 1990-2016

2.4 Emissions of Indirect Greenhouse Gases

The total emissions of SO_2, NO_X, NMVOC and CO for the years 1990 to 2016 are summarised in Table 2.2 and Figure 2.12. As in the case of CO_2, the emissions of SO_2, NO_X and CO in Ireland are dominated by those emanating from fuel combustion activities, while the bulk of NMVOC emissions are generated by agriculture, solvent use and transport. From 1990 to 2016, substantial decreases occurred in the emissions of SO_2 (92.5 per cent) and CO (70.8 per cent). Significant reductions of NO_X emissions (33.9 per cent) and NMVOC (24.3 per cent) also occurred in 2016 in comparison to 1990.

Table 2.2 Emissions of NO_X, SO_2, NMVOC and CO 1990-2016 (Tonnes)

Year	NOx	SO_2	NMVOC	CO
1990	168,311	182,712	142,972	346,322
1995	168,601	161,048	135,817	289,721
2000	174,038	139,759	121,440	246,510
2005	167,739	71,724	120,018	216,390
2006	163,263	60,791	119,759	199,371
2007	158,922	54,571	119,571	186,328
2008	145,399	45,105	115,081	178,689
2009	121,904	32,362	112,880	157,374
2010	116,184	26,276	109,340	143,924
2011	104,127	24,764	106,574	132,637
2012	107,006	23,293	107,922	125,482
2013	108,171	23,433	110,366	117,517
2014	107,427	16,815	106,146	110,438
2015	110,282	14,929	106,546	107,239
2016	111,183	13,680	108,256	101,073

Total SO_2 emissions decreased from 182,712 tonnes in 1990 to 13,680 tonnes in 2016. This decrease in emissions reflects the economic downturn in recent years, reductions in the sulphur content of fuels, fuel switching and use of abatement technologies. Power stations (1.A.1.a) were the largest source of SO_2 emissions until 2012. However, residential (1.A.4.b) became the largest source of SO_2 emissions having a share of 48.7 per cent of the total in 2016, whereas Power stations (1.A.1a) contributed 27.2 per cent of the total. Combustion sources in the industrial (1.A.2) sector account for a contribution of 18.9 per cent in 2016. In 1990, coal combustion accounted for 51.5 per cent of SO_2 emissions and fuel oil contributed 30.3 per cent. By 2016, the share of SO_2 emissions from coal had decreased marginally to 48.9 per cent and that from fuel oil had decreased to 6.6 per cent.

Road transport (1.A.3.b) is the principal source of NO_X emissions, contributing 35.4 per cent of the total in 2016. The reductions in NO_X emissions delivered by catalytic converters in cars and heavy-duty vehicles have been offset by large increases in vehicle numbers and fuel use in the past 10 years. This effect is exaggerated in latter years by so-called fuel-tourism, whereby a significant proportion of the automotive fuel sold in Ireland is used by vehicles in the UK and possibly to some extent in other countries. Combustion in the industrial (1.A.2) sector is another source of NO_X emissions, in 2016 accounting for 10.2 per cent of emissions, followed by power generation with 7.2 per cent share and combined commercial/residential sectors' 6.8 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 42.4 per cent share of total in 2016. Solvent use (2.D) was responsible for 17.2 per cent share and combined commercial/residential sectors produced 8.0 per cent of the 2016 total NMVOC emissions in Ireland. Technological controls for NMVOCs in motor vehicles have been more successful than in the case of NO_X, and have given a significant reduction in emissions from road transport over recent years with contributions of transport to the national total of 23.2 per cent in 1990, falling to 4.5 per cent in 2016.

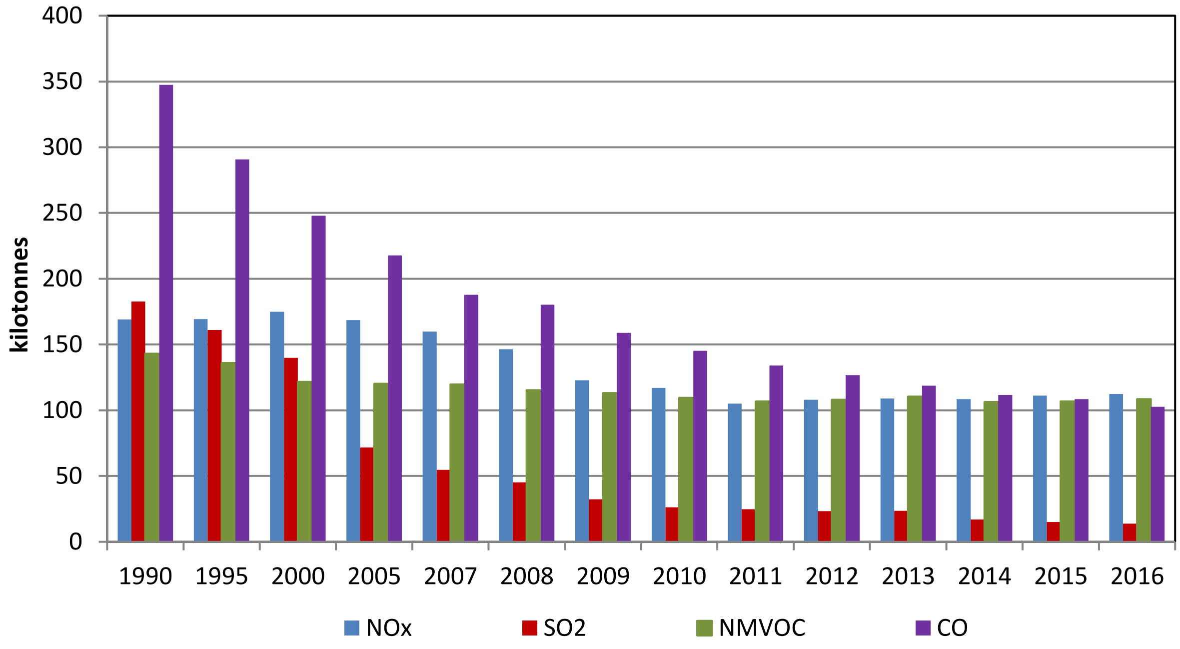

Figure 2.12 Trend in Indirect Greenhouse Gases 1990-2016

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 2016, Road transport (1.A.3.b) contributed to 48.3 per cent of the total CO emissions. A substantial decline in the CO emissions figures over the period of 1990 to 2016 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 21.5 per cent to 2016 total. Further reductions in the emissions of SO_2, NO_X and NMVOC will occur in the coming years as Ireland continues to implement programmes to comply with various EU legislation aimed at air quality improvement and emissions control.

3 Energy

3.1 Overview of Energy Sector

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

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

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

3.1.1 Emissions Overview

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

Emissions from *Energy* accounted for 56.1 per cent and 61.6 per cent of total national emissions (including indirect CO_2, without *LULUCF*) in 1990 and 2016, respectively. This sector accounted for 93.5 of total CO_2 emissions, 1.6 per cent of CH_4 emissions and 5.4 per cent of N_2O emissions in 2016. CO_2 emissions make up 98.5 per cent of the total for the sector in 2016.

There are 16 key categories by level assessment and 20 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 and in 2016 because of an increased use of natural gas.

- ***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.

- ***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. This corresponds to the pattern of emissions and is due to the effect of the economic downturn in Ireland and increases in biofuel use and subsequent return to economic growth.

- ***1.A.3.d Domestic Navigation*** emissions from this minor source steadily grew across the timeseries. Emissions in 2016 are the highest in the timeseries and making this a key category in 2016.

- ***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.

- ***1.B.2.b Fugitive Emissions from Oil and Natural Gas*** emissions have decreased considerably across the timeseries due to the introduction of polyethylene pipes across the distribution network. These are considered to result in negligible losses.

Other non-key categories in this sector include:

- ***1.A.3.a Domestic Aviation*** emissions peaked in 2006 after which emissions have significantly declined due to the reduction in the number of domestic flights due to the completion 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.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 industries.

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

- ***Carbon Dioxide*** emissions which make up 98.5 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 increased for the last 2 years.
- ***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 2016.
- ***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_2 emissions in most countries. The CO_2 emissions are quantified with reasonable accuracy as the fuel amounts are detailed in the energy balance sheets and information on their carbon contents is well established. The total amount of CO_2 released from combustion can therefore be readily ascertained.

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

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

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

The simple calculation spread sheet given in Table 3.1.1 of Annex 3.1.A shows how the emissions from combustion sources are computed for the year 2016 using the activity data and emission factors described below. The complete allocation to IPCC Level 1 source categories is readily achieved from this compilation, as shown in Table 3.1.2 of Annex 3.1.A. The correspondence between the national disaggregation of sources and IPCC combustion source categories is given in Table 3.1.3 of Annex 3.1.A.

All CO_2 emission factors for fuel combustion in the present submission, except in the case of biomass, are country-specific values, regardless of methodological tier used, which are determined directly from information on the carbon contents and net calorific values of the fuels used in stationary and mobile sources. Information on CO_2 emission factors and net calorific values are available for liquid, solid and gaseous fossil fuels in Table 4.C of Annex 4. The CO_2 emission factor for natural gas takes into account the increasing contribution of imported gas in the national total given by the energy balance. The importation of natural gas from the UK began around 1993 and imported gas accounted for 96.3 per cent of the total in 2015. However, the share of imported natural gas was reduced to 40.1% due to the opening of the natural gas refinery and the Corrib gas field in Ireland in late 2015. The CO_2 emission factor appropriate to the split between domestic and imported natural gas, which is more carbon intensive, is now used for all years from 1993 to 2016.

The annual returns to the EPA's Sustainable Production and Consumption Programme (SPCP) by participants in the EU Emissions Trading Scheme under Directive 2009/29/EC (EP and CEU, 2009, amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading scheme of the Community) comprise an important source of information on CO_2 emissions and emission factors that is now fully utilised for the national inventory compilation. The fuel combustion CO_2 emission factors for solid fuels used by participants under ETS take account of the fact that a very small fraction (typically less than 1 per cent) of fuel carbon may remain un-oxidised and IPCC oxidation factors appropriate to these fuels are applied when computing the emissions under the scheme. Complete oxidation of carbon is assumed in the case of liquid and gaseous fuels. For other stationary combustion sources, where activity data are in general top-down fuel use quantities taken from the energy balance, the inventory agency adopts the approach that no specific allowance is needed for un-oxidised carbon in the calculation of CO_2 emissions. Default CO_2 emission factors from the 2006 IPCC Guidelines are used only for biomass, which almost invariably refers to wood and wood wastes.

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

Table 3.1 Level 3 Source Methodology for Energy

1. Energy	***CO_2***	**CH_4**	**N_2O**
A. Fuel Combustion			
1. Energy Industries			
*a. Public Electricity and Heat Production**	T1,T3*	T1,T2	T1,T2
b. Petroleum Refining	T3	T1	T1
c. Manufacture of Solid Fuels and Other Energy Industries	T3	T1	T1
2. Manufacturing Industries and Construction			
a. Iron and Steel	T2,NA	T1,NA	T1,NA
*b. Non-Ferrous Metals**	T1,T2*	T1	T1
*c. Chemicals**	T2*	T1	T1
d. Pulp, Paper and Print	T2	T1	T1
*e. Food Processing, Beverages and Tobacco**	T1,T2*	T1	T1
*f. Non-metallic minerals**	T1,T2,T3*	T1	T1
*g. Other**	T1,T2*	T1	T1
3. Transport			
a. Domestic Aviation	T3	T2	T2
*b. Road Transportation**	T2,T3*	T3	T3
c. Railways	T2	T1	T1
d. Domestic navigation	T2	T1	T1
e. Other transportation	T2	T1	T1
4. Other Sectors			
*a. Commercial/Institutional**	T2*	T1	T1
*b. Residential**	T2*	T1*	T1
*c. Agriculture/Fishing**	T1,T2*	T1	T1
5. Other	NA	NA	NA
B. Fugitive Emissions from Fuels			
1. Solid Fuels			
a. Coal mining and handling	NA	T1	NA
b. Solid Fuel Transformation	NA	NA	NA
c. Other	NA	NA	NA
2. Oil and Natural Gas			
a. Oil	NA	T1	NA
*b. Natural gas**	T2	T2*	NA
c. Venting and Flaring	NA	NA	NA
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 4.B of Annex 4 shows the national energy balance sheets for 2016, 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 2016 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 1990-2016 underlies the estimates of emissions for *Energy* in this submission.

Table 3.2 Emissions from Energy 1990-2016

		Gas	Unit	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
1.A.1.a	Public Electricity and Heat Production	CO_2, CH_4, N_2O	kt CO_2 eq	10,953.9	13,132.9	15,754.4	15,244.8	14,055.8	14,155.1	12,610.6	12,895.1	11,556.5	12,356.3	10,952.9	10,771.9	11,328.3	12,076.4
1.A.1.b	Petroleum Refining	CO_2, CH_4, N_2O	kt CO_2 eq	168.7	181.3	274.8	411.9	360.8	367.5	315.4	310.5	285.4	313.5	294.5	279.5	358.7	313.6
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries	CO_2, CH_4, N_2O	kt CO_2 eq	100.5	69.4	87.2	171.9	166.4	183.9	191.5	173.3	135.8	145.4	161.2	133.7	114.5	125.4
1.A.2.a	Iron and Steel	CO_2, CH_4, N_2O	kt CO_2 eq	175.9	18.7	18.8	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.3	2.4	2.4	2.3
1.A.2.b	Non-Ferrous Metals	CO_2, CH_4, N_2O	kt CO_2 eq	811.5	1,207.4	1,437.9	1,152.6	1,541.7	1,544.3	1,227.7	1,519.0	1,484.0	1,479.1	1,439.4	1,439.8	1,446.4	1,403.9
1.A.2.c	Chemicals	CO_2, CH_4, N_2O	kt CO_2 eq	411.4	357.2	485.1	450.8	320.1	324.8	280.7	272.1	252.3	245.8	258.7	254.6	266.1	275.4
1.A.2.d	Pulp, Paper and Print	CO_2, CH_4, N_2O	kt CO_2 eq	28.5	62.6	102.7	50.4	12.2	21.9	23.1	21.1	17.9	16.1	15.8	14.8	15.4	16.1
1.A.2.e	Food Processing, Beverages and Tobacco	CO_2, CH_4, N_2O	kt CO_2 eq	1,021.4	1,175.6	1,608.6	1,296.1	1,100.3	1,118.1	1,075.3	977.5	808.8	801.6	863.1	800.7	863.5	869.2
1.A.2.f	Non-metallic minerals	CO_2, CH_4, N_2O	kt CO_2 eq	822.8	505.3	720.8	1,923.0	1,869.3	1,676.7	1,104.6	920.1	831.4	928.5	933.3	1,123.1	1,184.4	1,238.7
1.A.2.g	Other	CO_2, CH_4, N_2O	kt CO_2 eq	690.4	1,020.8	1,268.5	995.2	942.8	941.2	766.5	764.2	745.6	703.0	723.9	687.7	705.9	748.9
1.A.3.a	Domestic Aviation	CO_2, CH_4, N_2O	kt CO_2 eq	51.7	48.9	74.4	65.4	71.5	67.2	55.2	41.0	19.3	11.5	10.2	9.5	10.5	9.8
1.A.3.b	Road Transportation	CO_2, CH_4, N_2O	kt CO_2 eq	4,787.5	5,890.6	10,369.5	12,558.5	13,842.3	13,086.1	11,898.0	10,985.1	10,735.3	10,365.7	10,594.2	10,841.0	11,314.7	11,750.9
1.A.3.c	Railways	CO_2, CH_4, N_2O	kt CO_2 eq	148.9	124.5	137.6	136.6	147.7	156.5	137.4	136.3	136.5	131.9	131.4	120.5	122.8	125.1
1.A.3.d	Domestic navigation	CO_2, CH_4, N_2O	kt CO_2 eq	85.8	92.1	152.7	211.2	197.5	204.7	199.5	200.1	173.7	183.6	179.6	224.8	221.7	266.5
1.A.3.e	Other transportation	CO_2, CH_4, N_2O	kt CO_2 eq	62.9	118.7	57.8	153.3	132.0	147.5	152.5	166.7	155.3	143.8	150.6	151.2	143.3	141.7
1.A.4.a	Commercial/Institutional	CO_2, CH_4, N_2O	kt CO_2 eq	2,244.1	2,101.9	2,364.1	2,428.2	2,373.6	2,600.9	2,300.2	2,318.0	2,108.8	2,115.4	1,937.5	1,772.6	1,820.9	1,867.8
1.A.4.b	Residential	CO_2, CH_4, N_2O	kt CO_2 eq	7,523.7	6,452.0	6,462.6	7,271.9	6,928.5	7,521.6	7,467.0	7,800.9	6,609.8	6,232.4	6,395.4	5,745.6	6,041.4	6,046.6
1.A.4.c	Agriculture/Fishing	CO_2, CH_4, N_2O	kt CO_2 eq	818.5	1,166.7	1,023.0	1,098.6	988.8	1,042.8	893.6	829.7	785.0	757.8	674.3	608.6	580.1	600.5
1.B.1.a	Coal mining and handling	CH_4	kt CO_2 eq	55.6	33.3	27.0	23.5	22.5	22.1	21.7	21.2	20.9	20.5	20.1	19.8	19.5	19.2
1.B.2.a	Oil	CO_2, CH_4	kt CO_2 eq	0.2	0.3	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.4	0.3	0.3	0.4	0.4
1.B.2.b	Natural gas	CO_2, CH_4	kt CO_2 eq	156.1	135.9	101.3	67.4	71.0	61.1	42.0	37.3	32.8	28.3	23.3	28.0	23.2	21.7
	Total Energy			**31,120**	**33,896**	**42,529**	**45,714**	**45,148**	**45,247**	**40,765**	**40,392**	**36,898**	**36,983**	**35,762**	**35,030**	**36,584**	**37,920**

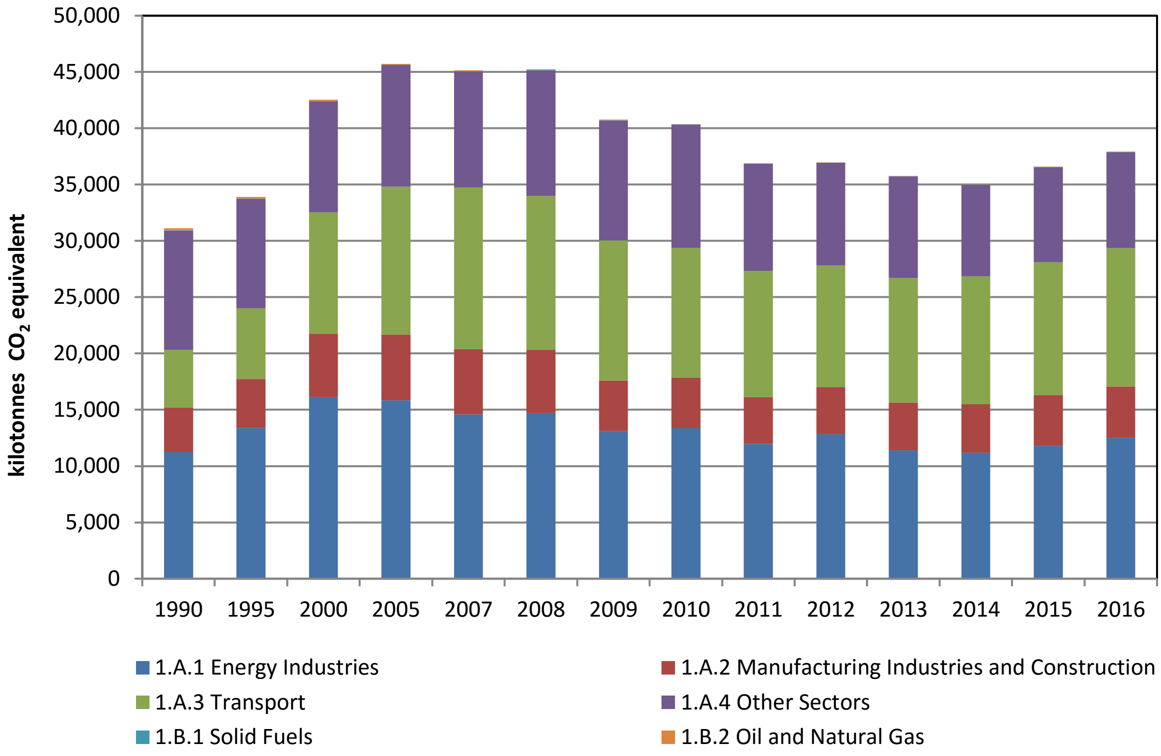

Figure 3.1 Total Emissions from Energy by Category, 1990-2016

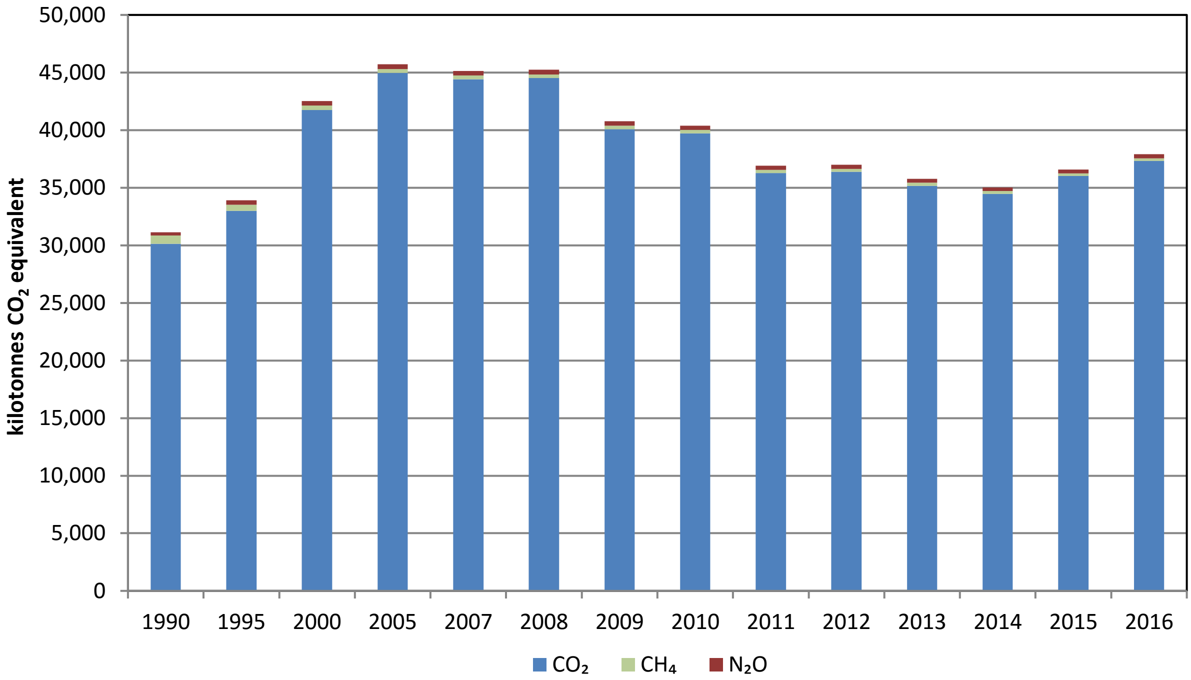

Figure 3.2 Total Emissions from Energy by Gas, 1990-2016

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 SPCP of the EPA, which acts as the competent authority for the ETS in Ireland. Following receipt of the raw ETS data from SPCP, the inventory experts allocate the CO_2 estimates and corresponding energy amounts to the appropriate sub-categories for CRF reporting and then return the compilation to the SPCP contact person for final checking and accounting of any amendments following the ETS verification process. This ensures that where ETS emissions estimates cover a category completely, such as in *1.A.1*, the verified CO_2 values are transferred directly to the national inventory and consistency of results is guaranteed. In the case where the CO_2 estimates from ETS do not completely cover the category, as for *1.A.2*, the benefit is realised as better information on fuels and more representative emission factors, which improves the top-down estimates of emissions obtained using the energy balance.

3.2 Emissions from Fuel Combustion (1.A)

3.2.1 Comparison of the Sectoral Approach with the Reference Approach

Following the methods decision tree of the 2006 IPCC Guidelines for combustion sources, the information in Table 4.B of Annex 4 allows for the full application of the two available 2006 IPCC Guidelines methods for emission sources in *Energy*, i.e. the Sectoral Approach and the Reference Approach.

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

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

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

The Reference Approach is used in Ireland as a verification procedure for CO_2 emissions from fuel combustion activities. The calculation sheet for the Reference Approach (Table 1.A (b) of the 2018 CRF) is reproduced as Table 3.1.4 of Annex 3.1.A of this report. The apparent consumption of fuels, the basic activity data in this case, is determined as:

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

where production applies only to primary fuels.

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

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

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

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

The overall differences in the Reference Approach for 2016, energy use (excluding non-energy use, reductants and feedstocks) and CO_2 emissions were; 0.41 and 0.98 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 2016.

3.2.2 International Bunker Fuels

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

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

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

The allocation of jet kerosene use to international aviation (bunker fuel) is done by subtracting jet kerosene used in civil aviation estimated by the inventory agency from total jet kerosene fuel sales compiled by SEAI. In 2016, the amount of jet kerosene fuel allocated to domestic aviation was 0.37 per cent of the total recorded under air transport in the energy balance. Emissions of CH_4 and N_2O have been estimated for all years for fuel used in marine bunkers. Emissions factors from Tables 3.5.2 and 3.5.3 Chapter 3, Vol 2 2006 IPCC Guidelines of 7 kg/TJ and 2 kg/TJ, for CH_4 and N_2O respectively, have been used to estimate emissions.

3.2.3 Feedstocks and Non-energy Use of Fuels

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

There are a number of fuel types applicable in Ireland:

- Lubricants – IPCC default oxidation value of 0.2 is used, see category 2.D.1;
- Bitumen – IPCC default value of 1.0 is used for the proportion of carbon stored;
- Paraffin wax – IPCC oxidation value of 0.9 is used for candles and 0.2 for all other paraffin wax, see category 2.D.2;
- White spirit – IPCC default value of 1.0 is used for the proportion of carbon stored;
- Natural Gas – a significant amount of natural gas feedstock was used in ammonia production from 1990-2003.

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

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

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

*All carbon is stored

3.2.4 Energy Industries (1.A.1)

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

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

3.2.4.1.1 Category Description

The emissions data from a total of 19 electricity generating stations are the basis for compiling the results in this important category. The verified CO_2 estimates reported by the ETS participants were used directly and the corresponding fuel use, as given in the national energy balance, was used to estimate CH_4 and N_2O emissions using the appropriate 2006 IPCC Guidelines emission factors mentioned in the previous section. Emissions are presented by gas and fuel in Figure 3.3.

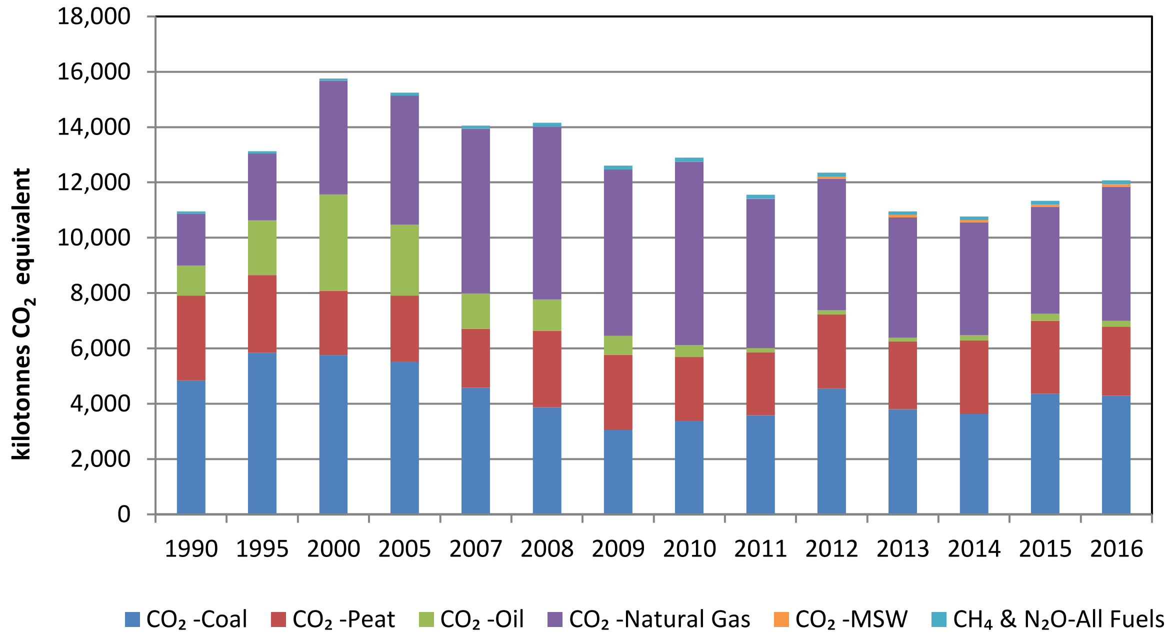

Figure 3.3 Emissions from 1.A.1.a Public Electricity and Heat Production 1990-2016

3.2.4.1.2 Methodological Issues

The CO_2 emissions are obtained from 2016 AEMs (Annual Emission Monitoring Reports) are estimated by ETS operators using tier 3 methodologies (as is the case with the years 2005-2015) 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. Annual Emission Monitoring Reports are reported 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) plant which was commissioned in 2011. 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.

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

3.2.4.1.3 Uncertainties and Time-series Consistency

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

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

3.2.4.1.4 Category-specific QA/QC and verification

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

These methods involve a rigorous accounting of fuel consumption and detailed information on fuel properties based on fuel sampling protocols agreed in the greenhouse gas emission permits for each installation and the application of specific emission factors for each fuel determined by accredited laboratories. The summarised CO_2 emissions compiled in the ETS database according to fuel type for all installations that constituted sub-category *1.A.1.a* in 2016 are aggregated to report the CO_2 emissions for this category.

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

3.2.4.1.5 Category-specific Recalculations

There are no recalculations in Public Electricity and Heat Production *1.A.1.a* in this submission.

3.2.4.1.6 Category-specific Planned Improvements

CO_2 from this sector, which accounts for 98.8 per cent of this category emissions in 2016, are accurately quantified and there is therefore little scope for further improvement in future versions of the inventory.

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

3.2.4.2.1 Category Description

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

3.2.4.2.2 Methodological Issues

Similar to *1.A.1.a Public electricity and heat production* emissions in this category are estimated using tier 3 methodologies in accordance with the monitoring and verification guidelines for combustion activities set down in Decision 2004/156/EC. The emissions are estimated from the use of high-pressure gas, low-pressure gas (refinery gas), Natural Gas, LPG and small amounts of other gases as well as gasoil and historically residual fuel oil using country-specific emission factors. However, those fuels are aggregated in the national energy balance into fewer and hence less detailed categories than fuels reported under ETS. Since activity data is derived from the energy balance and CO_2 emissions originate from ETS the resulting implied emission factors for CO_2 fluctuate significantly. The issue raised during reviews regarding national energy balance fuel proportions in comparison with ETS data is still to be resolved. However, total fuel reported under ETS is still very similar to total fuel reported in the national energy balance, 95 per cent in 2016.

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

3.2.4.2.3 Uncertainties and Time-series Consistency

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

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

3.2.4.2.4 Category-specific QA/QC and verification

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

3.2.4.2.5 Category-specific Recalculations

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

3.2.4.2.6 Category-specific Planned Improvements

Emissions of CO_2 from this sector, which accounts for 99.9 per cent of this category's emissions in 2016, are accurately quantified and there is therefore little scope for further improvement in the inventories as delivered in the 2018 submission.

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

3.2.4.3.1 Category Description

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

3.2.4.3.2 Methodological Issues

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

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

3.2.4.3.3 Uncertainties and Time-series Consistency

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

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

3.2.4.3.4 Category-specific QA/QC and verification

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

3.2.4.3.5 Category-specific Recalculations

Emissions were only reported from the production of peat briquettes in the previous submission. The natural gas production platform, previously fully reported in natural gas transport (1.A.3.e) and new refinery were added in this latest submission as a new source, as the natural gas refinery opened in late 2015.

The category-specific improvement in *1.A.1.c* was conducted following the improvement of the latest national energy balance. SEAI included natural gas data for the period 2005-2016 and the liquid fuel (gas oil and kerosene) and solid fuel (coal) data that were used in peat and natural gas refineries for the period 2005-2016, and 2010 respectively. CO_2, CH_4 and N_2O emissions from these new fuels, and new source were estimated by applying the methods in section 3.2.4.3.2, and reported along with the previously reported emissions from the production of the peat briquettes. This improvement resulted in an increase of emission (CO_2 eq.) in between 31.3 to 56.7 per cent for the period 2005-2015.

3.2.4.3.6 Category-specific Planned Improvements

Emissions of CO_2 from this sector, which account for 99.6 per cent of this category's emissions, are accurately quantified and there is therefore little scope for further improvement in the inventories as delivered in the 2018 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 1990-2016. The emissions from this category show a large decrease between 2008 and 2009 reflecting the impact of the economic downturn in Ireland particularly in the cement production sector. This downward trend was maintained to 2011 after which emissions have increased on an annual basis as Ireland's economy returns to growth.

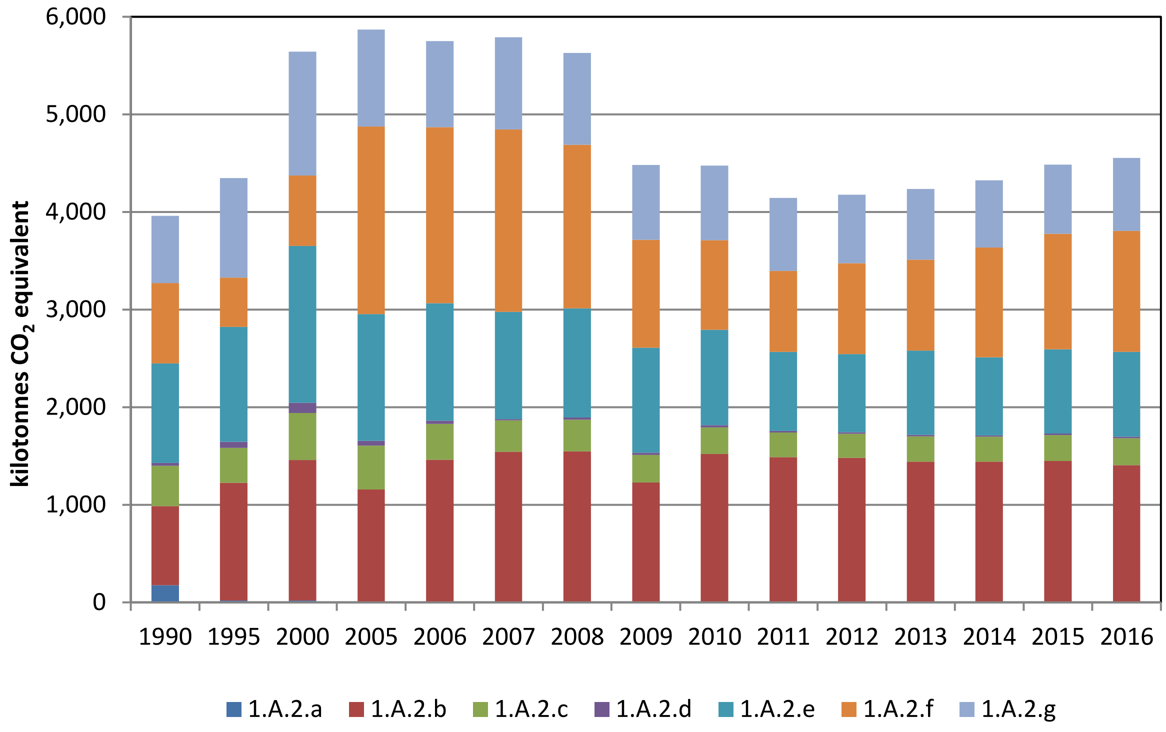

Figure 3.4 Emissions from 1.A.2 Manufacturing Industries and Construction 1990-2016

3.2.5.2 Methodological Issues

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

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

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

Information provided from the ETS on fuel data have been used to develop an annual country-specific CO_2 emission factor for petroleum coke since 2005. Petroleum coke is used in sub-categories and years: *1.A.2.b* (1991-2000), *1.A.2.e* (1991-2003), *1.A.2.f* (1990-2000, 2002-2016) and *1.A.2.g* (1991-2003, 2008-2009, 2015-2016). The 2006 IPCC Guidelines emission factor of 97.5 t CO_2/TJ compares well with the year specific emission factors which vary from 92.84 to 95.12 CO_2/TJ. The average (93.65 CO_2/TJ) of the five years between 2005 and 2009 of yearly specific emission factors is applied to all years from 1990 to 2004, as ETS data is only available from 2005 onwards.

Petroleum coke is included with "liquid fuels", because it is derived from petroleum. However, the properties of petroleum coke are similar to those of solid fuels. As a result, when considered at an aggregated level, properties of liquid fuels can be heavily influenced by the amount of petroleum coke consumed. When the country-specific emission factor for petroleum coke is taken into account, the implied emission factors for liquid fuels in sub-category *1.A.2.f* fluctuate significantly depending on the proportion of petroleum coke included in liquid fuels. It is mostly evident in sub-category 1.A.2.f as petroleum coke accounts for a high proportion of all liquid fuels in this category (50 per cent on average across the time series). Other sectors with a smaller proportion of this fuel to their liquid fuel totals were less affected by fluctuating CO_2 implied emission factor. This can be seen in Table 3.1.8 of Annex 3.1.A.

For sub-category *1.A.2.e*, the largest quantities of petroleum coke are used in 2000 to 2002, giving rise to a peak in the liquid fuels implied emission factor of 79.83 t CO_2/TJ in 2001. However, the average implied emission factor for years 2004-2014 was 71.93 t CO_2/TJ for liquid fuels as no petroleum coke had been consumed in the sub-category since 2004.

In *1.A.2.f*, the implied emission factor for liquid fuels decreases from 83.79 t CO_2/TJ in 1990 to 73.40 t CO_2/TJ in 2001 as no petroleum coke was consumed that year, subsequently the IEF increases to reach maximum at 89.46 t CO_2/TJ in 2006 but then decreases to 83.59 t CO_2/TJ in 2010 reflecting the decline in petroleum coke use in cement production and rise again to 88.69 t CO_2/TJ in 2016 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 80.36 t CO_2/TJ in 2001. However, the average implied emission factor for years 2004-2016 is 69.28 t CO_2/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_2 emission factors are used for most combustion sources, which gives a basis for assigning the uncertainties for emission factors while again taking into account the applicable tiers. Uncertainties in the emission factors for CH_4 and N_2O from combustion sources are high and not well established quantitatively. For CH_4 and N_2O emission factors for combustion categories, the 2006 IPCC Guidelines values are used and an indicative uncertainty of 50 per cent is applied for both gases.

3.2.5.4 Category-specific QA/QC and verification

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

3.2.5.5 Category-specific Recalculations

Revised fuel consumption in the national energy balance for fuels and years: Gas oil (2015), biomass (2015) and natural gas (2005-2015) result in recalculations for the years 2005-2015. Overall recalculations are minor and are presented in Table 3.10 a and 3.10b.

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.

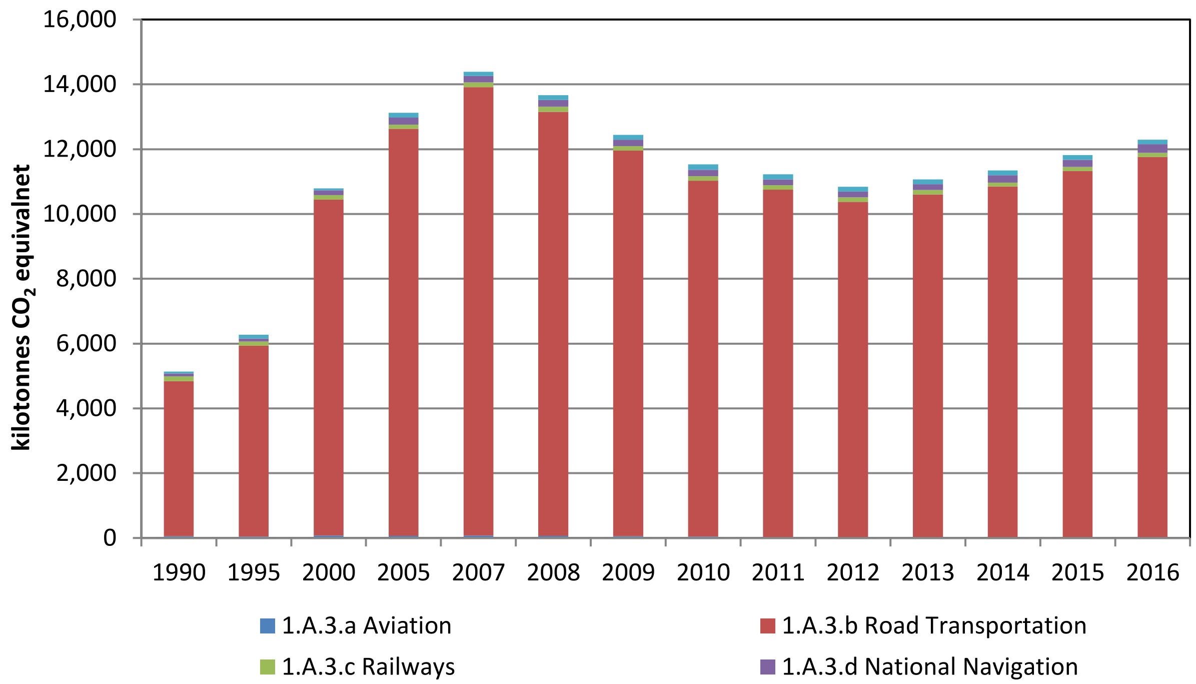

Figure 3.5 Emissions from 1.A.3 Transport 1990-2016

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

3.2.6.1.1 Category Description

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

3.2.6.1.2 Methodological Issues

The fuel consumption within Ireland associated with sub-category *1.A.3.a Civil Aviation* is estimated using a Tier 3a approach (Table 3.6.2, 2006 IPCC Guidelines) based on origin and destination data for domestic air travel provided by the Irish Aviation Authority (IAA), 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. This approach is used for all years from 2004 to 2016 where airport pair data are available. The inventory agency receives annual flight data for all Irish airports from the IAA, for all years from 2004 to 2016. 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.

For the years 1990 to 2003, 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 civil flights.

For data handling purposes, the inventory agency aggregated approximately 15 small regional airport/aerodrome pairs to "*Other*" which account for approximately 2 per cent of all domestic flights along with nine Irish airports which account for the remaining 98 per cent of all domestic flights.

The tier 3a methodology estimates both LTO and cruise emissions based on origin and destination, flight distances and by aircraft type. The inventory agency estimated fuel consumption for the LTO and cruise phases of each flight based on 37 aircraft types using fuel consumption emission factors from the EMEP/EEA emission inventory guidebook (EMEP/EEA 2013). Table 3.1.11 of Annex 3.1.B outlines the emission factors used for LTO for fuel, CH_4 and N_2O by aircraft type. CH_4 and N_2O emission factors by aircraft type are sourced from Table 3.6.9 of the 2006 IPCC Guidelines. Table 3.1.12 of Annex 3.1.B presents implied emission factors (IEF) for fuel consumption used in the cruise phase of flights weighted by number of flights per airport.

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*". Table 3.1.10 of Annex 3.1.B outlines the distance between the airport pairs in nautical miles (nm) used in estimating fuel used in the cruise phase.

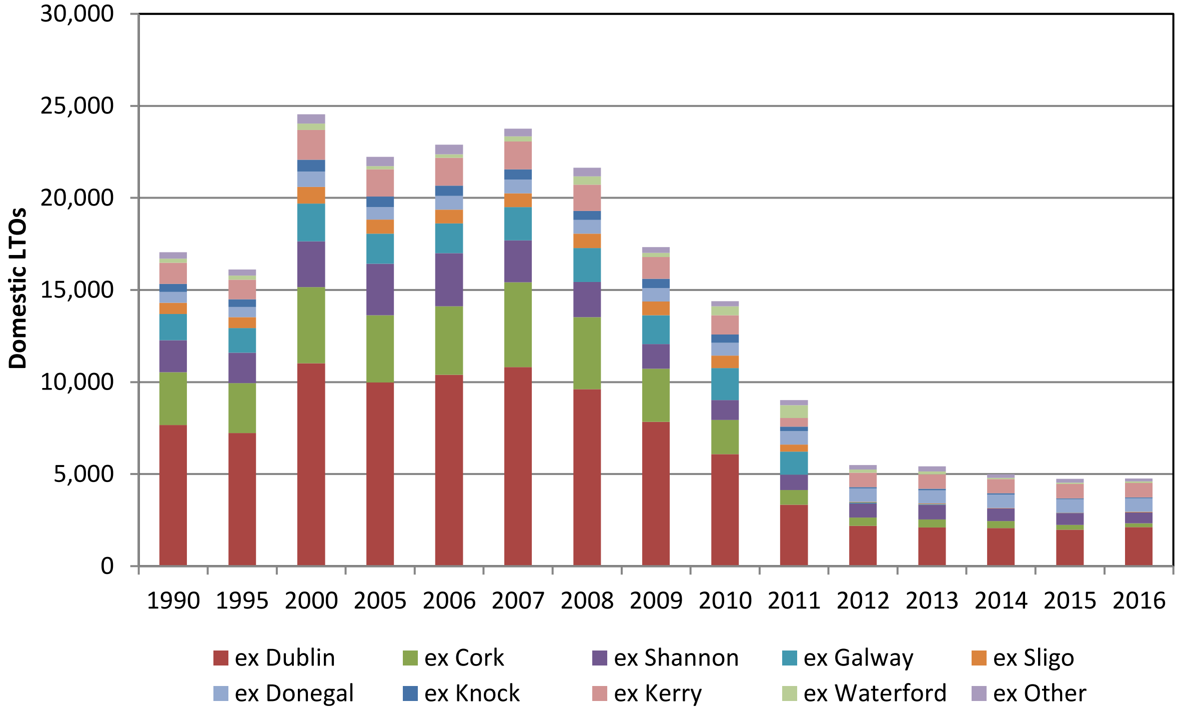

Figure 3.6 Number of LTOs from Irish airports 1990-2016

3.2.6.1.3 Uncertainties and Time-series Consistency

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

3.2.6.1.4 Category-specific QA/QC and verification

The inventory agency completed a verification exercise comparing civil aviation flight and LTO fuel estimates for 2005 to 2016 using data sourced from Eurocontrol through the EU's Working Group 1 of the Climate Change Committee and national data. The verification exercise showed close agreement between the two datasets for the number of civil LTOs and fuel used for both LTO and cruise phases. The differences in civil LTOs were 7.2, 19.6, 16.7, 19.7 and 19.6 per cent in the years 2012, 2013, 2014, 2015 and 2016 respectively. The inventory team investigated the cause and revealed that training flights from Cork were not included in the national data. It is intended to repeat this verification exercise for the 2019 inventory submission and if the situation continues to occur, to consider options to replace the current national dataset with Eurocontrol data. This was also the plan in for this year's submission, however, due to the late availability of the Eurocontrol this was not possible. The main findings of this verification procedure are outlined in Figures 3.7 to 3.9.

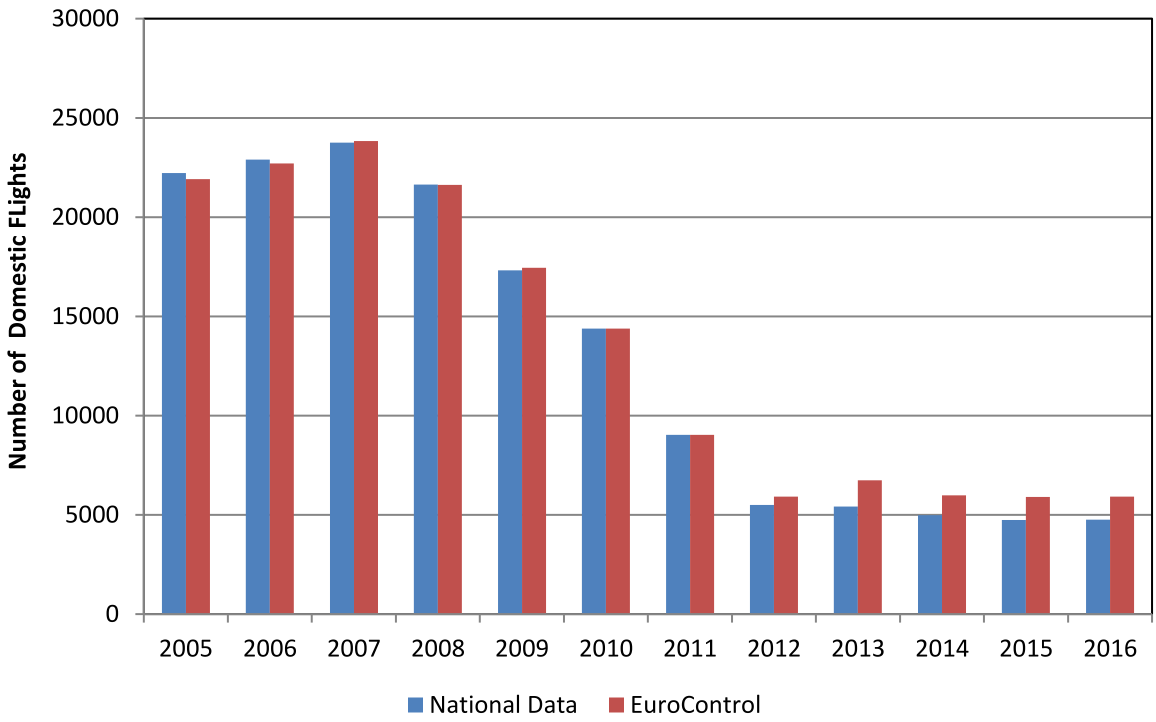

Figure 3.7 National LTO data and Eurocontrol LTO data for 2005-2016

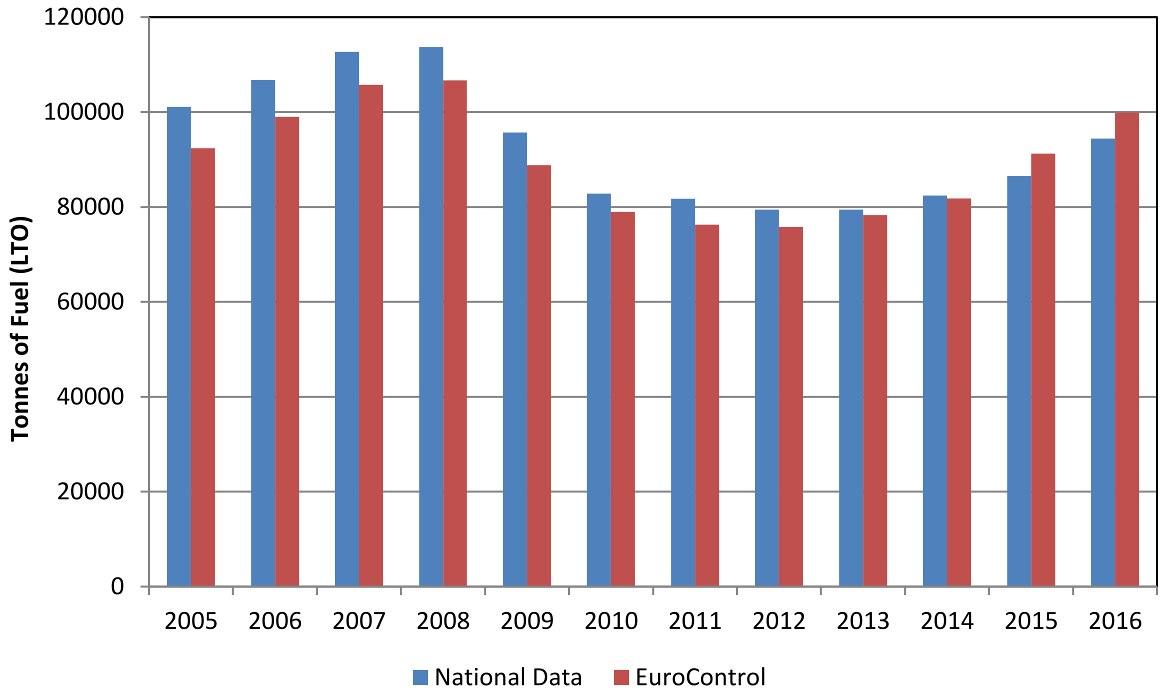

Figure 3.8 National LTO fuel data and Eurocontrol LTO fuel data for 2005-2016

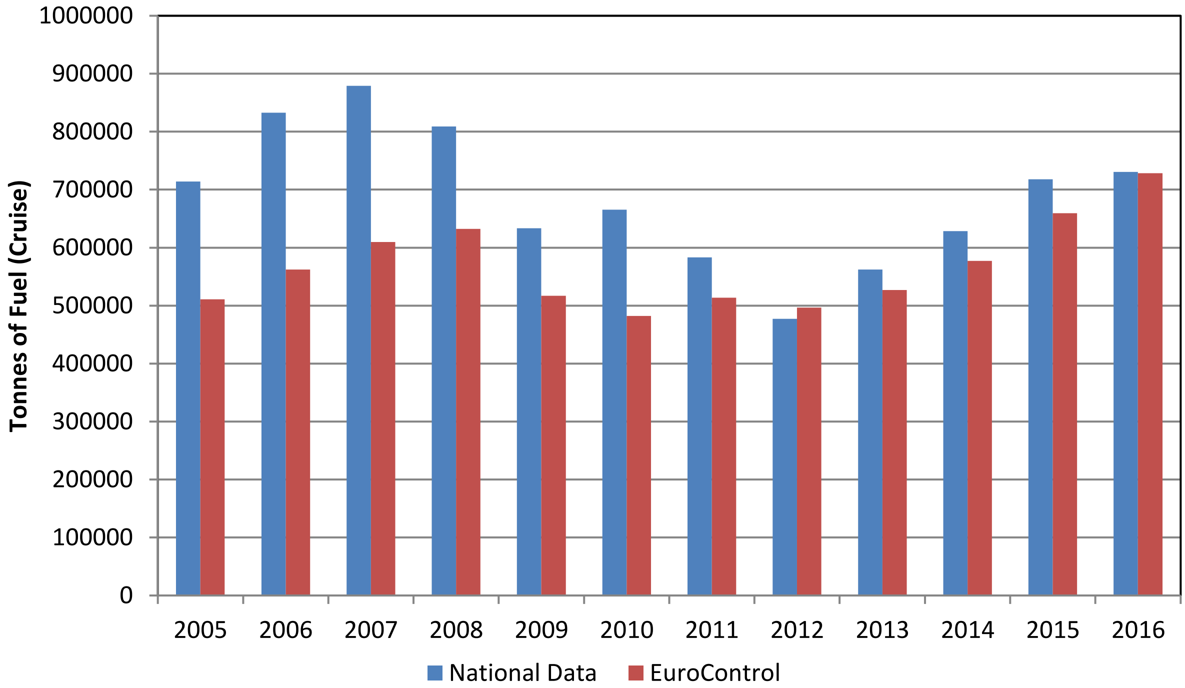

Figure 3.9 National Cruise fuel data and Eurocontrol Cruise fuel data for 2005-2016

3.2.6.1.5 Category-specific Recalculations

There are no recalculations to emissions from *Civil Aviation* in this submission.

3.2.6.1.6 Category-specific Planned Improvements

The inventory agency intends to review information on aircraft fuel consumption rates in the version of the EMEP/EEA Guidebook made available in 2016, to see whether it is appropriate to update data that is currently used in the emissions estimations and to consider using Eurocontrol data if available on time.

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

3.2.6.2.1 Category Description

Emissions of CO_2 reported under *1.A.3.b Road Transportation* are computed from the amounts of petrol, diesel, LPG 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 a proportion of automotive fuels purchased in Ireland are used in the UK (1.0 per cent of petrol and 13.3 per cent of diesel fuel in 2016). For CO_2 emission estimates, complete oxidation of carbon content of the fuel is considered as per the 2006 IPCC Guidelines; however the proportion of emissions by vehicle category type are estimated using the COPERT model. The CH_4 and N_2O emissions from road traffic are estimated directly from the COPERT 5 model (Pastramas N. et al., 2014), developed within the CORINAIR programme for estimating a range of emissions from this important source. Figure 3.10 shows the trend in emissions from *1.A.3.b Road Transport* over the time series.

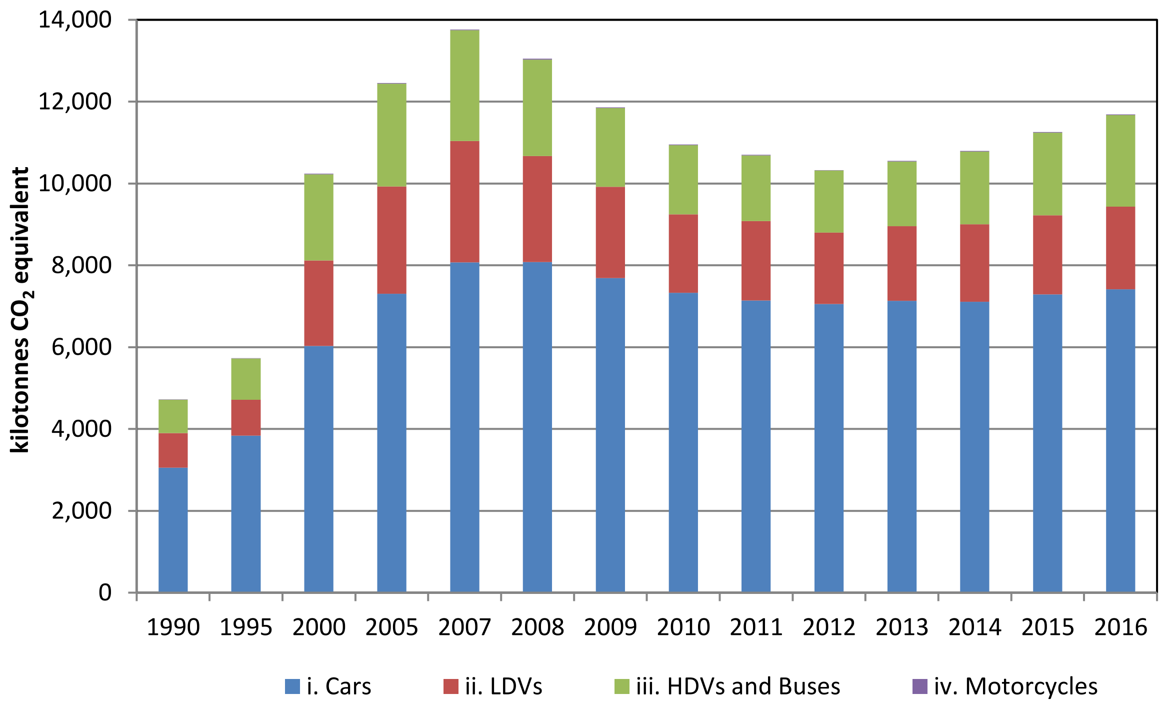

Figure 3.10 Emissions from 1.A.3.b Road Transport 1990-2016

3.2.6.2.2 Methodological Issues

The COPERT 5 model estimates emissions of CH_4 and N_2O on the basis of distance travelled using a detailed bottom-up approach (Tier 3) that accounts for such factors as fuel type, fuel consumption, engine capacity, driving speed and a range of applicable technological emission controls that may be applied on the basis of the age of the vehicle. The model is applied annually in Ireland to derive CO_2 emission proportions between vehicle categories and CH_4 and N_2O emissions estimates. The resultant 2016 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).

Data Modelling: Fleet and Mileage

Detailed information on vehicle population by type is presented in Table 3.1.13 of Annex 3.1.B. The historical vehicle fleet and mileage were recalculated from the year 1990 to 2013 from national statistics- Vehicle Bulletin of Driver Statistics (DOE, DELG, DEHLG, DOT, DOTTS, 1990-2016) and the same methodology was applied in this year. The restructuring of 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 recalculation and latest year's inventory, vehicles were subsequently derived from national statistics into disaggregated level; firstly, vehicle category (e.g. passenger car), then fuel technology (e.g. petrol) and subsequently engine size (e.g. Large, or >2 litre). The final split of vehicle categories was based on Emission bands using the following formula for the number of vehicles in Emission band E_i:

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

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

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

Table 3.4 EURO class vehicle commencement years

Technology	Passenger car	LDVs	HDVs	Buses	Coaches	Mopeds and Motorcycles
Pre-ECE	Up to 1969					
ECE 15/00-01	1970-1978					
ECE 15/02	1979-1980					
ECE 15/03	1981-1985					
ECE 15/04	1986-1991					
Conventional		Up to 1993	Up to 1994	Up to 1993	Up to 1993	Up to 1999
Euro-1 / Euro I	1992-1996	1994-1997	1995-1997	1994-1996	1994-1996	2000-2003
Euro-2 /Euro-II	1997-2001	1998-2001	1998-2001	1997-2001	1997-2001	2004-2006
Euro-3 /Euro-III	2002-2005	2002-2005	2002-2005	2002-2006	2002-2006	2007-present
Euro-4 /Euro-IV	2006-2010	2006-2010	2006-2010	2007-2009	2007-2009	
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 1st January 2011 or from 1st January 2012 for some vehicles. Euro 6 will apply to new vehicle registrations from 2015 (RSA, 2006, 2007, 2008, 2011).

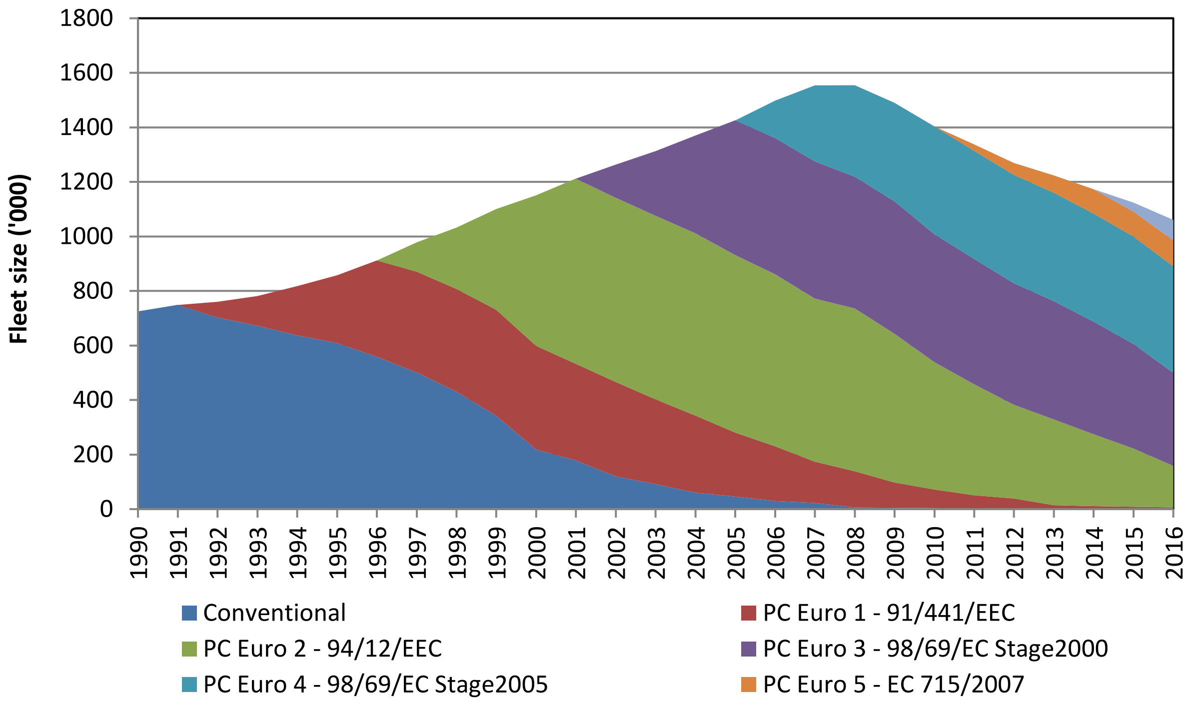

Figure 3.10.1(a) Historic passenger car fleet in Irish transport sector, Petrol

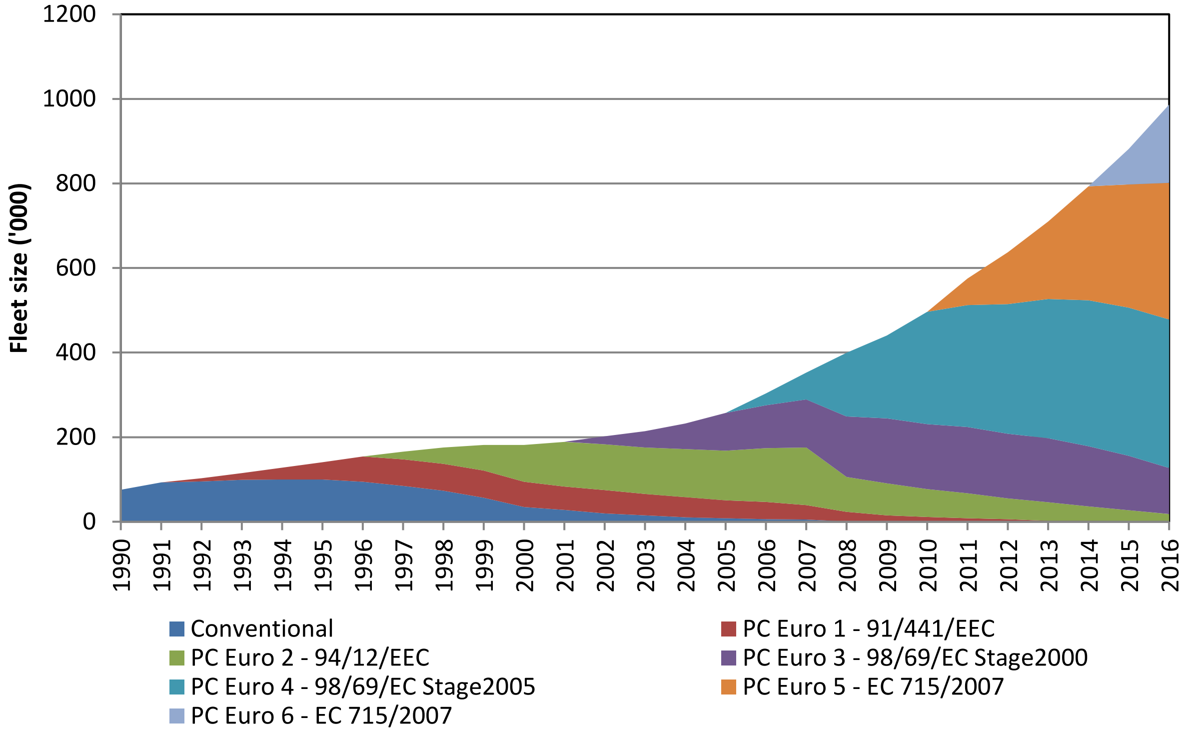

Figure 3.10.1(b) Historic passenger car fleet in Irish transport sector, Diesel

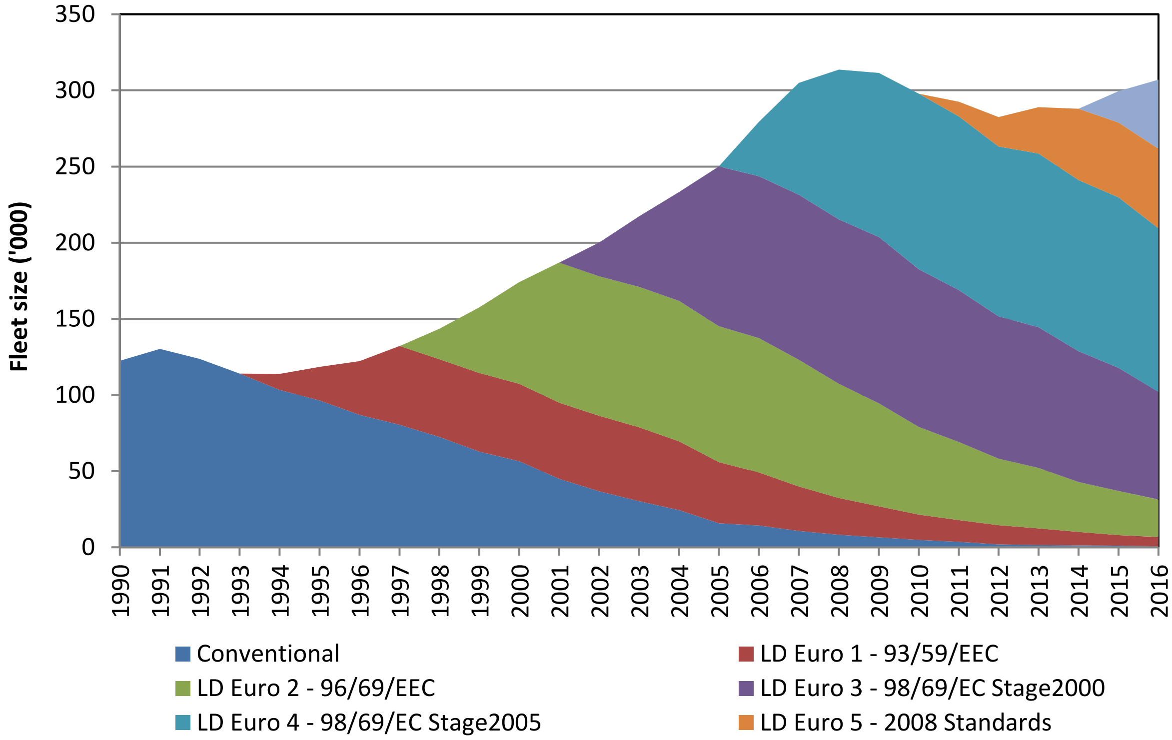

Figure 3.10.2 (a) Historic LDV fleet in Irish transport sector

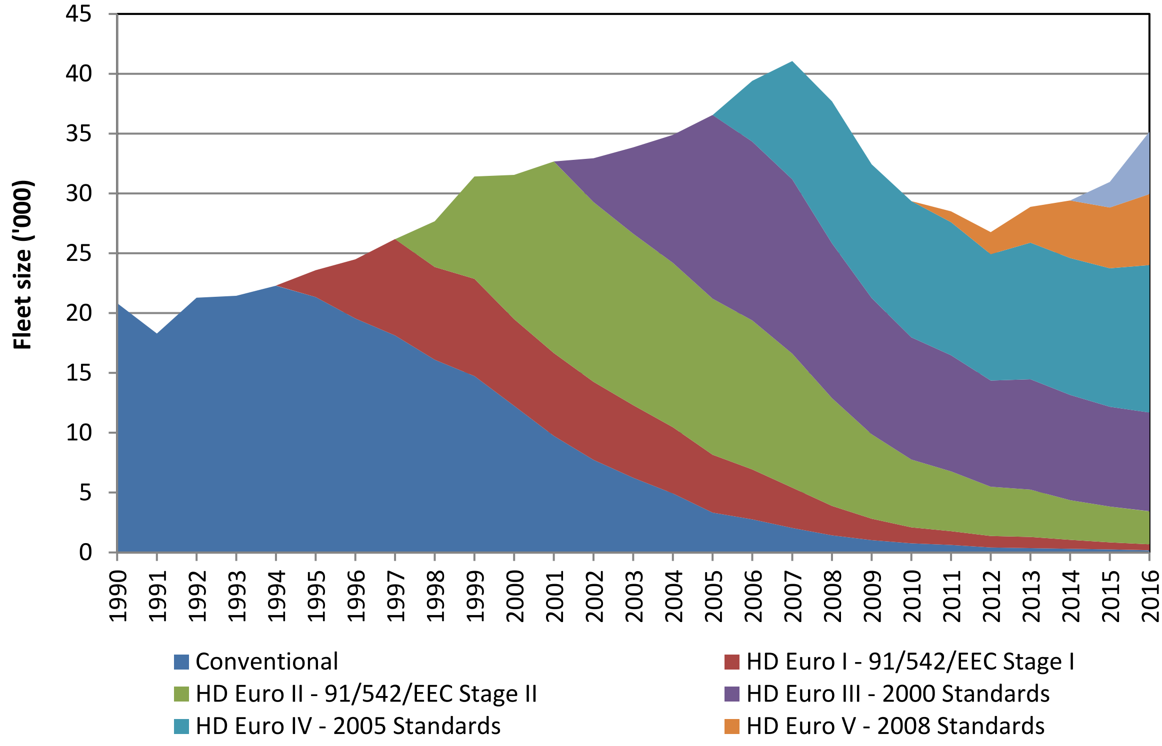

Figure 3.10.2 (b) Historic HDV fleet in Irish transport sector

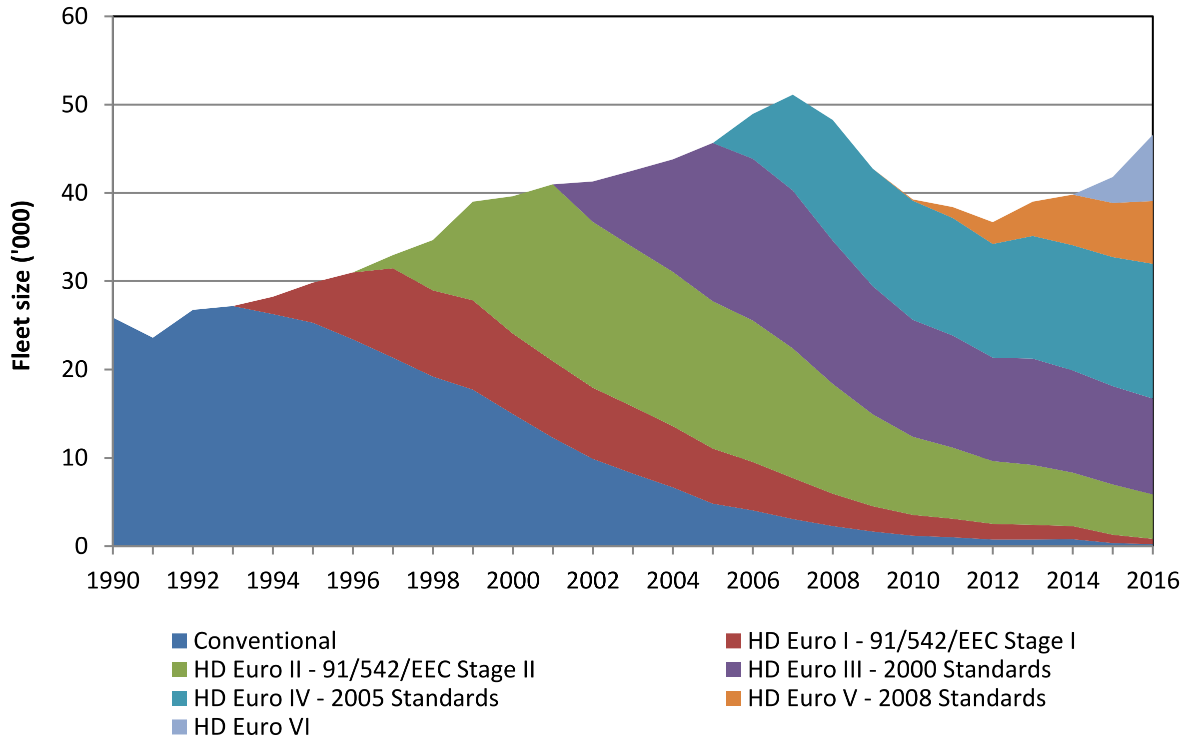

Figure 3.10.3(a) Historic Buses and coaches fleet in Irish transport sector

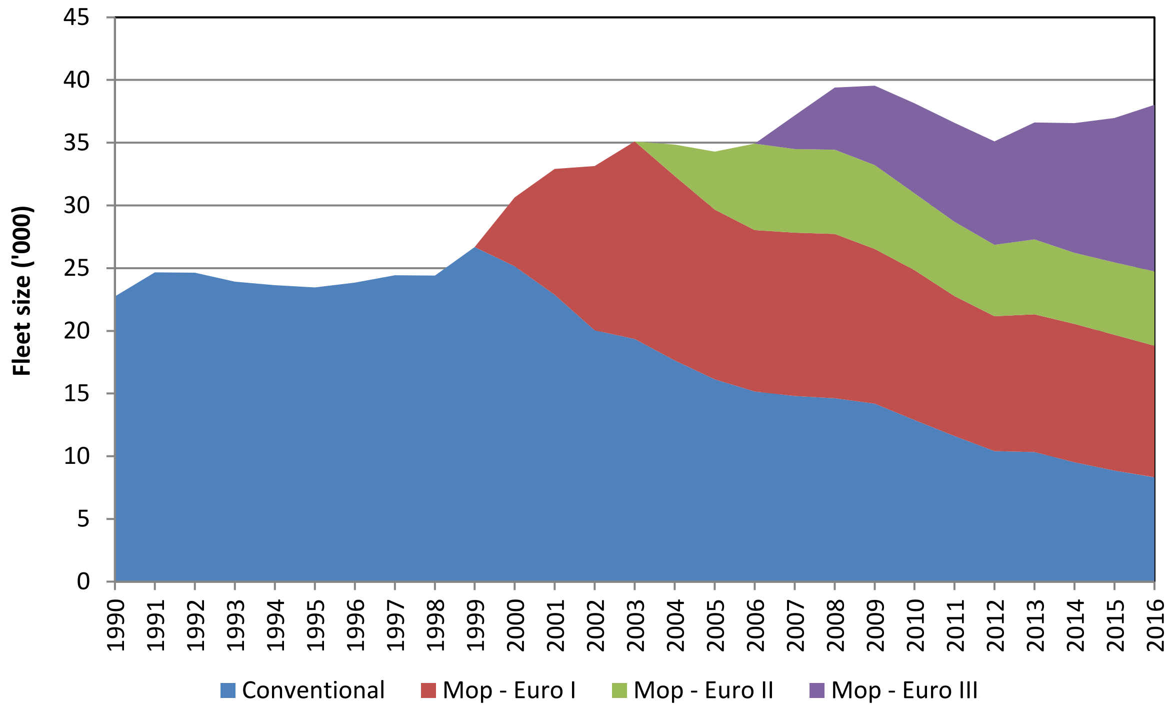

Figure 3.10.3 (b) Historic Mopeds and Motorcycle fleet in Irish transport sector

The estimation of mileage in modelling emission from 1990-2016 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 was described here and the back-extrapolation was 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.

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

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

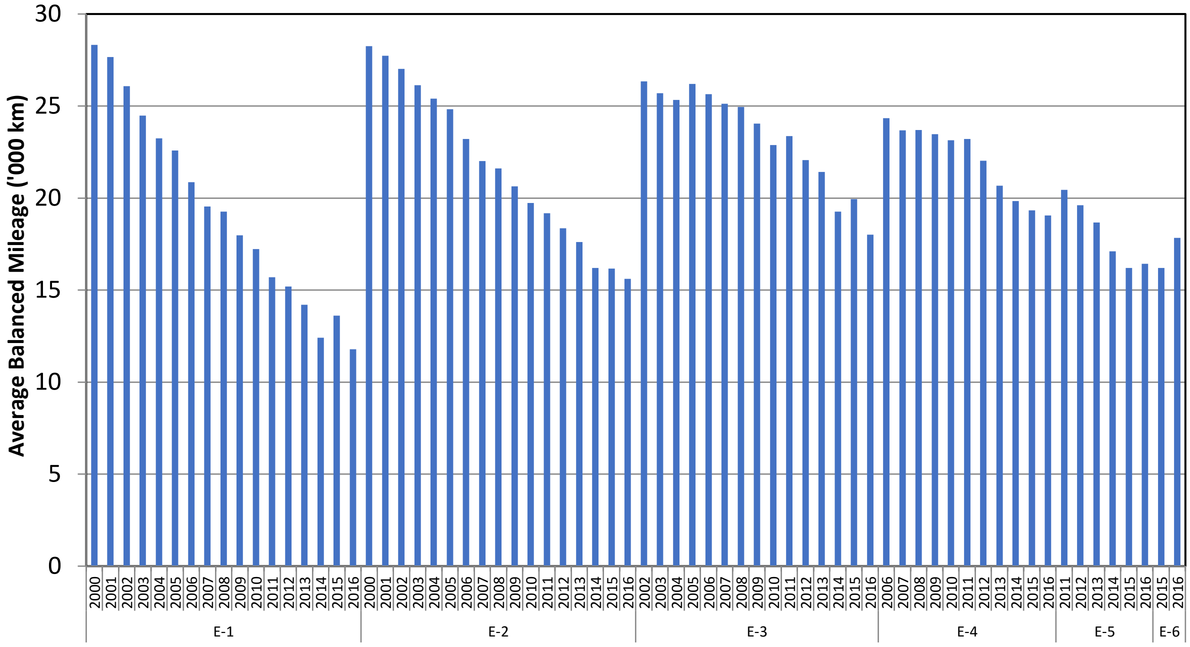

Figure 3.10.4 Average Balanced Vehicle mileage for Petrol PC1.4-2L (2000-2016)

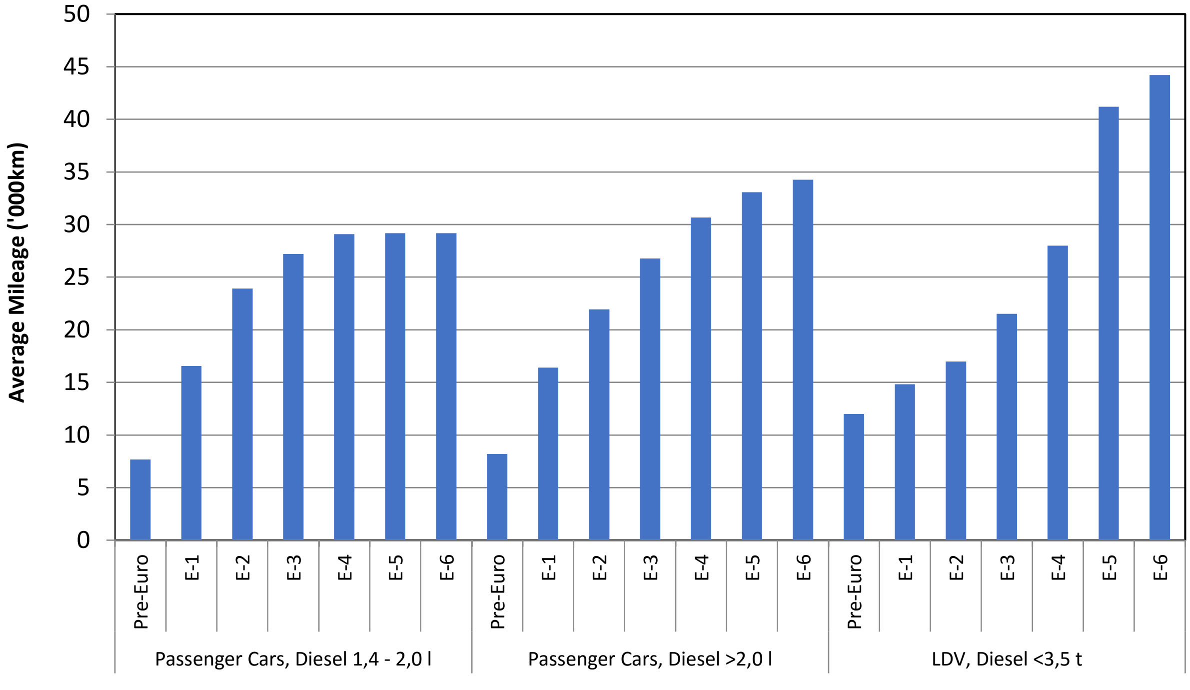

Figure 3.10.5 Average Balanced Vehicle mileage for Diesel Passenger car and LDV (2016)

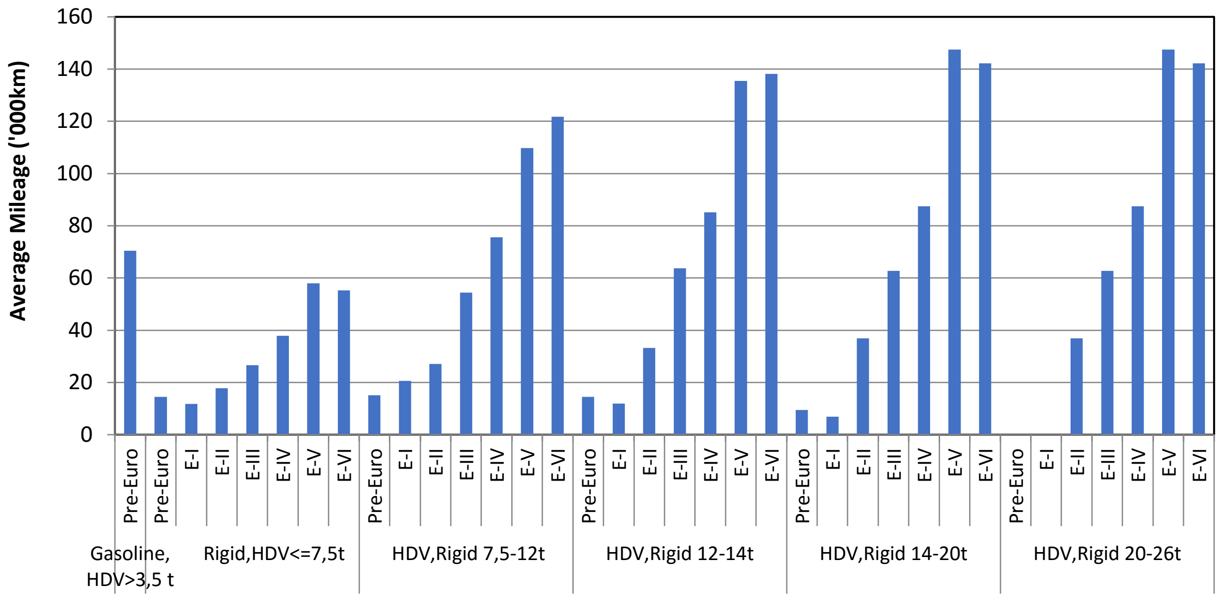

Figure 3.10.6 Average Balanced Vehicle mileage for HD Vehicle categories (2016)

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 sufficiently detailed country specific information is available. These data were applied into the COPERT 5 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 the last year's emissions inventory reports and applied similarly for this year. The sulphur content in fuels was obtained from the annual survey 2016 for fuel quality monitoring under Directive 98/70/EC. The speed data was obtained from several nation surveys and was mentioned in the Annex 3.1.14.

COPERT 4 Background

COPERT 4 (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 is 5 (5.0.1145 - May 2017) 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. The architecture of the COPERT 5 was changed in comparison to the COPERT 4 methodology for feeding input data, estimation of emission and output file structure. The emissions are now estimated based on the energy rather than the fuel use, and thus several input types were required to adjust to adopt the change. However, the emission factors and methodology remain the same in general between the latest COPERT IV and COPERT 5 versions. The methodology supports the calculation of CO_2 and two other greenhouse gases (CH_4 and N_2O) according to four broad vehicle technologies that are consistent with the CRF categories:

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

Exhaust emissions from road transport arise from the combustion of fuels such as gasoline, diesel, liquefied petroleum gas (LPG), and natural gas in internal combustion engines. For more detailed emission estimation methods the above four 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 177 vehicle categories.

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

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

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

where,

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

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

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

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

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

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

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

where,

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

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

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

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

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

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

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

where,

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

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

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

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

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

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

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

where,

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

Total emissions are calculated by combining activity data for each vehicle category with appropriate emission factors. The emission factors vary according to the input data (driving situations, climatic conditions). Also, information on fuel consumption and fuel specification is required to maintain a fuel balance between the figures provided by the user and the model calculations.

More details on the methods, vehicle specifications, calculation algorithms and other parameters used for calculating relevant road traffic exhaust emissions can be found in EMEP/EEA emission inventory guidebook, 2016.

3.2.6.2.3 Uncertainties and Time-series Consistency

The CO_2 emission factor uncertainty is 2.5 per cent and is subject to fuel consumption and fuel blends as per the 2006 IPCC Guidelines. Uncertainties in emission factors for CH_4 and N_2O are in the range of 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 is 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 2016.

Different forms of disaggregated mileage 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). As a result a consistent time series has been generated for mileage data.

3.2.6.2.4 Category-specific QA/QC and verification

A QA/QC check for the fleet and mileage 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 with caution using software applications like SPSS, R, and MS Excel and ensured consistency with approaches found in published literature.

3.2.6.2.5 Category-specific Recalculations

The input data for modelling emissions using COPERT 4 was migrated to COPERT 5 and the COPERT 5 model was calibrated to replicate emissions of COPERT 4. Thus, there were no significant recalculations in this sub-category for the 2018 submission.

3.2.6.2.6 Category-specific Planned Improvements

The inventory agency intends to use the latest COPERT 5 software when available.

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

3.2.6.3.1 Category Description

Emissions from railways (1.A.3.c) are estimated for diesel used in shunting or yard locomotives, railcars and line haul locomotives. There are no coal fired steam 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.

3.2.6.3.2 Methodological Issues

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

Table 3.5 Emission factors for Rail and Navigation

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

The emissions reported in sub-category *1.A.3.e Other Transportation* are due to natural gas combustion at 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_2 and the default values for CH_4 and N_2O used in the Energy Sector (Section 3.1.2) are used.

3.2.6.3.3 Uncertainties and Time-series Consistency

The uncertainties applicable to Railways, Navigation and Other Transportation are provided in Annex 2. The emission time series for 1990-2016 is consistent. Key activity data such as fuel use statistics are available for all years and are used in a consistent manner.

3.2.6.3.4 Category-specific QA/QC and verification

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

3.2.6.3.5 Category-specific Recalculations

There were no significant recalculations in this sub-category for the 2018 submission.

3.2.6.3.6 Category-specific Planned Improvements

There are no planned improvements for this category.

3.2.7 Other Sectors (1.A.4)

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. Emissions in *1.A.4* sector decreased from 2011 to 2014 due to milder than normal winter months before subsequently increasing in 2015 and 2016.

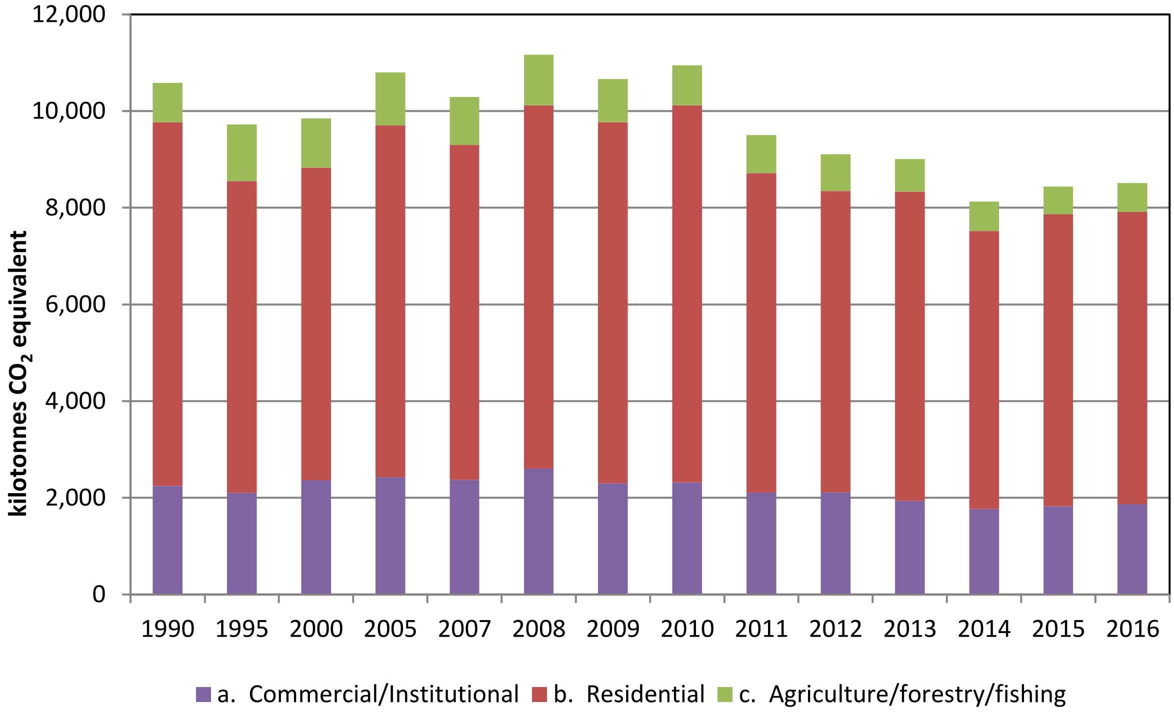

Figure 3.11 Emissions from 1.A.4 Other Sectors 1990-2016

3.2.7.1 Methodological Issues

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

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

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

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

Table 3.6 Emission factors for fuel use in Agriculture

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

Table 3.7 Emission factors for Charcoal use in Residential

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

3.2.7.2 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 1990-2016 is consistent. Key activity data such as fuel use statistics are available for all years and are used in a consistent manner.

3.2.7.3 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.

3.2.7.4 Category-specific Recalculations

There were no significant recalculations in this sub-category for the 2018 submission.

3.2.7.5 Category-specific Planned Improvements

There are no planned improvements for this category.

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 1990-2016 and from coal mining for the period 1990-1995 (only emissions from abandoned mines are reported after 1995).

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

3.3.1.1 Category Description

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

- *1.B.1.a.1(i)* Emissions from *Underground mining activities* for years 1990-1995;
- *1.B.1.a.1(ii)* Emissions from *Post-mining activities* for years 1990-1995;
- *1.B.1.a.1(iii)* Emissions from *Abandoned underground mines* for full 1990-2016.

Only three mines (Arigna, Rossmore and Castlecomer) were active in 1990 when production was reported at 25 kt. Arigna mine closed down 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.

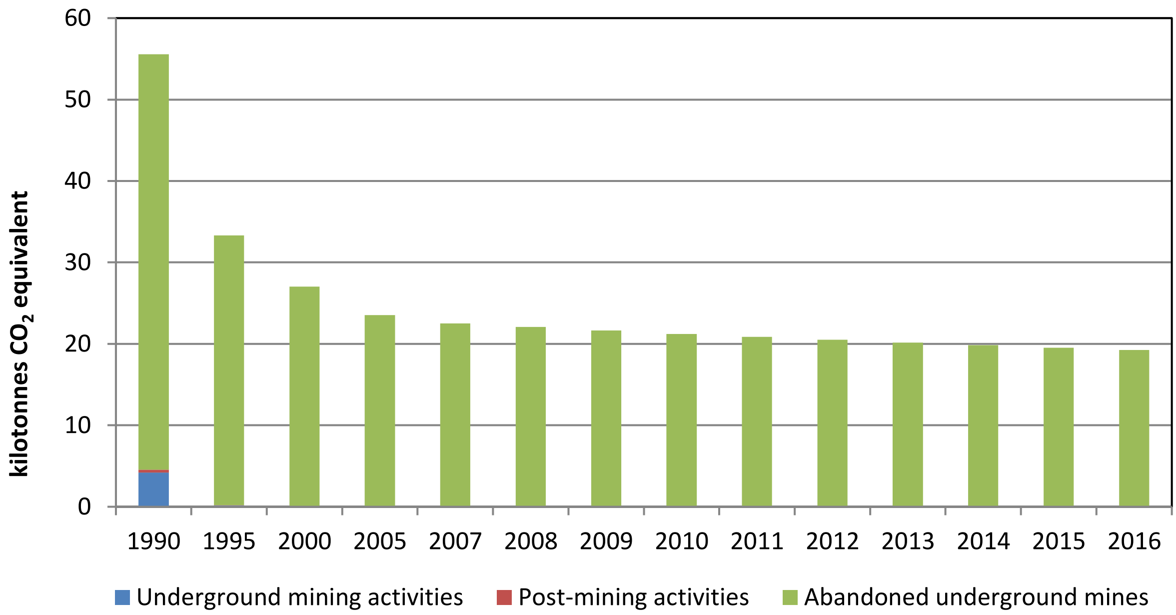

Figure 3.12 Fugitive emissions from Underground Coal Mines 1990-2016

3.3.1.2 Methodological Issues

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

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

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

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

After mining has ceased, abandoned coal mines may also continue to emit methane, hence the third category *Abandoned underground mines* is applicable for the emission time series 1990-2016. This category is based on the number of existing abandoned mines (remaining unflooded) 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 first time band (years 1900-1925) the default lower percentage of gassy mines is zero and the consequent emissions are not occurring. In the last time band (2001-present) there were no mines in Ireland closed down within that period hence there were no emissions resulting from this time band. Emissions are calculated for the middle three time bands only.

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

Time band	Number of existing abandoned mines	Fraction of gassy mines (%)	CH_4 EF	Unit	CH_4 Conversion Factor	Unit	Reference
1926 - 1950	9	3	0.343 -0.279	Mm^3 /mine	0.67	kt CH_4 /Mm^3	2006 IPCC Guidelines, Eq. 4.1.10, Table 4.1.5, Table 4.1.6
1951 - 1975	19	5	0.478 -0.340	Mm^3 /mine	0.67	kt CH_4 /Mm^3	2006 IPCC Guidelines, Eq. 4.1.10, Table 4.1.5, Table 4.1.6
1976 - 2000	20	8	1.561 - 0.469	Mm^3 /mine	0.67	kt CH_4 /Mm^3	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 1990–2016 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

ERVIA (previously Bord Gais Eireann(BGE)), Ireland's gas company has assessed gas losses in the pipeline network in the context of the needs of annual inventory reporting and a long-term programme to replace cast-iron mains with polyethylene pipe in all urban areas served by natural gas. The change to polyethylene pipe is considered to result in negligible losses.

The gas company indicated that gas loss in 1995, determined as the difference between system input and metered sales, was 1.92 million therms, which equates to 4,085 tonnes of methane, when the amounts of indigenous and imported gas and their respective properties are taken into account. This value implied a loss of the order of 0.2 per cent of total sales.

Projections made by BGE for five-year intervals from 2000 show losses decreasing to negligible amounts (unquantifiable) in 2020 on completion of the pipe replacement programme. This data continues to be used as the best available source for this particular fugitive emission source. Linear interpolation is applied to calculate estimated losses for all years in the time-series.

Gas consumption recorded in the national energy balance for the industrial, commercial and residential sectors is used as activity data rather than total sales and the appropriate split between indigenous and imported gas is applied for all years. The inventory agency was informed by BGE in 2004 that natural gas losses from the distribution network were so small that they could not be measured.

Emissions of CO_2 have been calculated and included in the inventory for the first time in this submission. The estimates are calculated based on the CO_2 content of the natural gas as reported by the suppliers, and the calculated losses as described above.

Only two companies are involved in natural gas production in Ireland. Emissions to the atmosphere from offshore gas production platforms are reported to the Department of Communications Climate Action and Environment (DCCAE) 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 relate largely to gas extraction but which also account for a small amount of flaring in some years, indicate a close relationship between emissions and the amount of gas produced. This relationship has been applied in terms of the indicative emission rates of CO_2 and CH_4 per unit of gas extracted to estimate the emissions for those years for which no reports were received.

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

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

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

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 1990-2016 is consistent. Key activity data such as gas and oil statistics are available for all applicable years and are used in a consistent manner.

3.3.2.4 Category-specific QA/QC and verification

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

3.3.2.5 Category-specific Recalculations

There are no significant recalculations in this category.

3.3.2.6 Category-specific Planned Improvements

There are no planned improvements for this category.

3.4 CO_2 Transport and Storage (1.C)

This activity does not occur in Ireland. Emissions are reported as Not Occurring (NO) for all years 1990-2016.

Table 3.10(a) Previous and current emission estimates in the Energy Sector (1990-2015)

2017 Submission		Unit	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1.A.1.a	Public Electricity and Heat Production	kt CO_2e	10,953.9	13,132.9	15,754.4	15,244.8	14,527.0	14,055.8	14,155.1	12,610.6	12,895.1	11,556.5	12,356.3	10,952.9	10,771.9	11,328.3
1.A.1.b	Petroleum Refining	kt CO_2e	168.7	181.3	274.8	411.9	377.1	360.8	367.5	315.4	310.5	285.4	313.5	294.5	279.5	358.7
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries	kt CO_2e	100.5	69.4	87.2	110.1	120.2	114.1	124.1	145.5	121.3	93.3	104.8	122.7	97.7	73.1
1.A.2.a	Iron and Steel	kt CO_2e	175.9	18.7	18.8	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.3	2.4	2.4
1.A.2.b	Non-Ferrous Metals	kt CO_2e	811.5	1,207.4	1,437.9	1,152.6	1,459.2	1,541.7	1,544.4	1,227.7	1,519.0	1,484.0	1,479.2	1,439.3	1,439.8	1,448.4
1.A.2.c	Chemicals	kt CO_2e	411.4	357.2	485.1	450.8	366.6	324.4	330.0	285.4	276.0	255.5	248.9	261.7	256.9	283.5
1.A.2.d	Pulp, Paper and Print	kt CO_2e	28.5	62.6	102.7	50.4	32.6	12.4	22.2	23.4	21.3	18.1	16.3	15.9	14.9	16.2
1.A.2.e	Food Processing, Beverages and Tobacco	kt CO_2e	1,021.4	1,175.6	1,608.6	1,296.3	1,203.4	1,107.7	1,125.8	1,082.8	983.8	814.0	806.5	867.9	804.4	888.7
1.A.2.f	Non-metallic minerals	kt CO_2e	822.8	505.3	720.8	1,923.0	1,806.1	1,871.6	1,677.9	1,105.9	921.1	832.2	925.0	920.2	1,111.9	1,161.5
1.A.2.g	Other	kt CO_2e	690.4	1,020.8	1,268.5	995.2	882.4	951.5	951.6	777.7	773.5	753.4	710.3	731.1	693.2	748.2
1.A.3.a	Domestic Aviation	kt CO_2e	51.7	48.9	74.4	65.4	77.3	71.5	67.2	55.2	41.0	19.3	11.5	10.2	9.5	10.5
1.A.3.b	Road Transportation	kt CO_2e	4,786.3	5,887.5	10,366.5	12,554.9	13,184.3	13,839.4	13,084.7	11,896.8	10,984.3	10,734.7	10,365.0	10,593.8	10,841.3	11,328.9
1.A.3.c	Railways	kt CO_2e	148.9	124.5	137.6	136.6	136.6	147.7	156.5	137.4	136.3	136.5	131.9	131.4	120.5	122.8
1.A.3.d	Domestic navigation	kt CO_2e	85.8	92.1	152.7	211.2	250.1	197.5	204.7	199.5	200.1	173.7	183.6	179.6	224.8	221.7
1.A.3.e	Other transportation	kt CO_2e	62.9	118.7	57.8	153.3	153.2	132.0	147.5	152.5	166.7	155.3	143.8	150.6	151.2	143.3
1.A.4.a	Commercial/Institutional	kt CO_2e	2,244.1	2,101.9	2,364.1	2,428.2	2,292.8	2,373.6	2,600.4	2,299.6	2,317.6	2,108.5	2,115.2	1,937.3	1,772.5	1,740.8
1.A.4.b	Residential	kt CO_2e	7,523.7	6,452.0	6,462.6	7,271.9	7,157.5	6,928.5	7,521.6	7,467.0	7,800.9	6,609.8	6,232.4	6,395.4	5,745.6	6,041.4
1.A.4.c	Agriculture/Forestry/Fishing	kt CO_2e	818.5	1,166.7	1,023.0	1,098.6	1,043.7	988.8	1,042.8	893.6	829.7	785.0	757.8	674.3	608.6	580.1
1.B.1.a	Coal mining and handling	kt CO_2e	55.6	33.3	27.0	23.5	23.0	22.5	22.1	21.7	21.2	20.9	20.5	20.1	19.8	19.5
1.B.2.a	Oil	kt CO_2e	0.2	0.3	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.4	0.3	0.3	0.4
1.B.2.b	Natural gas	kt CO_2e	156.1	135.9	101.3	67.4	55.8	71.0	61.1	42.0	37.3	32.8	28.3	23.3	28.0	23.2
Total Energy			**31,118.5**	**33,893.1**	**42,526.1**	**45,648.8**	**45,151.8**	**45,115.2**	**45,209.9**	**40,742.4**	**40,359.6**	**36,871.7**	**36,953.6**	**35,725.0**	**34,994.7**	**36,541.6**
2018 Submission																
1.A.1.a	Public Electricity and Heat Production	kt CO_2e	10,953.9	13,132.9	15,754.4	15,244.8	14,527.0	14,055.8	14,155.1	12,610.6	12,895.1	11,556.5	12,356.3	10,952.9	10,771.9	11,328.3
1.A.1.b	Petroleum Refining	kt CO_2e	168.7	181.3	274.8	411.9	377.1	360.8	367.5	315.4	310.5	285.4	313.5	294.5	279.5	358.7
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries	kt CO_2e	100.5	69.4	87.2	171.9	172.4	166.4	183.9	191.5	173.3	135.8	145.4	161.2	133.7	114.5
1.A.2.a	Iron and Steel	kt CO_2e	175.9	18.7	18.8	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.3	2.4	2.4
1.A.2.b	Non-Ferrous Metals	kt CO_2e	811.5	1,207.4	1,437.9	1,152.6	1,459.0	1,541.7	1,544.3	1,227.7	1,519.0	1,484.0	1,479.1	1,439.4	1,439.8	1,446.4
1.A.2.c	Chemicals	kt CO_2e	411.4	357.2	485.1	450.8	366.5	320.1	324.8	280.7	272.1	252.3	245.8	258.7	254.6	266.1
1.A.2.d	Pulp, Paper and Print	kt CO_2e	28.5	62.6	102.7	50.4	32.6	12.2	21.9	23.1	21.1	17.9	16.1	15.8	14.8	15.4
1.A.2.e	Food Processing, Beverages and Tobacco	kt CO_2e	1,021.4	1,175.6	1,608.6	1,296.1	1,203.3	1,100.3	1,118.1	1,075.3	977.5	808.8	801.6	863.1	800.7	863.5
1.A.2.f	Non-metallic minerals	kt CO_2e	822.8	505.3	720.8	1,923.0	1,806.1	1,869.3	1,676.7	1,104.6	920.1	831.4	928.5	933.3	1,123.1	1,184.4
1.A.2.g	Other	kt CO_2e	690.4	1,020.8	1,268.5	995.2	882.4	942.8	941.2	766.5	764.2	745.6	703.0	723.9	687.7	705.9
1.A.3.a	Domestic Aviation	kt CO_2e	51.7	48.9	74.4	65.4	77.3	71.5	67.2	55.2	41.0	19.3	11.5	10.2	9.5	10.5
1.A.3.b	Road Transportation	kt CO_2e	4,787.5	5,890.6	10,369.5	12,558.5	13,187.7	13,842.3	13,086.1	11,898.0	10,985.1	10,735.3	10,365.7	10,594.2	10,841.0	11,314.7
1.A.3.c	Railways	kt CO_2e	148.9	124.5	137.6	136.6	136.6	147.7	156.5	137.4	136.3	136.5	131.9	131.4	120.5	122.8
1.A.3.d	Domestic navigation	kt CO_2e	85.8	92.1	152.7	211.2	250.1	197.5	204.7	199.5	200.1	173.7	183.6	179.6	224.8	221.7
1.A.3.e	Other transportation	kt CO_2e	62.9	118.7	57.8	153.3	153.2	132.0	147.5	152.5	166.7	155.3	143.8	150.6	151.2	143.3
1.A.4.a	Commercial/Institutional	kt CO_2e	2,244.1	2,101.9	2,364.1	2,428.2	2,292.8	2,373.6	2,600.9	2,300.2	2,318.0	2,108.8	2,115.4	1,937.5	1,772.6	1,820.9
1.A.4.b	Residential	kt CO_2e	7,523.7	6,452.0	6,462.6	7,271.9	7,157.5	6,928.5	7,521.6	7,467.0	7,800.9	6,609.8	6,232.4	6,395.4	5,745.6	6,041.4
1.A.4.c	Agriculture/Forestry/Fishing	kt CO_2e	818.5	1,166.7	1,023.0	1,098.6	1,043.7	988.8	1,042.8	893.6	829.7	785.0	757.8	674.3	608.6	580.1
1.B.1.a	Coal mining and handling	kt CO_2e	55.6	33.3	27.0	23.5	23.0	22.5	22.1	21.7	21.2	20.9	20.5	20.1	19.8	19.5
1.B.2.a	Oil	kt CO_2e	0.2	0.3	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.4	0.3	0.3	0.4
1.B.2.b	Natural gas	kt CO_2e	156.1	135.9	101.3	67.4	55.9	71.0	61.1	42.0	37.3	32.8	28.3	23.3	28.0	23.2
Total Energy			**31,119.7**	**33,896.2**	**42,529.2**	**45,713.9**	**45,207.2**	**45,147.5**	**45,246.7**	**40,765.1**	**40,392.1**	**36,897.8**	**36,982.9**	**35,761.9**	**35,030.1**	**36,584.1**

Table 3.10(b) Absolute and relative recalculations in the Energy Sector (1990-2015)

Absolute change		Unit	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1.A.1.a	Public Electricity and Heat Production	kt CO_2e	-	-	-	-0.00	0.00	-0.00	-0.00	-	-	-	-	-	-	-
1.A.1.b	Petroleum Refining	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries	kt CO_2e	-	-	-	61.79	52.22	52.31	59.78	45.97	51.98	42.51	40.55	38.47	35.98	41.42
1.A.2.a	Iron and Steel	kt CO_2e	-	-	-	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	0.00	-0.00	-0.00
1.A.2.b	Non-Ferrous Metals	kt CO_2e	-	-	-	-0.00	-0.11	-0.04	-0.04	-0.03	-0.03	-0.03	-0.08	0.02	-0.03	-1.99
1.A.2.c	Chemicals	kt CO_2e	-	-	-	-0.07	-0.04	-4.30	-5.20	-4.66	-3.85	-3.23	-3.03	-2.97	-2.28	-17.32
1.A.2.d	Pulp, Paper and Print	kt CO_2e	-	-	-	-0.01	-0.00	-0.15	-0.27	-0.24	-0.20	-0.17	-0.16	-0.15	-0.12	-0.89
1.A.2.e	Food Processing, Beverages and Tobacco	kt CO_2e	-	-	-	-0.13	-0.08	-7.42	-7.68	-7.55	-6.24	-5.23	-4.92	-4.81	-3.69	-25.15
1.A.2.f	Non-metallic minerals	kt CO_2e	-	-	-	-0.03	-0.02	-2.29	-1.27	-1.21	-1.00	-0.84	3.42	13.07	11.21	22.88
1.A.2.g	Other	kt CO_2e	-	-	-	-0.05	-0.03	-8.76	-10.39	-11.26	-9.30	-7.80	-7.33	-7.19	-5.51	-42.32
1.A.3.a	Domestic Aviation	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.A.3.b	Road Transportation	kt CO_2e	1.23	3.09	3.07	3.59	3.43	2.93	1.37	1.18	0.76	0.69	0.68	0.34	-0.35	-14.20
1.A.3.c	Railways	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.A.3.d	Domestic navigation	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.A.3.e	Other transportation	kt CO_2e	-	-	-	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.00	-0.01	-0.00
1.A.4.a	Commercial/Institutional	kt CO_2e	-	-	-	-	-	-	0.50	0.56	0.38	0.22	0.23	0.22	0.16	80.10
1.A.4.b	Residential	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	0.01	0.00	0.05
1.A.4.c	Agriculture/Forestry/Fishing	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.04
1.B.1.a	Coal mining and handling	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.B.2.a	Oil	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.B.2.b	Natural gas	kt CO_2e	-	-	-	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Energy		**kt CO_2e**	**1.23**	**3.09**	**3.07**	**65.11**	**55.36**	**32.28**	**36.79**	**22.74**	**32.51**	**26.11**	**29.34**	**36.99**	**35.37**	**42.52**
Relative change																
1.A.1.a	Public Electricity and Heat Production	%	-	-	-	-0.0%	0.0%	-0.0%	-0.0%	-	-	-	-	-	-	-
1.A.1.b	Petroleum Refining	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries	%	-	-0.0%	0.0%	56.1%	43.4%	45.8%	48.2%	31.6%	42.8%	45.6%	38.7%	31.3%	36.8%	56.7%
1.A.2.a	Iron and Steel	%	-	-	-	-0.0%	-0.0%	-0.0%	-0.0%	-0.0%	-0.0%	-0.0%	-0.0%	0.0%	-0.0%	-0.0%
1.A.2.b	Non-Ferrous Metals	%	-	-	-	-0.0%	-0.0%	-0.0%	-0.0%	-0.0%	-0.0%	-0.0%	-0.0%	0.0%	-0.0%	-0.1%
1.A.2.c	Chemicals	%	-	-	-	-0.0%	-0.0%	-1.3%	-1.6%	-1.6%	-1.4%	-1.3%	-1.2%	-1.1%	-0.9%	-6.1%
1.A.2.d	Pulp, Paper and Print	%	-	-	-	-0.0%	-0.0%	-1.2%	-1.2%	-1.0%	-0.9%	-0.9%	-1.0%	-1.0%	-0.8%	-5.5%
1.A.2.e	Food Processing, Beverages and Tobacco	%	-	-	-	-0.0%	-0.0%	-0.7%	-0.7%	-0.7%	-0.6%	-0.6%	-0.6%	-0.6%	-0.5%	-2.8%
1.A.2.f	Non-metallic minerals	%	-	-	-	-0.0%	-0.0%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	0.4%	1.4%	1.0%	2.0%
1.A.2.g	Other	%	-	-	-	-0.0%	-0.0%	-0.9%	-1.1%	-1.4%	-1.2%	-1.0%	-1.0%	-1.0%	-0.8%	-5.7%
1.A.3.a	Domestic Aviation	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.A.3.b	Road Transportation	%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.0%	-0.1%
1.A.3.c	Railways	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.A.3.d	Domestic navigation	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.A.3.e	Other transportation	%	-	-	-	-0.0%	-0.0%	-0.0%	-0.0%	-0.0%	-0.0%	-0.0%	-0.0%	-0.0%	-0.0%	-0.0%
1.A.4.a	Commercial/Institutional	%	-	-	-	-	-	-	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	4.6%
1.A.4.b	Residential	%	-	-	-	-	-	-	-	-	-	-	-	0.0%	0.0%	0.0%
1.A.4.c	Agriculture/Forestry/Fishing	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.0%
1.B.1.a	Coal mining and handling	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.B.2.a	Oil	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.B.2.b	Natural gas	%	-	-	-	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Total Energy		**%**	**0.0%**	**0.0%**	**0.0%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**

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 one particular greenhouse gas, such as cement production for CO_2 or adipic acid production in the case of N_2O, while others may be more important in terms of their indirect greenhouse gas emissions, such as the use of solvents.

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

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

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

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

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

4.1.1 Emissions Overview

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

Emissions from *Industrial Processes and Product Use* accounted for 6.0 per cent and 5.6 per cent of total national emissions (including indirect CO_2, without *LULUCF*) in 1990 and 2016, respectively. This sector accounted for 100 per cent of fluorinated gas emissions (HFCs, PFCs, SF_6 and NF_3), 5.3 per cent of CO_2 emissions and 0.6 per cent of N_2O emissions in 2016.

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

- **2.*A.1 Cement Production*** (Trend and Level) is a significant activity in Ireland, which peaked in 2007 prior to the economic downturn in 2008.
- ***2.F.1 Refrigeration and Air-Conditioning*** (Trend and Level) has become a significant source in Ireland due to the growth in HFC use as replacement refrigerants across virtually all refrigeration sub-categories since 1991.
- ***2.F.4 Product Uses as Substitutes for ODS – Aerosols including MDIs*** is now highlighted as a key category under the trend assessment though is not under the level assessment and indicates that although a small category, there has been significant growth in the use of HFCs.

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

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

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

- ***Carbon dioxide*** emissions originate from *2.A Mineral Production* and *2.D Non-energy products from fuels and solvent use* sectors: *2.D.1 Lubricant Use* and *2.D.2 Paraffin Wax Use*. Historically, *2.B Chemical Production* was also a source, however the plant closed in 2003. There was a significant decrease in emissions from 2007-2009 due to the economic downturn after which emissions have remained relatively stable. Indirect CO_2 emissions (included in

IPPU) originate from NMVOC emissions from sector *2.D.3 Solvents, 2.G.4 Other Solvent use (Use of Tobacco)* and *2.H.2. Food and Beverages industry.*

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

The emission estimates clearly indicate that the combined emissions of HFC, PFC, SF_6 and NF_3 have generally increased year on year. This overall trend largely reflects the increasing use of HFCs across a range of applications (e.g. often as replacements in applications where the use of CFC and HCFCs is no longer permitted under the Montreal Protocol) and hence the presence of larger fluid banks from which operational leakage potentially occurs.

4.1.2 Methodology Overview

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

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

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

Table 4.1 Level 3 Source Methodology for IPPU

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

* Key Category, T1,2,3: Tier 1, Tier 2, Tier 3 as described in the 2006 IPCC Guidelines, NA: not applicable because emissions of the gas do not occur in the source category

Table 4.2 Emissions from Industrial Processes and Product Use 1990-2016

IPCC	Description	Gas	Unit	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
2.A.1	Cement Production	CO_2	kt CO_2e	884.0	879.0	1700.9	2357.1	2374.1	2106.7	1326.8	1105.1	966.3	1177.0	1111.7	1461.1	1652.0	1793.5
2.A.2	Lime Production	CO_2	kt CO_2e	214.1	187.5	190.4	183.5	199.1	187.8	157.2	193.4	200.5	215.9	189.6	189.0	177.3	173.9
2.A.3	Glass Production	CO_2	kt CO_2e	13.3	12.0	10.7	0.5	0.5	0.3	0.0	NO	NO	NO	NO	NO	NO	NO
2.A.4.a	Other- Ceramics	CO_2	kt CO_2e	5.23	5.64	6.66	7.53	7.04	4.18	0.53	0.42	0.83	0.03	0.03	NO	0.50	0.78
2.A.4.b	Other- Soda Ash Use	CO_2	kt CO_2e	0.10	0.07	0.07	0.08	0.06	0.04	0.05	0.07	0.07	0.09	0.06	0.07	0.06	0.04
2.A.4.d	Other- Limestone use	CO_2	kt CO_2e	NO	NO	NO	4.17	2.11	2.52	1.54	1.03	1.04	0.44	0.21	0.28	0.45	0.16
2.B.1	Ammonia Production	CO_2	kt CO_2e	990.2	973.4	882.3	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.B.2	Nitric Acid Production	N_2O	kt CO_2e	995.3	781.0	781.0	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.C.1	Iron and Steel Production	CO_2	kt CO_2e	26.1	24.8	28.8	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.D.1	Lubricant Use	CO_2	kt CO_2e	35.97	11.78	70.08	59.54	23.57	20.47	22.39	16.82	18.73	18.28	19.08	19.84	20.35	20.56
2.D.2	Paraffin Wax Use	CO_2	kt CO_2e	5.87	8.19	14.71	32.37	30.18	22.16	22.32	20.36	19.94	18.48	20.80	18.83	22.51	21.55
2.D.3	Solvent use	Indirect CO_2	kt CO_2e	51.41	52.40	47.54	50.81	59.24	51.63	48.09	43.07	42.44	41.05	40.54	42.06	40.75	40.95
2.D.3	Urea Used as a Catalyst	CO_2	kt CO_2e	NO	NO	NO	1.04	3.88	4.36	4.06	3.84	4.05	4.05	4.68	6.05	7.60	9.06
2.E.1	Integrated Circuit or Semiconductor	HFCs, PFCs, SF_6, NF_3	kt CO_2e	1.17	145.33	491.70	310.12	238.87	179.86	107.30	68.19	41.13	31.55	34.63	20.27	46.84	57.04
2.F.1	Refrigeration and Air Conditioning	HFCs	kt CO_2e	NO	75.54	309.29	516.54	747.28	677.21	752.68	762.62	786.48	781.78	903.73	977.47	909.62	1021.89
2.F.2	Foam Blowing Agents	HFCs	kt CO_2e	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.F.3	Fire Protection	HFCs	kt CO_2e	NO	NO	7.33	14.30	16.99	18.31	19.63	32.36	32.38	32.39	32.41	32.42	32.44	32.45
2.F.4	Aerosols	HFCs	kt CO_2e	0.64	25.35	124.91	144.68	137.29	145.64	139.08	132.83	133.18	131.63	130.48	130.48	130.22	133.61
2.G.1	Electrical Equipment	SF_6	kt CO_2e	20.52	25.08	7.43	22.44	28.45	10.40	13.34	12.33	20.70	16.22	18.60	19.15	19.70	19.06
2.G.2	SF_6 and PFCs from Other Product Uses	SF_6	kt CO_2e	12.90	12.99	14.69	11.81	5.68	5.15	5.87	3.35	2.61	2.76	2.92	3.08	3.24	3.24
2.G.3.a	N_2O from product uses	N_2O	kt CO_2e	31.34	32.20	33.88	36.96	39.12	40.10	40.53	40.72	40.90	40.99	41.06	41.21	41.44	42.57
2.G.4	Other Solvent and product use	Indirect CO_2	kt CO_2e	0.07	0.08	0.09	0.07	0.07	0.06	0.06	0.05	0.05	0.05	0.04	0.04	0.04	0.04
2.H.2	Food and beverages industry	Indirect CO_2	kt CO_2e	21.16	22.47	21.30	30.93	31.47	31.53	34.99	39.71	40.01	44.91	49.48	41.87	44.09	46.77
Total	**IPPU**		**kt CO_2e**	**3309.4**	**3274.8**	**4743.8**	**3784.4**	**3944.9**	**3508.5**	**2696.5**	**2476.3**	**2351.3**	**2557.6**	**2600.2**	**3003.2**	**3149.2**	**3417.2**

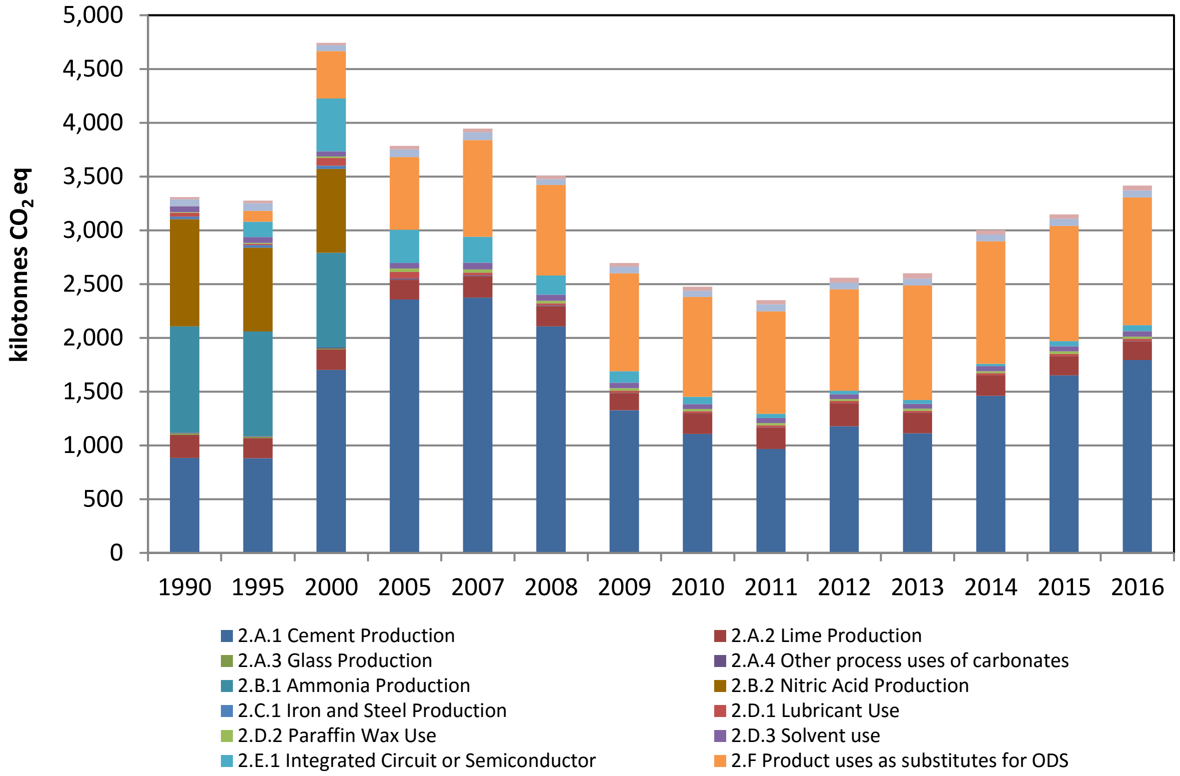

Figure 4.1 Total Emissions from IPPU by Category, 1990-2016

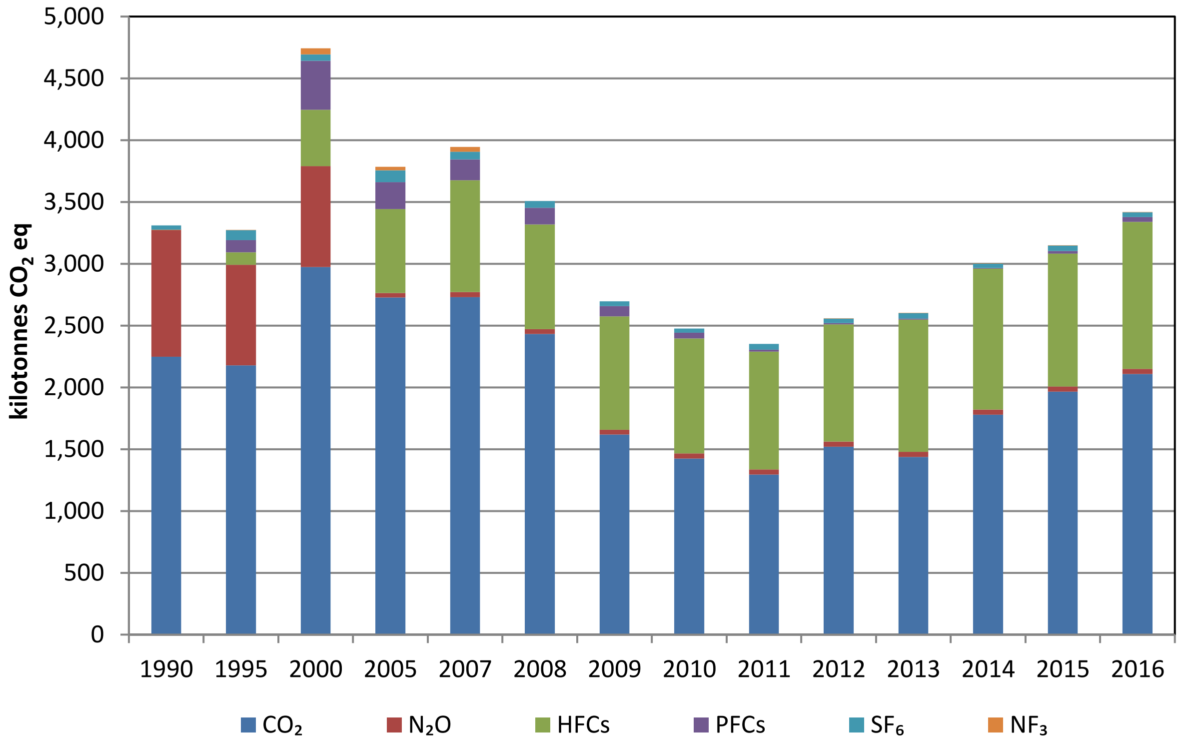

Figure 4.2 Total Emissions from IPPU by Gas, 1990-2016

4.2 Emissions from Mineral Industry (2.A)

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

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

4.2.1 Cement Production (2.A.1)

4.2.1.1 Category Description

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

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

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

4.2.1.2 Methodological Issues

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

This method has been used for all years from 2005 to 2016. Plant specific CO_2 emissions and corresponding production process data such as clinker, CKD and non-carbonated elements/lime fines are also available for all cement plants for the years 2005 onwards and these data are used directly to report emissions for category *2.A.1 Cement Production* in Ireland. The annual results incorporate verification of fuel use, limestone and carbonate use, combustion and process CO_2 estimates in accordance with Decision 2004/156/EC.

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

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

For the two original cement plants which were operated by a single cement producer, the company concerned supplied estimates of process emissions for the years 1990-2001 that it had calculated internally in line with the specific information provided for the years 2002 and 2003 and used for NAP1. The associated values of annual clinker production were not provided. For the purposes of complete and consistent reporting, the inventory agency estimated annual clinker production for the years 1990-2001 based on the plant specific process emission factors available for the two plants for the years from 2002 onwards. This is appropriate, as the company has always used the same local on-site supply of limestone, and the time-series of process CO_2 emissions for cement production overall may therefore be considered consistent for the period 1990-2016.

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, their validity is fully established in the context of the companies' documented methods and data and the associated guidance on emissions estimation methods provided by Decision 2004/156/EC (CEC, 2004). Such verification allows for accurate accounting of combustion emissions and process emissions separately.

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

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

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

4.2.1.5 Category-specific Recalculations

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

4.2.1.6 Category-specific Planned Improvements

There are no planned improvements for this source category.

4.2.2 Lime Production (2.A.2)

4.2.2.1 Category Description

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

Currently, there are two companies operating 3 lime plants in Ireland and a fourth that operated until 1999. 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 1990-2005, emissions from lime production are based on a Tier 3 input-based carbonate approach and equation 2.7 Chapter 2, Volume 3 of the 2006 IPCC guidelines. The CO_2 estimates for lime production in 2016 have been obtained from the ETS returns to the EPA.

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

The implied emission factor for aggregated lime production was 0.76 t CO_2/t lime in 2016. 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%) 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. 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 plant 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

It is planned to revise the uncertainty associated with lime production to bring it in line with the information provided in Table 2.5 of the 2006 IPCC guidelines.

4.2.3 Glass Production (2.A.3)

4.2.3.1 Category Description

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

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

4.2.3.2 Methodological Issues

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

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

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

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

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

4.2.3.3 Uncertainties and Time-series Consistency

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

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

There are no planned improvements for this source category.

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

4.2.4.1 Category Description

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

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

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

4.2.4.2 Methodological Issues

Emissions of CO_2 have been estimated using a Tier 3, carbonate input approach, for sources in this category. Limestone has been used as environmental pollution control method to reduce the sulphur emitted from peat burning in one electricity generating station since 2001 and in a second such plant since 2007. The CO_2 emissions estimates are taken from ETS Annual Emission Monitoring reports to the EPA. They are estimated on the basis of limestone quantity used by the companies and reported process emissions, giving an implied emission factor in the range from 0.43 to 0.44 t CO_2/t limestone between 2001 and 2016. The stoichiometric ratio of CO_2 to $CaCO_3$ is 0.44.

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

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

The emissions associated with soda ash use by one company in Ireland are reported by the company under ETS for the years 2005 onwards and have been used directly in the inventory. The other uses of soda ash are already reported under 2.A.3 glass production. Activity data for years prior to the ETS data were sourced by the inventory agency from the company. Estimates of CO_2 for all years from 1990-2004 were calculated using an emission factor of 0.41 t CO_2/t soda ash, indicated by the average 2005-2008 ETS data. This approach has allowed a full 1990-2016 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 2016 there is one plant producing bricks and ceramics in Ireland with an emission of 0.78 kt CO_2. Emission estimates for bricks and ceramics were prepared from the ETS data where one company provided estimates of emissions for the years 2005-2013 and 2015-2016, 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_2/tonne carbonate input. The emissions for the years prior to ETS are calculated from the companies' estimates of material use and their respective average ETS emission factors. Additional detailed information on raw material use, emissions and IEFs is available in Table 3.2.D in Annex 3.2.

4.2.4.3 Uncertainties and Time-series Consistency

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

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

4.2.4.4 Category-specific QA/QC and verification

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

4.2.4.5 Category-specific Recalculations

There 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 1990-2016 and are reported as Not Occurring (NO).

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

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

4.3.1 Ammonia Production (2.B.1)

4.3.1.1 Category Description

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

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

4.3.1.2 Methodological Issues

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

Primary steam reforming:

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

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

Secondary air reforming:

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

Overall reaction:

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

Ammonia synthesis:

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

Secondary reformer process gas shift conversion:

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

4.3.1.3 Uncertainties and Time-series Consistency

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

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

4.3.1.4 Category-specific QA/QC and verification

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

4.3.1.5 Category-specific Recalculations

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

4.3.1.6 Category-specific Planned Improvements

There are no planned improvements for this category.

4.3.2 Nitric Acid Production (2.B.2)

4.3.2.1 Category Description

Nitric acid is used as a raw material mainly in the manufacture of nitrogenous-based fertiliser. Nitric acid may also be used in the production of adipic acid and explosives (e.g., dynamite), for metal etching and in the processing of ferrous metals. During the production of nitric acid (HNO_3), nitrous oxide (N_2O) is generated as an unintended by-product of the high temperature catalytic oxidation of ammonia (NH_3).

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

4.3.2.2 Methodological Issues

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

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

4.3.2.3 Uncertainties and Time-series Consistency

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

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

4.3.2.4 Category-specific QA/QC and verification

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

4.3.2.5 Category-specific Recalculations

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

4.3.2.6 Category-specific Planned Improvements

There are no planned improvements for this category.

4.3.3 Adipic Acid Production (2.B.3)

This activity has not existed in Ireland during the time series 1990-2016. 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 1990-2016. 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 1990-2016. 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 1990-2016. 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 1990-2016. 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 1990-2016. 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 1990-2016. 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 1990-2016. This category is reported as Not Occurring (NO).

4.4 Emissions from Metal Industry (2.C)

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

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

4.4.1.1 Category Description

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

4.4.1.2 Methodological Issues

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

4.4.1.3 Uncertainties and Time-series Consistency

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

4.4.1.4 Category-specific QA/QC and verification

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

4.4.1.5 Category-specific Recalculations

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

4.4.1.6 Category-specific Planned Improvements

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

4.4.2 Ferroalloys Production (2.C.2)

This activity has not existed in Ireland during the timeseries 1990-2016. 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 1990-2016. 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 1990-2016. 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 1990-2016. 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 1990-2016. 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 1990-2016. 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 environmental way. A small proportion of lubricant oils oxidise during use, and CO_2 emissions from this category are reported in 2.D.1 Lubricant use.

4.5.1.2 Methodological Issues

Ireland uses a Tier 1 method to estimate emissions of CO_2 from non-energy use of lubricants based on equation 5.2 in the 2006 IPCC guidelines and an ODU (Oxidising During Use) default factor 0.2 from table 5.2 shown below. The national energy balance provides data on lubricant consumption for the full time series 1990-2016.The carbon content of lubricants value is 20.0 tonne carbon/TJ. Emissions of CO_2 estimated for this category are presented in Table 4.2.

Equation 5.2 Lubricants – Tier 1 Method

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

Where:

CO_2 Emissions = CO_2 emissions from lubricants, tonne CO_2

LC = total lubricant consumption, TJ

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

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

44/12 = mass ratio of CO_2/C

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 only minor recalculations in this source category. There were updates to the national energy balance, which resulted in the inclusion of a figure for 1990 and 1991 and a change of 35.97 kt CO_2e in 1990 and 24.81 kt CO_2e in 1991.

4.5.1.6 Category-specific Planned Improvements

The uncertainties associated with the source category will be reviewed for the next submission.

4.5.2 Paraffin Wax Use (2.D.2)

4.5.2.1 Category Description

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

4.5.2.2 Methodological Issues

Ireland uses a Tier 2 method to estimate emissions of CO_2 from non-energy use of paraffin wax based on equation 5.5 in the 2006 IPCC guidelines and an ODU (Oxidising During Use) factor 0.9 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 1990-2016. The carbon content of paraffin wax value is 20.0 tonne carbon/TJ. Emissions of CO_2 estimated for this category are presented in Table 4.2. CO_2 emissions estimated for this category are presented in Table 4.2.

Equation 5.5 Waxes – Tier 2 Method

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

Where:

CO_2 Emissions = CO_2 emissions from waxes, tonne CO_2

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

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

ODU_i = ODU factor for wax type i, fraction

44/12 = mass ratio of CO_2/C

4.5.2.3 Uncertainties and Time-series Consistency

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

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

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

Recalculations in this source category are the result of a slight revision to the AD. In previous submissions candle wax AD was subtracted from paraffin wax totals as it was assumed that the paraffin wax AD included candle wax. Correspondence with the national statistics agency revealed that it is not included and so should not be subtracted. The effect of this recalculation is an average increase of 2.47kt CO_2 (16.8 per cent) over the entire time series.

4.5.2.6 Category-specific Planned Improvements

There are no planned improvements for this category.

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

4.5.3.1 Category Description

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

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

4.5.3.2 Methodological Issues

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

4.5.3.3 Uncertainties and Time-series Consistency

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

4.5.3.4 Category-specific QA/QC and verification

Quality control checks have been 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.

4.5.3.5 Category-specific Recalculations

Recalculations in this source category are due to the disaggregation of indirect emissions between 2.D.3, 2.G.4 and 2.H.2. Indirect CO_2 emissions associated with these NMVOC emissions in 2.G.4 and 2.H.2 are reported under these categories in the 2018 submission.

4.5.3.6 Category-specific Planned Improvements

There are no planned improvements for this category.

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

4.5.4.1 Category Description

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

SCR technology was considered from Euro IV technologies in the previous submission and thus urea solution as an additive was estimated for different years according to the penetration of technologies from Euro IV onwards. 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 2002 onwards for Euro 3 vehicles.

4.5.4.2 Methodological Issues

The amount of CO_2 produced by urea solution in road transport was estimated using the COPERT 5 model which is a Tier 3 approach. In order to estimate CO_2 produced by urea solution, a share of 3 to 6 per cent urea additive of the fuel consumption for eligible vehicles categories (e.g. HDV) and a share of 76 per cent vehicles having SCR technologies of the eligible categories were applied in the model. The estimated CO_2 from the model output was then applied to the following equation (T2 Method, Chapter 3: Volume 2, IPCC, 2006) to calculate amount of urea solution.

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

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

4.5.4.3 Uncertainties and Time-series Consistency

As the CO_2 was estimated from a model using parameters based on assumptions, a 30 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

SCR technology was considered from Euro IV technologies in the previous submission and thus urea solution as an additive was estimated for different years according to the penetration of technologies from Euro IV onwards for different categories of vehicles in Ireland. 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 2002 onwards for Euro 3 vehicles.

4.5.4.6 Category-specific Planned Improvements

There are no planned improvements for this category.

4.6 Emissions from Electronics Industry (2.E)

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

4.6.1.1 Category Description

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

PFC emissions peaked in 2000 in Ireland after which they have gradually decreased. This is due to the economic downturn as well as the voluntary agreement implemented by the European Semiconductor Industry Association (ESIA, 2011) for the reduction of PFC emissions. NF_3 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_6 and NF_3 in their plants over the full time series 1990-2016.

4.6.1.3 Uncertainties and Time-series Consistency

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

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

4.6.1.4 Category-specific QA/QC and verification

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

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 1990-2016. 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 1990-2016. 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 1990-2016. 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 1990-2016. This category is reported as Not Occurring (NO).

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

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

- Refrigeration and air conditioning 2.F.1,
- Foam blowing agents 2.F.2,
- Fire protection 2.F.3,
- Aerosols 2.F.4,
- Solvents 2.F.5,
- Other applications 2.F.6.

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

Table 4.3. Emissions of HFC, PFC, SF_6 and NF_3 from IPPU 1990-2016 (kt CO_2 eq)

IPCC Source Category	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
2.F.1 Refrigeration and Air-Conditioning	NO	71.28	261.75	394.20	580.23	488.97	552.96	554.01	573.83	575.94	697.40	766.72	690.77	789.42
2.F.1 Mobile Air Conditioning	NO	4.25	47.54	122.34	167.05	188.25	199.72	208.61	212.65	205.84	206.33	210.74	218.85	232.47
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	16.99	18.31	19.63	32.36	32.38	32.39	32.41	32.42	32.44	32.45
2.F.4 Aerosols	7.23	25.35	88.62	99.58	90.29	95.87	89.61	82.70	82.44	81.36	80.98	80.65	79.79	81.49
2.F.4 Metered Dose Inhalers	NO	NO	36.29	45.10	47.00	49.78	49.47	50.13	50.75	50.27	49.50	49.83	50.43	52.12
2.E.1 Semiconductor manufacture	0.59	2.31	15.13	2.81	4.29	4.59	3.70	4.19	3.11	2.80	3.39	0.58	3.83	1.73
HFCs	**1.23**	**103.19**	**456.66**	**678.33**	**905.85**	**845.76**	**915.08**	**932.01**	**955.15**	**948.60**	**1,070.01**	**1,140.94**	**1,076.11**	**1,189.68**
2.E.1 Semiconductor manufacture	0.12	97.61	397.76	216.39	168.10	136.14	83.63	46.58	15.88	9.56	8.32	3.56	20.50	37.36
PFCs	**0.12**	**97.61**	**397.76**	**216.39**	**168.10**	**136.14**	**83.63**	**46.58**	**15.88**	**9.56**	**8.32**	**3.56**	**20.50**	**37.36**
2.E.1 Semiconductor manufacture	0.46	41.04	29.64	62.54	28.81	39.14	19.97	17.41	22.15	18.41	22.01	15.17	21.55	16.99
2.G.1 Electrical equipment	20.52	25.08	7.43	22.44	28.45	10.40	13.34	12.33	20.70	16.22	18.60	19.15	19.70	19.06
2.G.2 Other - window soundproofing	0.52	0.61	0.41	0.58	0.88	1.03	1.18	1.33	1.48	1.63	1.78	1.94	2.09	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	10.47	4.04	3.37	2.05	1.26	0.36	0.37	0.37	0.38	0.39	0.40
2.G.2 Other - gas-air tracers	11.63	11.63	11.63	0.00	0.00	0.00	1.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SF_6	**33.88**	**79.11**	**51.76**	**96.78**	**62.94**	**54.69**	**39.18**	**33.09**	**45.45**	**37.39**	**43.53**	**37.40**	**44.49**	**39.30**
2.E.1 Semiconductor manufacture	NO	4.37	49.17	28.38	37.67	0.00	0.00	0.00	0.00	0.78	0.90	0.96	0.96	0.96
NF_3	**NO**	**4.37**	**49.17**	**28.38**	**37.67**	**0.00**	**0.00**	**0.00**	**0.00**	**0.78**	**0.90**	**0.96**	**0.96**	**0.96**
HFC, PFC, SF_6 and NF_3	35.23	284.29	955.35	1,019.88	1,174.56	1,036.58	1,037.89	1,011.69	1,016.48	996.33	1,122.77	1,182.87	1,142.06	1,267.30

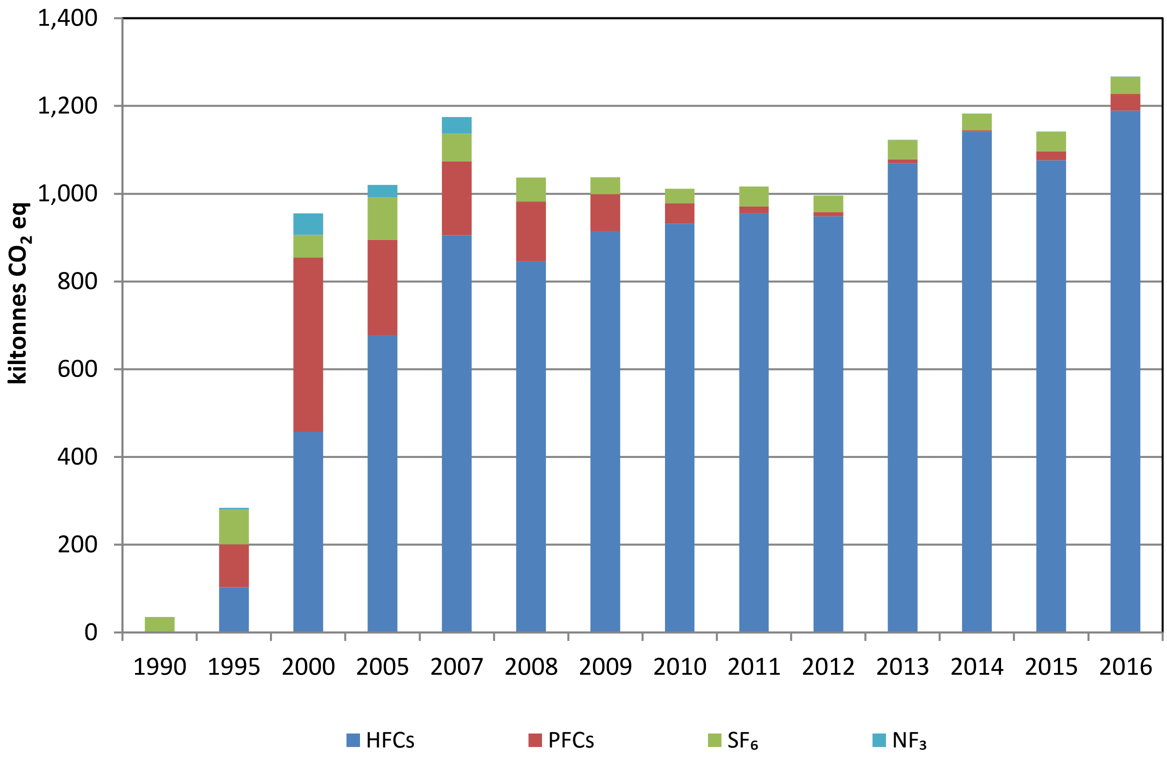

Figure 4.3 Emissions of HFC, PFC, SF_6 and NF_3

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 (2016) and the trend assessment (1990-2016). 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 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*.

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).

4.7.1.3 Uncertainties and Time-series Consistency

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

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

4.7.1.4 Category-specific QA/QC and verification

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

4.7.1.5 Category-specific Recalculations

No significant recalculations were applied to this source category for this submission.

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 this category are reported as not occurring (NO).

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 a number of 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. The majority of 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, but this activity has not yet taken place in Ireland.

4.7.3.3 Uncertainties and Time-series Consistency

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

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

4.7.3.4 Category-specific QA/QC and verification

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

4.7.3.5 Category-specific Recalculations

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

4.7.3.6 Category-specific Planned Improvements

There are no planned improvements for this category.

4.7.4 Aerosols (2.F.4)

4.7.4.1 Category Description

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

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

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

4.7.4.2 Methodological Issues

Emission estimates for Metered Dose Inhalers (MDI) 2.F.4.a are made on the basis of 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_6 emissions. The uncertainty of the activity data and the uncertainty of the emission factor were obtained from these studies.

4.7.4.4 Category-specific QA/QC and verification

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

4.7.4.5 Category-specific Recalculations

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

4.7.4.6 Category-specific Planned Improvements

There are no planned improvements for this category.

4.7.5 Solvents (2.F.5)

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

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

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

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

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

- Electric equipment 2.G.1,
- SF_6 and PFCs from other product use 2.G.2,
    1. Soundproof windows 2.G.2.c,
    2. Adiabatic properties: shoes and tyres 2.G.2.d,
    3. Other-Medical Applications and Tracer in Leak Detection 2.G.2.e,
- N_2O from Product Uses,
    1. Medical Application 2.G.3.a,
    2. Propellant for pressure and aerosol products 2.G.3.b

4.8.1 Electrical Equipment (2.G.1)

4.8.1.1 Category Description

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

Electrical equipment containing SF_6 is imported into Ireland. Quantities of SF_6 are needed for servicing and repair of existing equipment. There are, therefore, no manufacturing emissions.

Significant reduction in emissions in the years 2008 to 2010 are attributed to the network operators investment in staff training, leak detection equipment and closed cycle SF_6 handling equipment. This resulted in 3 year rolling average losses. 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 1 approach based on an analysis of opening and closing stocks of SF_6. The inventory estimates assume that the usage of SF_6 in equipment maintenance for one year is equal to the leakage emissions from electrical equipment in the same year. This method was reviewed by the project team and deemed to be acceptable and in line with IPCC GPG (IPCC, 2000).

The company supplies an estimate of SF_6 emissions from their equipment maintenance operations to the inventory agency on a yearly basis. Those annual SF_6 usage returns include:

- The number of cylinders that are booked out for each year;
- Cylinder size: 40kg, 63kg and 5kg;
- Assumption that for the 40kg and 63kg cylinders, 60 per cent of the contained SF_6 is used for maintenance and the remaining 40 per cent is either unused or used for new works and thus not related to leakage emissions;
- Assumptions that one third of the SF_6 in the smaller cylinders (5kg) is used for maintenance whilst the remaining quantity is used for new works.

4.8.1.3 Uncertainties and Time-series Consistency

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

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

4.8.1.4 Category-specific QA/QC and verification

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

4.8.1.5 Category-specific Recalculations

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

4.8.1.6 Category-specific Planned Improvements

There are no planned improvements for this category.

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

4.8.2.1 Category Description

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

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

- **Tracer in Leak Detection 2.G.2.e**–SF_6 has been used as a tracer gas for leak detection and in agricultural research as a tracer gas to determine the rates of methane emissions from enteric fermentation in cattle.

4.8.2.2 Methodological Issues

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

A 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_6 remaining inside the window at the end of life is emitted, because to-date no recovery process exists.

There is no specific information available in relation to the use of SF_6 in *Adiabatic properties 2.G.2.d* (sports goods, shoes) in Ireland, so a population-proxy is used to estimate emissions based on UK inventory data for the release of SF_6 upon disposal of sporting goods, as the market share of such products is assumed to be similar to that in the UK.

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

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

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

4.8.2.3 Uncertainties and Time-series Consistency

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

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

4.8.2.4 Category-specific QA/QC and verification

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

4.8.2.5 Category-specific Recalculations

There are no 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_2O from Product Use (2.G.3)

4.8.3.1 Category Description

Evaporative/fugitive emissions of nitrous oxide (N_2O) can arise from various types of product use, including;

- Medical applications (anaesthetic use, analgesic use and veterinary use);
- Use as a propellant in aerosol products, primarily in food industry (pressure-packaged whipped cream, etc.);
- Oxidising agent and etchant used in semiconductor manufacturing;
- Oxidising agent used, with acetylene, in atomic absorption spectrometry;
- Production of sodium azide, which is used to inflate airbags;
- Fuel oxidant in auto racing; and
- Oxidising agent in blowtorches used by jewellers and others.

In general, medical applications and use as a propellant in aerosol products are likely to be larger sources than others.

The use of N_2O as an anaesthetic in hospitals is a source of emissions and has been estimated in this submission. Emission estimates for *Medical applications 2.G.3.*a are presented in Table 4.2.

Ireland is unable to estimate emissions for 2.G.3.b due to the lack of data on N_2O from propellant use in aerosol products. Ireland does not estimate N_2O emissions from propellant use for pressure and aerosol products and reports this category as not estimated (NE), considered insignificant. Ireland considers the likely level of emissions of N_2O to be below 0.05 per cent of national total emissions, 30.77 kt CO_2 equivalent. This equates to less than 21.7 g of N_2O from products per capita per annum.

4.8.3.2 Methodological Issues

In absence of methodologies or emission factors in the existing guidelines, population-based activity data has been developed with assumed usage of 30 grams of N_2O per capita per year and emission factor of 1 (as all used gas is emitted into the atmosphere). This assumption is similar to that of other Annex I Parties that estimate emissions from this category.

4.8.3.3 Uncertainties and Time-series Consistency

The uncertainties applicable to category N_2O from Product Use are provided in Annex 2. The emission time series for 1990–2016 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

Ireland will investigate further to try and source activity data for propellant for pressure and aerosol products to estimate N_2O emissions in its next annual submission.

4.8.4 Other – Other Product Manufacture and Use (2.G.4)

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

4.8.4.1 Methodological Issues

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

4.8.4.2 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 in this category for the first time in this report. NMVOCs are indirect greenhouse gases which result from various activities in the food and beverage industry including;

- Bread baking
- Beer production
- Spirit production
- Meat, fish etc, frying and curing
- Coffee roasting
- Animal Feedstock

The indirect CO_2 emissions associated with these NMVOC emissions are reported under this category. Previously, these estimates were reported in CRF Table 6 and included in Ireland's national total, without LULUCF with indirect.

4.9.1.1 Methodological Issues

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

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

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 (1990-2015)

2017 Submission		**Gases**	**Units**	**1990**	**1995**	**2000**	**2005**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
2.A.1	Cement Production	CO_2	kt CO_2eq	884.00	879.00	1700.90	2357.06	2374.06	2106.73	1326.78	1105.11	966.27	1177.02	1111.75	1461.12	1652.01
2.A.2	Lime Production	CO_2	kt CO_2eq	214.08	187.51	190.43	183.48	199.08	189.32	157.22	193.38	200.54	215.86	189.64	188.98	177.35
2.A.3	Glass Production	CO_2	kt CO_2eq	13.33	11.97	10.71	0.48	0.45	0.31	0.02	NO	NO	NO	NO	NO	NO
2.A.4	Other Process Uses of Carbonates	CO_2	kt CO_2eq	5.32	5.71	6.73	11.78	9.21	6.75	2.13	1.52	1.94	0.56	0.31	0.35	1.00
2.B.1	Ammonia Production	CO_2	kt CO_2eq	990.23	973.44	882.30	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.B.2	Nitric Acid Production	N_2O	kt CO_2eq	995.32	781.00	781.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.C.1	Iron and Steel Production	CO_2	kt CO_2eq	26.08	24.80	28.80	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.D.1	Lubricant Use	CO_2	kt CO_2eq	0.00	11.78	70.08	59.54	23.57	20.47	22.39	16.82	18.73	18.28	19.08	19.84	20.44
2.D.2	Paraffin Wax Use	CO_2	kt CO_2eq	5.09	7.53	13.05	26.14	25.27	19.07	18.86	17.46	17.54	15.15	17.30	17.53	17.69
2.D.3	Other Solvent Use	Indirect CO_2	kt CO_2eq	72.15	74.43	69.50	73.61	82.00	76.03	72.39	71.74	69.72	70.87	73.72	76.12	80.25
2.D.3	Urea as Catalyst	CO_2	kt CO_2eq	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.27	0.48	1.10	2.28	2.39
2.E.1	Integrated Circuit or Semiconductor	HFCs, PFCS, SF_6, NF_3	kt CO_2eq	1.17	145.33	491.70	310.12	238.87	179.86	107.30	68.19	41.13	31.55	34.63	20.27	46.84
2.F.1	Refrigeration and Air Conditioning	HFCs	kt CO_2eq	0.00	75.54	309.29	516.62	747.34	677.22	752.69	762.63	786.50	781.79	903.74	989.09	909.62
2.F.3	Fire Protection	HFCs	kt CO_2eq	NO	NO	7.33	14.30	16.99	18.31	19.63	32.36	32.38	32.39	32.41	32.42	32.44
2.F.4	Aerosols	HFCs	kt CO_2eq	0.64	25.35	124.91	144.68	137.29	145.64	139.08	132.83	133.18	131.63	130.48	130.48	130.91
2.G.1	Electrical Equipment	SF_6	kt CO_2eq	20.52	25.08	7.43	22.44	28.45	10.40	13.34	12.33	20.70	16.22	18.60	19.15	19.70
2.G.2	SF_6 and PFCs from Other Product Uses	NF_3	kt CO_2eq	12.90	12.99	14.69	11.81	5.68	5.15	5.87	3.35	2.61	2.76	2.92	3.08	3.24
2.G.3	N_2O from Product Uses	N_2O	kt CO_2eq	31.34	32.20	33.88	36.96	39.12	40.10	40.53	40.72	40.90	40.99	41.06	41.21	41.44
2.G.4	Other Solvent and product use	Indirect CO_2	kt CO_2eq	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
2.H.2	Food and beverages industry	Indirect CO_2	kt CO_2eq	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
Total IPPU (including Indirect CO_2)			**kt CO_2eq**	**3272.17**	**3273.64**	**4742.75**	**3769.00**	**3927.37**	**3495.36**	**2678.21**	**2458.49**	**2332.39**	**2535.56**	**2576.73**	**3001.92**	**3135.31**
2018 Submission																
2.A.1	Cement Production	CO_2	kt CO_2eq	884.00	879.00	1700.90	2357.06	2374.06	2106.73	1326.78	1105.11	966.27	1177.02	1111.75	1461.12	1652.01
2.A.2	Lime Production	CO_2	kt CO_2eq	214.08	187.51	190.43	183.48	199.08	187.80	157.22	193.38	200.54	215.86	189.64	188.98	177.35
2.A.3	Glass Production	CO_2	kt CO_2eq	13.33	11.97	10.71	0.48	0.45	0.31	0.02	NO	NO	NO	NO	NO	NO
2.A.4	Other Process Uses of Carbonates	CO_2	kt CO_2eq	5.32	5.71	6.73	11.78	9.21	6.75	2.13	1.52	1.94	0.56	0.31	0.35	1.00
2.B.1	Ammonia Production	CO_2	kt CO_2eq	990.23	973.44	882.30	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.B.2	Nitric Acid Production	N_2O	kt CO_2eq	995.32	781.00	781.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.C.1	Iron and Steel Production	CO_2	kt CO_2eq	26.08	24.80	28.80	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.D.1	Lubricant Use	CO_2	kt CO_2eq	35.97	11.78	70.08	59.54	23.57	20.47	22.39	16.82	18.73	18.28	19.08	19.84	20.35
2.D.2	Paraffin Wax Use	CO_2	kt CO_2eq	5.87	8.19	14.71	32.37	30.18	22.16	22.32	20.36	19.94	18.48	20.80	18.83	22.51
2.D.3	Other Solvent Use	Indirect CO_2	kt CO_2eq	51.41	52.40	47.54	50.81	59.24	51.63	48.09	43.07	42.44	41.05	40.54	42.06	40.75
2.D.3	Urea as Catalyst	CO_2	kt CO_2eq	0.00	0.00	0.00	1.04	3.88	4.36	4.06	3.84	4.05	4.05	4.68	6.05	7.60
2.E.1	Integrated Circuit or Semiconductor	HFCs, PFCS, SF_6, NF_3	kt CO_2eq	1.17	145.33	491.70	310.12	238.87	179.86	107.30	68.19	41.13	31.55	34.63	20.27	46.84
2.F.1	Refrigeration and Air Conditioning	HFCs	kt CO_2eq	0.00	75.54	309.29	516.54	747.28	677.21	752.68	762.62	786.48	781.78	903.73	977.47	909.62
2.F.3	Fire Protection	HFCs	kt CO_2eq	NO	NO	7.33	14.30	16.99	18.31	19.63	32.36	32.38	32.39	32.41	32.42	32.44
2.F.4	Aerosols	HFCs	kt CO_2eq	0.64	25.35	124.91	144.68	137.29	145.64	139.08	132.83	133.18	131.63	130.48	130.48	130.22
2.G.1	Electrical Equipment	SF_6	kt CO_2eq	20.52	25.08	7.43	22.44	28.45	10.40	13.34	12.33	20.70	16.22	18.60	19.15	19.70
2.G.2	SF_6 and PFCs from Other Product Uses	NF_3	kt CO_2eq	12.90	12.99	14.69	11.81	5.68	5.15	5.87	3.35	2.61	2.76	2.92	3.08	3.24
2.G.3	N_2O from Product Uses	N_2O	kt CO_2eq	31.34	32.20	33.88	36.96	39.12	40.10	40.53	40.72	40.90	40.99	41.06	41.21	41.44
2.G.4	Other Solvent and product use	Indirect CO_2	kt CO_2eq	0.07	0.08	0.09	0.07	0.07	0.06	0.06	0.05	0.05	0.05	0.04	0.04	0.04
2.H.2	Food and beverages industry	Indirect CO_2	kt CO_2eq	21.16	22.47	21.30	30.93	31.47	31.53	34.99	39.71	40.01	44.91	49.48	41.87	44.09
Total IPPU (including Indirect CO_2)			**kt CO_2eq**	**3272.17**	**3309.41**	**3274.83**	**4743.83**	**3784.38**	**3944.88**	**3508.48**	**2696.46**	**2476.27**	**2351.35**	**2557.58**	**2600.15**	**3003.21**

Table 4.4(b) Absolute and relative recalculations in the IPPU Sector (1990-2015)

Absolute change		Gases	Units	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015
2.A.1	Cement Production	CO_2	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-
2.A.2	Lime Production	CO_2	kt CO_2eq	-	-	-	-	-	-1.53	-	-	-	-	-	-	-
2.A.3	Glass Production	CO_2	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-
2.A.4	Other Process Uses of Carbonates	CO_2	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-
2.B.1	Ammonia Production	CO_2	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-
2.B.2	Nitric Acid Production	N_2O	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-
2.C.1	Iron and Steel Production	CO_2	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-
2.D.1	Lubricant Use	CO_2	kt CO_2eq	35.97	-	-	-	-	-	-	-	-	-	-	-	-0.09
2.D.2	Paraffin Wax Use	CO_2	kt CO_2eq	0.78	0.67	1.65	6.23	4.91	3.09	3.45	2.91	2.40	3.33	3.50	1.30	4.82
2.D.3	Other Solvent Use	Indirect CO_2	kt CO_2eq	-20.75	-22.04	-21.96	-22.80	-22.76	-24.40	-24.30	-28.67	-27.28	-29.82	-33.18	-34.07	-39.50
2.D.3	Urea as Catalyst	CO_2	kt CO_2eq	-	-	-	1.04	3.88	4.36	4.06	3.79	3.79	3.56	3.58	3.77	5.22
2.E.1	Integrated Circuit or Semiconductor	HFCs, PFCS, SF_6, NF_3	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-
2.F.1	Refrigeration and Air Conditioning	HFCs	kt CO_2eq	-	-	-	-0.08	-0.06	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-11.62	-0.00
2.F.3	Fire Protection	HFCs	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-
2.F.4	Aerosols	HFCs	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-0.69
2.G.1	Electrical Equipment	SF_6	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-
2.G.2	SF_6 and PFCs from Other Product Uses	NF_3	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-
2.G.3	N_2O from Product Uses	N_2O	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-
2.G.4	Other Solvent and product use	Indirect CO_2	kt CO_2eq	0.07	0.08	0.09	0.07	0.07	0.06	0.06	0.05	0.05	0.05	0.04	0.04	0.04
2.H.2	Food and beverages industry	Indirect CO_2	kt CO_2eq	21.16	22.47	21.30	30.93	31.47	31.53	34.99	39.71	40.01	44.91	49.48	41.87	44.09
Total IPPU (including Indirect CO_2)			**kt CO_2eq**	**37.24**	**1.19**	**1.08**	**15.38**	**17.51**	**13.12**	**18.25**	**17.78**	**18.95**	**22.02**	**23.43**	**1.29**	**13.90**
Relative change																
2.A.1	Cement Production	CO_2	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-
2.A.2	Lime Production	CO_2	kt CO_2eq	-	-	-	-	-	-0.8%	-	-	-	-	-	-	-
2.A.3	Glass Production	CO_2	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-
2.A.4	Other Process Uses of Carbonates	CO_2	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-
2.B.1	Ammonia Production	CO_2	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-
2.B.2	Nitric Acid Production	N_2O	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-
2.C.1	Iron and Steel Production	CO_2	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-
2.D.1	Lubricant Use	CO_2	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-0.5%
2.D.2	Paraffin Wax Use	CO_2	kt CO_2eq	15.3%	8.9%	12.6%	23.8%	19.4%	16.2%	18.3%	16.6%	13.7%	22.0%	20.2%	7.4%	27.2%
2.D.3	Other Solvent Use	Indirect CO_2	kt CO_2eq	-28.8%	-29.6%	-31.6%	-31.0%	-27.8%	-32.1%	-33.6%	-40.0%	-39.1%	-42.1%	-45.0%	-44.8%	-49.2%
2.D.3	Urea as Catalyst	CO_2	kt CO_2eq	-	-	-	-	-	-	-	7,764.5%	1,418.8%	738.2%	325.9%	165.7%	218.5%
2.E.1	Integrated Circuit or Semiconductor	HFCs, PFCS, SF_6, NF_3	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-
2.F.1	Refrigeration and Air Conditioning	HFCs	kt CO_2eq	-	-	-	-0.0%	-0.0%	-0.0%	-0.0%	-0.0%	-0.0%	-0.0%	-0.0%	-1.2%	-0.0%
2.F.3	Fire Protection	HFCs	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-
2.F.4	Aerosols	HFCs	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-0.5%
2.G.1	Electrical Equipment	SF_6	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-
2.G.2	SF_6 and PFCs from Other Product Uses	NF_3	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-
2.G.3	N_2O from Product Uses	N_2O	kt CO_2eq	-	-	-	-	-	-	-	-	-	-	-	-	-
2.G.4	Other Solvent and product use	Indirect CO_2	kt CO_2eq	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.H.2	Food and beverages industry	Indirect CO_2	kt CO_2eq	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Total IPPU (including Indirect CO_2)			**kt CO_2eq**	**1.1%**	**0.0%**	**0.0%**	**0.4%**	**0.4%**	**0.4%**	**0.7%**	**0.7%**	**0.8%**	**0.9%**	**0.9%**	**0.0%**	**0.4%**

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 eight key categories in this sector:

- ***3.A.1 Enteric Fermentation, Dairy Cattle*** (Level)
- ***3.A.1 Enteric Fermentation, Non-Dairy Cattle*** (Trend and Level)
- ***3.A.2 Enteric Fermentation, Sheep*** (Trend and Level)
- ***3.B.1.1 Manure Management (CH_4), Cattle*** (Level)
- ***3.D.1 Direct Soil Emissions*** (Trend and Level)
- ***3.D.2 Indirect Soil Emissions*** (Level)
- ***3.G Liming*** (Trend and 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_4), Sheep***
- ***3.B.1.3 Manure Management (CH_4), Swine***
- ***3.B.1.4 Manure Management (CH_4), Other Livestock***
- ***3.B.2.1 Manure Management (N_2O), Cattle***
- ***3.B.2.2 Manure Management (N_2O), Sheep***
- ***3.B.2.3 Manure Management (N_2O), Swine***
- ***3.B.2.4 Manure Management (N_2O), Other Livestock***
- ***3.B.2.5 Manure Management (N_2O), Indirect N_2O 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 increased by 15.5 per cent between 1990-2016.

- ***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, and contributed 65.7 per cent of agricultural emissions in 2016.

The 2018 submission shows total GHG emissions of 19,250.82 kt CO_2 equivalent in the *Agriculture* sector in 2016, of which *3.A Enteric Fermentation* accounts for 58.4 per cent *3.D Agricultural Soils* 29.1 per cent, *3.B Manure Management* 10.1 per cent, *3.G Liming* 2.2 per cent, and *3.H Urea Application* 0.2 per cent. The latest estimates show that emissions in the *Agriculture* sector have decreased by 1.4 per cent from 1990 to 2016 mainly due to a 1.0 per cent decrease in CH_4 emissions from *3.A Enteric Fermentation* and 4.3 per cent decrease in N_2O emissions from *3.D Agricultural Soils*.

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.

Table 5.1 Level 3 Source Methodology for Agriculture

3. Agriculture	CO_2	CH_4	N_2O
A. Enteric Fermentation			
1. Cattle*	NA	T2*	NA
2. Sheep*	NA	T1*	NA
3. Swine	NA	T1	NA
4. Other Livestock	NA	T1	NA
B. Manure Management			
1. Cattle*	NA	T2*	T1
2. Sheep	NA	T1	T2
3. Swine	NA	T1	T2
4. Other Livestock	NA	T1	T2
5. Indirect N_2O emissions*	NA	NA	T2*
C. Rice Cultivation	NO	NO	NO
D. Agricultural Soils			
1. Direct N_2O from Managed Soils*	NA	NA	T1*
2. Indirect N_2O from Managed Soils*	NA	NA	T1*
E. Prescribed Burning of Savannas	NO	NO	NO
F. Field Burning of Agricultural Residues	NO	NA	NA
G. Liming*	T1*	NO	NO
H. Urea Application	T1	NO	NO
I. Other Carbon-containing fertilisers	NA	NO	NO
J. Other	NO	NO	NO

* Key Category.

T1,2,3: Tier 1, Tier 2, Tier 3 as described in the 2006 IPCC Guidelines; NE : emissions not estimated; NO : activity not occurring; NA : not applicable (no emissions of the gas occur in the source category); IE : emissions included elsewhere.

There is extensive and up-to-date statistical data on all aspects of the agriculture sector in Ireland. The majority of this data 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, agriculture researchers, DAFM and CSO, which grew out of the improved inventory methodologies for both CH_4, N_2O and NH_3. 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.

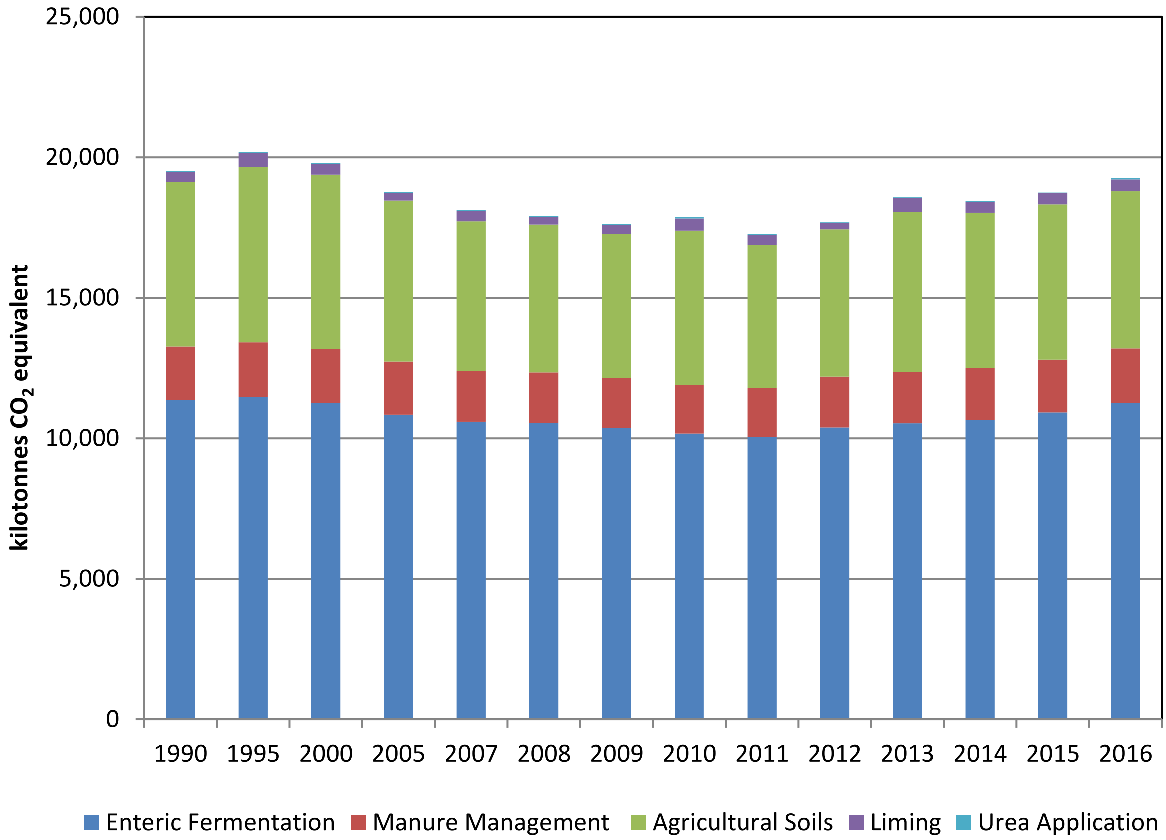

Figure 5.1 Total Emissions from Agriculture by Sector, 1990-2016

Table 5.2 Emissions from Agriculture 1990-2016

		Gas	Unit	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
3.A.1	**Cattle**	**CH_4**	**kt CO_2eq**	10101.4	10190.7	10049.7	9839.8	9709.4	9721.7	9602.2	9420.2	9290.1	9578.1	9736.8	9864.0	10144.5	10478.8
3.A.2	**Sheep**	**CH_4**	**kt CO_2eq**	1176.3	1195.2	1114.4	904.7	778.8	716.1	666.7	637.3	650.6	695.1	696.4	694.2	683.1	670.6
3.A.3	**Swine**	**CH_4**	**kt CO_2eq**	41.4	52.0	56.9	55.2	51.1	50.1	48.9	51.1	51.8	51.3	50.0	50.7	50.1	52.2
3.A.4	**Other livestock**	**CH_4**	**kt CO_2eq**	37.9	42.3	39.8	43.4	47.7	51.2	52.2	53.5	52.7	54.8	49.6	47.0	46.0	45.6
3.B.1	**Cattle**	**CH_4**	**kt CO_2eq**	1038.8	1004.8	949.1	924.6	910.4	916.8	904.1	879.3	869.6	908.1	917.6	923.3	950.5	985.1
3.B.1	**Cattle**	**N_2O**	**kt CO_2eq**	263.8	273.8	274.3	281.6	273.7	276.6	273.2	259.9	256.2	272.6	276.5	271.8	276.8	288.9
3.B.2	**Sheep**	**CH_4**	**kt CO_2eq**	99.2	103.7	98.7	79.8	69.8	63.3	58.6	54.0	55.3	60.3	60.9	62.0	60.2	59.5
3.B.2	**Sheep**	**N_2O**	**kt CO_2eq**	22.7	23.1	23.1	19.8	16.8	15.6	14.6	14.4	14.6	15.3	15.2	15.0	14.8	14.8
3.B.3	**Swine**	**CH_4**	**kt CO_2eq**	206.5	258.6	292.4	284.5	259.2	245.9	238.0	249.1	257.4	253.7	253.6	256.7	250.6	260.4
3.B.3	**Swine**	**N_2O**	**kt CO_2eq**	10.1	12.5	13.6	13.2	12.2	11.9	11.6	12.1	12.2	12.0	11.8	12.0	11.8	12.3
3.B.4	**Other livestock**	**CH_4**	**kt CO_2eq**	61.6	50.2	54.9	64.1	60.6	61.1	69.1	69.3	69.7	81.3	85.3	87.6	95.8	97.3
3.B.4	**Other livestock**	**N_2O**	**kt CO_2eq**	11.2	10.6	10.5	11.4	11.4	11.8	12.6	12.8	12.8	13.6	12.9	12.9	13.1	13.1
3.B.5	**Indirect N2O emissions**	**N_2O**	**kt CO_2eq**	190.8	199.9	200.7	202.8	195.4	195.5	193.3	188.7	188.3	197.0	198.4	198.9	203.7	212.0
3.D.1	**Direct N2O Emissions From Managed Soils**	**N_2O**	**kt CO_2eq**	5296.1	5657.0	5627.4	5200.5	4821.5	4765.7	4627.4	4973.6	4613.6	4754.7	5167.7	5019.3	5006.5	5062.9
3.D.2	**Indirect N2O Emissions from Managed Soils**	**N_2O**	**kt CO_2eq**	557.2	582.1	578.3	533.7	497.0	502.5	503.8	516.7	479.3	482.7	511.7	507.3	515.5	536.0
3.G.1	**Limestone CaCO3**	**CO_2**	**kt**	355.0	494.6	366.4	266.7	376.8	262.2	307.3	427.9	360.7	229.4	515.7	382.3	392.5	425.6
3.H	**Urea Application**	**CO_2**	**kt**	44.5	39.7	42.2	27.9	23.4	30.8	40.9	45.2	32.3	21.3	21.7	25.1	28.3	35.8
3	**Total Agriculture**		**kt CO_2eq**	**19514.4**	**20190.6**	**19792.6**	**18753.7**	**18115.1**	**17898.6**	**17624.4**	**17865.3**	**17267.2**	**17681.2**	**18581.7**	**18430.1**	**18743.9**	**19250.8**

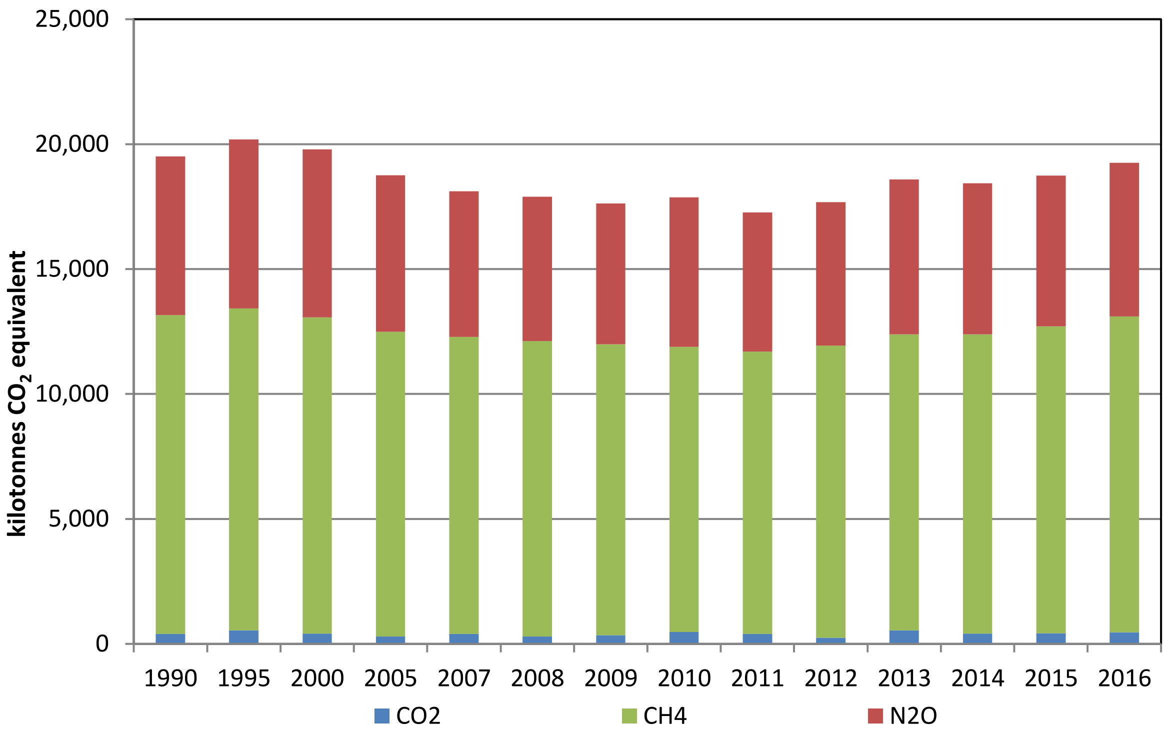

Figure 5.2 Total Emissions from Agriculture by Gas, 1990-2016

5.2 Emissions from livestock (3.1)

The two IPCC Level 2 emission source categories under *3.1 Livestock* in 2016 are *3.A Enteric Fermentation* and *3.B Manure Management.* Total emissions from these activities amounted to 13,190.57 kt CO_2eq in 2016.

Two large research projects have greatly contributed to improving the estimation of emissions from enteric fermentation and manure management in Ireland:

- O'Mara (2007), Development of emission factors for the Irish Cattle Herd
- Hyde et al. (2008), an extensive Farm Facilities (Manure Management) Survey.

This research, along with other relevant work related to the development of a nitrogen-flow approach to NH_3 emissions as outlined in the EMEPA/EEA Emission Inventory Guidebook (EMEP/EEA, 2013, 2016), 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

- 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 2015 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 11,247.27 kt CO_2eq in 2016.

5.2.1.1 Enteric Fermentation, Cattle (3.A.1)

5.2.1.1.1 Category Description

Methane is produced in herbivores as a by-product of enteric fermentation, a digestive process by which carbohydrates are broken down by micro-organisms into simple molecules for absorption into the bloodstream. The amount of methane that is released depends on the type of digestive tract, age, and weight of the animal, and the quality and quantity of the feed consumed. Ruminant livestock (e.g., cattle, sheep) are major sources of methane with moderate amounts produced from non-ruminant livestock (e.g., pigs, horses).

Enteric fermentation from cattle is both a trend and level key category of CH_4 in Ireland.

5.2.1.1.2 Methodological Issues

The Tier 2 approach in the 2006 IPCC Guidelines is used for *Enteric Fermentation, Cattle.* The Tier 2 approach has been used for 1990 and for the years 2003 to 2016. Interpolation has been used to complete the time series.

In the Tier 2 approach, the Irish cattle herd is characterised by 11 principal animal classifications as shown in Table 5.3 for which annual census data are provided by the CSO. In-depth analysis of production systems and the associated animal feed and energy requirements is conducted for all categories within the Irish cattle population to determine CH_4 production. Substantial further subdivision is incorporated for dairy and beef cattle to adequately describe the wide range of cattle rearing and finishing systems applicable in Ireland. In total, dairy cows are covered by 12 systems and 18 system types are analysed for suckler cows, while up to 30 systems are examined for both male and female beef cattle (O'Mara, 2006).

Table 5.3 Animal Classifications for Cattle Population

Cattle Type	**Classification**		
Breeding cattle	Dairy cows	Suckler (Beef) cows	
Beef cattle	Male < 1 year Female < 1 year	Male 1 – 2 years Female 1 – 2 years	Male > 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)

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). 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[1].

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_l). This international energy system, which is well established and used locally in Ireland, is considered more appropriate to the local conditions than the system and equations used by the 2006 IPCC guidelines. The energy gains and losses refer to intra-annual changes for the animal and do not mean that average body weight for animals in the dairy herd is increasing from year to year. The live-weight of 535 kg for dairy cows is an indicative weight supplied by the DAFM, as dairy cow live-weights are not in general monitored on farms. The live-weight is adopted as the reference point for the annual emission factor derivation for the herd and is chosen to be consistent with other parameters relevant to the estimation of emissions from cattle, e.g. manure production.

The important equations contained within the approach are:

Maintenance NE_l requirements (MJ) = 9.96 + (0.6 x LW/100), where LW is live-weight. A 10 per cent activity allowance was added for the housed period and a 20 per cent allowance was added for the grazing period as outlined by INRA (1989);

NE_l (MJ) required per kg milk = 0.376 * fat content + 0.209 * protein content + 0.948;

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

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

[1] 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.

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 three-year lifetime (O'Mara 2007).

Important parameters such as housing dates (O'Mara, 2006 and Hyde et al., 2008), turnout dates (O'Mara, 2006 and Hyde et al., 2008) 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). 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 animals lifetime using the INRAtion computer programme, version 3.0. This programme was devised by the French research organisation Institute National de la Recherche Agronomique (INRA) and is based on the net energy system for cattle. In version 3 of INRAtion, some adaptation for Irish conditions was made to the equations for estimating the energy requirements of growing and finishing animals (O'Mara, 1997, Crowley, 2001 and Crowley *et al*, 2002). Net energy requirements of growing beef cattle are defined in terms of UFL, as in the case of dairy cattle, while for finishing cattle, net energy requirements are defined in terms of UFV (from the French *unité fourragère viande*) where 1 UFV is the net energy value of 1 kg of barley for meat production and is equal to 7.61 MJ NE_{mg}.

The composition of the diet in each system is described by grazing season and winter housing period and daily intake is calculated by reference to the daily energy requirement. The concentrate allowance is fixed while forage intake is varied according to energy requirements. The Irish modifications to the INRAtion programme were predominantly for animals at weanling and finishing stages (i.e. at times that concentrates were likely to be fed). No modifications were made for 'heavy' growing animals, (typically animals in their second grazing season or later that were not being finished). For animals in these stages, intakes were adjusted as appropriate by expert opinion. 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). 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 data thereafter. Female beef cattle in the category 1-2 years old are assumed to be slaughtered on 3rd February of their third year (O'Mara, 2006). Adjustment for the slightly longer period is not made in respect of in-calf heifers, as they are carrying a calf in addition to normal growth which is reflected in the calculation methodology.

Table 5.4 Tier 2 CH_4 Enteric Fermentation Emission Factors for 1990 to 2016

	Enteric Fermentation (kg/head/year)													
	1990	**1995**	**2000**	**2005**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Dairy cows	101.38	104.10	106.82	111.32	111.29	109.93	108.37	112.65	112.89	110.43	111.12	110.85	113.43	112.31
Suckler cows	74.03	74.09	74.16	75.47	73.22	74.92	72.78	72.95	74.07	75.53	73.12	73.71	74.75	74.30
Male cattle < 1 year	30.46	30.09	29.73	29.74	29.69	29.71	29.77	29.11	29.82	30.15	30.26	30.01	30.07	30.40
Male cattle 1 - 2 years	62.22	61.55	60.89	58.94	59.19	59.07	58.57	59.96	58.01	56.63	56.20	57.94	57.60	56.01
Male cattle > 2 years	55.08	47.01	38.95	37.67	38.58	36.98	38.84	39.79	38.29	37.25	37.32	36.40	36.54	35.46
Female cattle < 1 year	27.05	27.34	27.63	27.74	27.61	27.60	27.57	27.55	27.60	27.70	27.73	27.59	27.70	27.76
Female cattle 1 - 2 years	53.54	50.10	46.67	45.61	46.60	47.00	47.71	48.62	47.93	47.99	48.08	49.47	49.09	48.85
Female cattle > 2 years	21.65	21.96	22.27	22.43	22.42	22.55	22.63	22.63	22.72	22.73	22.64	22.48	22.35	22.28
Bulls for breeding	86.38	84.52	82.66	81.55	81.55	81.55	81.55	81.55	81.55	81.55	81.55	81.55	81.55	81.55
Dairy in-calf heifers	51.82	51.18	50.55	50.16	50.16	50.16	50.16	50.16	50.16	50.16	50.16	50.16	50.16	50.16
Beef in-calf heifers	55.42	54.75	54.08	53.68	53.68	53.68	53.68	53.68	53.68	53.68	53.68	53.68	53.68	53.68

5.2.1.1.3 Uncertainties and Time-series Consistency

The uncertainties applicable to *Enteric Fermentation* are provided in Annex 2. The emission time series for agriculture 1990–2016 is consistent. Key activity data such as disaggregated animal numbers are available for all years and are used in a consistent manner.

5.2.1.1.4 Category-specific QA/QC and verification

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

5.2.1.1.5 Category-specific Recalculations

Recalculations in 3.A are linked to emission factors associated with the cattle categories 0-1 years and greater than two years old for 2014 and 2015. This revision is associated with a 0.1 per cent decrease in emissions in 2014 and 2015. The effect of this revision is presented in Table 5.8.

5.2.1.1.6 Category-specific Planned Improvements

The Department of Agriculture, Food and the Marine has funded the establishment of The Agricultural Greenhouse Gas Research initiative for Ireland (AGRI-I). This is an organisational and collaborative framework designed to: build a critical mass of scientific expertise in GHG research, co-ordinate uniform measurement protocols, and address a specific set of research issues. The AGRI-I network has a specific set of research aims, primarily focussed on the inclusion of validated GHG emissions mitigation strategies into the national inventory. This research include a review of feed intake parameters and assumed nitrogen content of feeds and updates as necessary. A separate but related research project investigated the development of country specific B_O and MCF values using a range of cattle manures and environmental conditions. In addition the EPA has funded a research project aimed at reviewing the Tier 2 methodology used for the estimation of CH_4 emissions from cattle. Outputs of the outlined research projects will be reviewed as they become available with a view to including relevant information in the national inventory as appropriate.

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

5.2.1.2.1 Category Description

This grouping includes **sheep 3.A.2**, **swine 3.A.3**, and **other livestock 3.A.4**. Enteric fermentation from other livestock in Ireland consists of **deer, goats, horses, mules and asses**, and **fur-bearing animals**. Enteric Fermentation emissions of CH_4 are not occurring for poultry and fur-bearing animals. *Enteric fermentation, sheep 3.A.2* is a key category in Ireland.

5.2.1.2.2 Methodological Issues

The Tier 1 approach in the 2006 IPCC guidelines is used for *Enteric Fermentation; Sheep, Swine,* and *Other Livestock.*

The type of information used to derive the Tier 2 emission factors for cattle is not available for other important livestock categories in Ireland, such as **sheep** and **swine**. 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 IPCC are adjusted as shown in Table 3.3.B of Annex 3.3. For sheep, the emission factor for lambs is calculated on the basis that lambs have an assumed lifetime of 180 days before slaughter and a CH_4 conversion rate (Y_m) of 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_4 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.

5.2.1.2.3 Uncertainties and Time-series Consistency

The uncertainties applicable to *Enteric Fermentation* are provided in Annex 2. The emission time series for agriculture 1990–2016 is consistent. Key activity data such as disaggregated animal numbers are available for all years and are used in a consistent manner.

5.2.1.2.4 Category-specific QA/QC and verification

Standard QA/QC procedures have been applied to *Enteric Fermentation, All Other Livestock*. Details of Ireland's QA/QC process can be found in Chapter 1 of this report.

5.2.1.2.5 Category-specific Recalculations

Recalculations from all other livestock (3.A.2 – 3.A.4) are confined to updated activity data for goats for 2014 and 2015, leading to a 0.12 per cent increase in emissions from all other livestock in 2014 and 2015.

5.2.1.2.6 Category-specific Planned Improvements

The inventory agency is in the process of investigating the applicability of developing Tier 2 estimates of CH_4 from enteric fermentation from sheep as recommended in previous annual inventory review reports. This is being investigated in tandem with the review of Tier 2 estimates for cattle as discussed in section 5.2.1.1.6. Outputs will be reviewed as they become available with a view to including relevant information in the national inventory as appropriate.

5.3 Emissions from Manure Management (3.B)

The IPCC Level 3 emission source categories relevant under *3.B Manure Management* in 2016 are *3.B.1 Cattle, 3.B.2 Sheep, 3.B.3 Swine, 3.B.4 Other Livestock,* and *3.B.5 Indirect N_2O Emissions*. Total emissions of CH_4 and N_2O from these activities amounted to 1,943.29 kt CO_2eq in 2016.

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

5.3.1.1 Category Description

This category describes how to estimate CH_4 produced during the storage and treatment of manure, and from manure deposited on pasture. The term 'manure' is used here collectively to include both dung and urine (both the solids and the liquids) produced by livestock. The main factors affecting CH_4 emissions are the amount of manure produced and the portion of the manure that decomposes anaerobically. The former depends on the rate of manure production per animal and the number of animals, and the latter on how the manure is managed. When manure is stored or treated as a liquid (e.g., in lagoons, ponds, tanks, or pits), it decomposes anaerobically and can produce a significant quantity of CH_4. The temperature and the retention time of the storage unit greatly affect the amount of methane produced. When manure is handled as a solid (e.g., in stacks or piles) or when it is deposited on pastures and rangelands, it tends to decompose under more aerobic conditions and less CH_4 is produced.

The decomposition of the organic material in cattle manures is both a level and trend key category of CH_4 emissions in Ireland.

This category also includes N_2O produced, directly and indirectly, during the storage and treatment of manure before it is applied to land or otherwise used for feed, fuel, or construction purposes. The N_2O emissions generated by manure in the system 'pasture, range, and paddock' occur directly and indirectly from the soil, and are therefore reported under the category '*N_2O Emissions from Managed Soils*'. Direct N_2O emissions occur via combined nitrification and denitrification of nitrogen contained in the manure. The emission of N_2O from manure during storage and treatment depends on the nitrogen and carbon content of manure, and on the duration of the storage and type of treatment. Indirect emissions result from volatile nitrogen losses that occur primarily in the forms of ammonia (NH_3) and nitrogen oxides (NO_x). The fraction of excreted organic nitrogen that is mineralised to ammoniacal nitrogen during manure collection and storage depends primarily on time, and to a lesser degree temperature.

5.3.1.2 Methodological Issues

The Farm Facilities Survey (Hyde et al., 2008) provides detailed data on manure management practices to support the adoption of a higher tier method. The Farm Facilities Survey was conducted 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 31 of 2014). 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 O'Mara (2006) in conjunction with the results of the Farm Facilities Survey (Hyde et al., 2008) for each particular subsystem. Having derived the time spent at pasture and the time spent in housing for cattle, the Farm Facilities Survey (Hyde, 2008) is 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 national Farm Facilities Survey (Hyde et al., 2008) and the work on emission factors for enteric fermentation in cattle (O' Mara., 2006) described in section 5.2.1 above is the basis of the CH_4 emission factors for manure management. The results from Hyde et al. (2008) 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 Farm Facilities Survey (Hyde et al., 2008) 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) includes a full evaluation of the organic matter content of the feeds applicable to the 11 classifications that characterise the national herd (Table 5.2), which facilitates the estimation of their respective levels of organic matter excretion. The emission factors for manure management are derived using the quantified organic matter excretion as volatile solids (VS), the methane production potential (B_O) of manure, the allocation to manure management systems based on the farm facilities survey (Hyde et al., 2008) and the corresponding values of MCF (methane conversion factor) given for the cool climate (≤ 10°C) zone in Table 10.17 of the 2006 IPCC guidelines. Ireland uses the values of 0.24 m^3 CH_4/kg VS and 0.18 m^3 CH_4/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). 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 grass based production systems. The emission factors for cattle are given in Table 5.4.

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 in2017 have led to revised nitrogen excretion rates for other cattle in this submission. Nitrogen excretion rates for all livestock are provided in Table 3.3.E of Annex 3.3 and with the exception of the cattle (both dairy and non-dairy) categories are sourced from SI 31 of 2014 (DECLG, 2014), 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 CH_4 emission factors 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 the Farm Facilities Survey (Hyde et al., 2008) as the basis of CRF Table 3.B (b) and data provided in Annex 3.3. Nitrogen excretion rates for all cattle categories are estimated using the information contained with the Tier 2 estimates of CH_4 from enteric fermentation and manure management and the Tier 2 approach to estimating nitrogen excretion by cattle in section 10.5.2, Volume 4 of the 2006 IPCC guidelines. Furthermore to allow for the application of disaggregated emission factors to the dung and urine deposited on pasture by cattle, the nitrogen excreted by cattle has been partitioned into that contained in urine and the nitrogen contained in dung. Further discussion on the derivation of these values is presented in Annex 3.3.E.

In relation to those animal categories for which nitrogen excretion rates are based on those presented in SI 31 of 2014 (DECLG, 2014) 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 31 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 2016 EMEP/EEA Inventory Guidebook.

Approximately two-thirds of animal manure nitrogen is excreted at pasture annually, reflecting the relatively short period that cattle are housed in Ireland. Animal manures excreted at pasture and the associated emissions are accounted for under N_2O emissions from managed agricultural soils (Section 5.5.1). In 2016 the bulk of cattle manures in housing were managed in pit storage systems (93.8 per cent and 76.2 per cent for dairy cattle and other cattle respectively) for eventual spreading on agricultural lands. The remainder of animal manures produced in-house are in deep bedding systems. The emission factors given by the 2006 IPCC guidelines, Table 10.21, 0.002 kg N_2O-N/N excreted for pit storage and 0.01 kg N_2O-N/N excreted for deep bedding manure management systems are used for cattle manures. The emission factor presented in the 2006 IPCC guidelines, Table 11.3 of 0.10 kg N2O-N (kg NH_3-N + NOx-N volatised) is used to estimate indirect N_2O emissions from manure management.

Table 5.5 Tier 2 CH_4 Manure Management Emission Factors for 1990 to 2016

	Manure Management (kg/head/year)													
	1990	**1995**	**2000**	**2005**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Dairy cows	10.57	10.39	10.22	10.27	10.23	10.17	10.07	10.30	10.31	10.18	10.19	10.18	10.30	10.23
Suckler cows	6.59	6.55	6.52	6.62	6.45	6.61	6.40	6.42	6.53	6.66	6.44	6.49	6.59	6.55
Male cattle < 1 year	4.48	4.26	4.05	3.96	3.96	3.97	4.00	4.08	4.03	4.09	4.09	4.02	4.01	4.06
Male cattle 1 - 2 years	7.09	6.69	6.29	5.90	5.91	5.89	5.85	6.01	5.71	5.46	5.41	5.67	5.58	5.33
Male cattle > 2 years	2.96	2.19	1.43	1.26	1.34	1.20	1.35	1.41	1.31	1.22	1.23	1.16	1.17	1.09
Female cattle < 1 year	4.05	3.96	3.87	3.82	3.81	3.81	3.81	3.80	3.81	3.81	3.81	3.78	3.78	3.79
Female cattle 1 - 2 years	6.26	5.40	4.53	4.13	4.20	4.27	4.42	4.56	4.40	4.42	4.47	4.71	4.58	4.51
Female cattle > 2 years	0.25	0.25	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26
Bulls for breeding	10.48	9.67	8.87	8.38	8.38	8.38	8.38	8.38	8.38	8.38	8.38	8.38	8.38	8.38
Dairy in-calf heifers	4.59	4.28	3.97	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78
Beef in-calf heifers	5.32	4.98	4.63	4.43	4.43	4.43	4.43	4.43	4.43	4.43	4.43	4.43	4.43	4.43

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 1990–2016 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

Recalculations of emissions in 3.B.1 are largely a direct result of the estimation for the first time in this submission of Tier 2 N excretion rates for other cattle (excluding suckler cows). In addition a revision of the CH_4 emission factor for the cattle categories 1-2 years old and greater than 2 years old has had a minor effect on emission levels. The combined effect of the identified improvements is 8.4 per cent on average across the timeseries.

5.3.1.6 Category-specific Planned Improvements

As previously mentioned results of the recently funded research project on the review of Tier 2 emission factor estimates for enteric fermentation and manure management will provide updated information for inclusion in national inventory estimates as they become available.

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_4 emissions from *Manure Management* from *Sheep, Goats, Horses, Mules and Asses, Poultry, Deer and Fur-bearing animals*. The allocations to manure management systems are based on the national farm facilities survey (Hyde et al., 2008) and appropriate values of B_O and VS from Table 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_o 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_2O emissions from *Manure Management* for *Sheep, Swine, Horses, Mules and Asses, Poultry, Deer and Fur-bearing animals*. Country specific N excretion rates and manure management system usage data are utilised.

In 2016, 89.8 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 18.6 per cent of manures is on pasture. The remainder of animal manures produced in-house are in different MMS as outlined with CH_4 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_2O-N/N excreted for pit storage and 0.01 kg N_2O-N/N excreted for deep bedding, 0.005 kg N_2O-N/N excreted for liquid system, 0.005 kg N_2O-N/N excreted for solid storage and dry lot, 0.001 kg N_2O-N/N excreted for litter manure management systems are used for all other livestock categories as presented in Annex 3.3. The emission factor presented in the 2006 IPCC guidelines, Table 11.3 0.10 kg N2O-N (kg NH_3-N + NOx-N volatised) is used to estimate indirect N_2O 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 1990–2016 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

Recalculations for CH_4 and N_2O emissions from manure management for all other livestock (3.B.2 – 3.B.4) are largely due to improvements undertaken in the estimation of emissions of CH_4 from swine *3.B.1.3* and N_2O emissions from sheep *3.B.2.2*. For swine, the GE and DE intake values were reviewed and updated to reflect feeding practices on Irish farms which resulted in a 31.5 per cent on average increase in CH_4 emissions. The time allocated to housing and grazing and the proportion of nitrogen excreted at pasture and in winter housing resulted in an on average increase N_2O emissions from sheep of 29.5 per cent for each year of the timeseries 1990-2015. This also has an effect on CH_4 emissions from sheep through the allocation of MCF's per MMS resulting in a 25.2 per cent increase in emissions of CH_4 from sheep. Similarly for horses *3.B.2.4.* the reallocation of the periods spent housed and at pasture results in a 25.9 per cent increase in N_2O emission for that species. Further minor recalculations for 2014 and 2015 are associated with revised goat population statistics for those years. The net effect of these recalculations and those associated with *3.B. Cattle* is a 92.8 kt CO_2 equivalent yearly increase in emissions across the timeseries 1990-2015.

5.3.2.6 Category-specific Planned Improvements

The inventory agency is in the process of investigating the availability of new data for manure management system practices in Ireland and will include relevant information in inventory estimates as and when they become available.

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 2016 are *3.D.1 Direct N_2O Emissions from Managed Soils* and *3.D.2 Indirect N_2O Emissions from Managed Soils.* Total emissions from these activities amounted to 5,598.85 kt CO_2eq in 2016.

The emissions of N_2O that result from anthropogenic N inputs or N mineralisation occur through both a direct pathway (i.e., directly from the soils to which the N is added/released), and through two indirect pathways: (i) following volatilisation of NH_3 and NOx from managed soils and the subsequent redeposition of these gases and their products NH_4^+ and NO_3^- to soils and waters; and (ii) after leaching and runoff of N, mainly as NO_3^-, from managed soils.

5.5.1 Direct N_2O Emissions From Managed Soils (3.D.1)

5.5.1.1 Category Description

Direct N_2O Emissions from Managed Soils is a key category 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 N_2O emissions from managed soils:

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

5.5.1.2 Methodological Issues

The Tier 1 approach in the 2006 IPCC Guidelines is used for *Direct N_2O Emissions from Managed Soils.*

The estimates of direct N_2O emissions from agricultural soils take into account the nitrogen inputs from all of these sources. The overarching equation used for estimating *Direct N_2O Emissions from Managed Soils* is equation 11.1 in Volume 4, Chapter 11 of the 2006 IPCC Guidelines, customised to Ireland's circumstances:

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

Where:

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

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

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

Where:

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

F_{ON} = annual amount of animal manure and sewage sludge applied to soils kg N yr^{-1}

F_{CR} = annual amount of N in crop residues returned to soils, kg N yr^{-1}

F_{SOM} = annual amount of N in mineral soils that is mineralised, in association with loss of soil C from soil organic matter as a result of changes to land use or management, kg N yr^{-1}

F_{PRP} = annual amount of urine and dung N deposited by grazing animals, kg N yr^{-1} (Note: the subscripts CPP and SO refer to Cattle, Poultry and Pigs, and Sheep and Other animals, respectively)

F_{OS} = annual area of managed/drained organic soils, ha (Note: the subscripts G, Temp, and NP refer to Grassland, Temperate and Nutrient Poor, respectively)

EF_1 = emission factor for N_2O emissions from N inputs, kg N_2O–N (kg N input)$^{-1}$

EF_2 = emission factor for N_2O emissions from drained/managed organic soils, kg N_2O–N ha^{-1} yr^{-1}

EF_{3PRP} = emission factor for N_2O emissions from urine and dung N deposited on pasture, range and paddock by grazing animals, kg N_2O–N (kg N input)$^{-1}$; (Note: the subscripts CPP and SO refer to Cattle, Poultry and Pigs, and Sheep and Other animals, respectively)

Emissions from **inorganic fertilisers** (F_{SN}) are estimated using country specific emission factors for the three types of nitrogen fertiliser on the Irish market, calcium ammonium nitrate, urea and urea with inhibitor. Further information on derivation of fertiliser type specific emission factors are presented in Annex 3.3.F based on the work of Harty et al. (2016) and Roche et al. (2016). The annual statistics on nitrogen fertiliser use (F_{SN}) by type are obtained from the Department of Agriculture, Food and the Marine. The emission factors applied are 0.0140, 0.0025 and 0.0040 kg N_2O-N/kg N applied, respectively for CAN, urea and urea + n-butyl thiophosphoric triamide. The implied emission factor for EF_1 is on average 24 percent (0.0124 kg N_2O-N/kg N) higher than the default value (0.010 kg N_2O-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_2O emissions from Managed Soils (3.D.2)* the quantity of these fertilisers which are volatilised as NH_3 and NO_x are subtracted. Published estimates of sludge production (O'Leary et al, 1997; O'Leary and Carty, 1998; O'Leary et al, 2000; Smith et al, 2003; Smith et, 2004; Smith et al, 2007; Monaghan et al, 2009; Monaghan et al, 2012; Shannon et al, 2014a; Shannon et al 2014b; Environmental Protection Agency, 2016) and the proportion applied on agricultural lands are used to estimate F_{SEW} on the basis of 5 per cent nitrogen content in sewage sludge (Pakhnenkoa et al, 2009) with typical dry solids content of 25 per cent (Fehily Timoney, 1985). Although the amount of sludge spreading on land is increasing, it contributed only 1.7 per cent of the organic nitrogen input to agricultural soils in 2015. 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 1990-2015.

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_2O-N/N kg ($EF_{3PRP,CPP}$), and emissions from sheep and other livestock (horses, mules, goats and deer), which utilize the emission factor of 0.01 kg N_2O-N/N kg ($EF_{3PRP,SO}$). In this submission emissions associated with urine and dung deposition on pasture by cattle are calculated using country specific disaggregated emission factors for dung ($F_{PRP\,cattle\text{-}dungl}$) and urine ($F_{PRP\,cattle-urine}$). Further information on the derivation of the country specific emission factors for the nitrogen contained in the dung and urine of cattle deposited on pasture is presented in Annex 3.3.F based on the work of Krol et al. (2016). The implied emission factor for EF_3 as a result of use the disaggregated emission factors described is 56 per cent lower than the default value (0.02 kg N_2O-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_2O emissions from crop residues returned to soils is provided in Tables 3.3.H of Annex 3.3.

Emissions from **mineralisation/immobilization associated with loss/gain of soil organic matter** (F_{SOM}) are estimated using equation 11.8 in Volume 4, Chapter 11 of the 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.

Emissions from **drainage/management of organic soils (i.e., Histosols)**(F_{OS}) are estimated using the area of drained/managed organic soils from official national statistics and EF_2 from Table 2.5 of the 2013 IPCC Wetland Supplement for nutrient poor grasslands.

Table 5.6 Information related to Direct N_2O Emissions from Managed Soils (3.D.1)

Parameter	**Emission Factor**	**Emission Factor Reference**
EF_{1CAN}	0.0140 kg N_2O-N/kg N	Harty et al. (2016) and Roche et al (2016).
EF_{1Urea}	0.0025 kg N_2O-N/kg N	Harty et al. (2016)
$EF_{1Urea+NBPT}$	0.0040 kg N_2O-N/kg N	Harty et al. (2016)
EF_2	4.3 kg N_2O-N/ha	Table 11.1, Volume 4, Chapter 11 of the 2006 IPCC Guidelines & Table 2.5, 2013 IPCC Wetland Supplement
$EF_{3\ PRP,CPP}$	0.02 kg N_2O-N/kg N	Table 11.1, Volume 4, Chapter 11 of the 2006 IPCC Guidelines
$EF_{3\ cattle-dung}$	0.0031 kg N_2O-N/kg N	Krol et al. (2016)
$EF_{3\ cattle\ -\ urine}$	0.012 kg N_2O-N/kg N	Krol et al. (2016()
$EF_{3PRP,SO}$	0.01kg N_2O-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_2O Emissions from Managed Soils* are provided in Annex 2. The emission time series for agriculture 1990–2016 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_2O 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

Recalculations in this category are associated with *3.D.1.1 Inorganic nitrogen fertilisers, 3.D.1.2. Organic nitrogen fertilisers, 3.D.1.3. Urine and dung deposited by grazing animals, 3.D.1.5 Mineralisation/immobilization associated with the loss/gain of soil organic matter* and *3.D.1.6 Cultivation of organic soils*. The implementation of country specific emission factors by inorganic nitrogen fertiliser type has resulted in a 24.1 per cent (381.4 kt CO_2 equivalent) increase in emissions from *3.D.1.1 Inorganic nitrogen fertilisers* for each year of the timeseries. Revisions to quantities of nitrogen excreted by cattle through the implementation of Tier 2 calculations to N_{ex} estimation and the application of country specific emission factors to cattle dung and urine account for the majority of the recalculation presented for *3.D.1.3. Urine and dung deposited by grazing animals*. Adjustments to the periods of time that other livestock categories (sheep and horses are housed) also have an effect. Combined the effect of this recalculation is 1,305.2 kt CO_2 equivalent (50.2 per cent) annually. Revised N_{ex} values for cattle and adjustments to housing period lengths are also the rationale behind the over 9 per cent (0.2 kt CO_2 equivalent) increase in emissions associated with *3.D.1.2. Organic nitrogen fertilisers*. Revisions in the estimation of emissions and removals in *4.B Croplands* and *4.C. Grasslands* are responsible for the recalculations in *3.D.1.6 Cultivation of organic soils* and *3.D.1.5 Mineralisation/immobilization associated with the loss/gain of soil organic matter*, respectively. For *3.D.1.5 Mineralisation/immobilization associated with the loss/gain of soil organic matter*, revisions to the pattern of change in cropland areas and temporary grassland has led to a 21.6 per cent (1.5 kt CO_2 equivalent) on average (except 2008 where the recalculation is significant higher) decrease in N_2O emissions from this source. Revised assessment of the area of organic soils under grassland is responsible for the recalculation shown for *3.D.1.6 Cultivation of organic soils* with emissions of N_2O on average 149 kt CO_2 equivalent higher annual in comparison to the previous submission. Overall, the net effect of recalculations in *3.D.1 Direct N_2O emissions from managed soils* is average decrease in emissions of 655.6 kt CO_2 equivalent annually.

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_2O emissions from soils, with a view to adopting a methodology that systematically accounts for the influences of soil type, fertiliser type and application rates, temperature and rainfall, which are not captured by the current IPCC methodology. However, the lack of reliable data in relation to the key soil properties including bulk density and organic carbon content has delayed the application of such a methodology at national level. Other countries are in similar positions, in that they are using relatively sophisticated methods for estimating emissions from enteric fermentation and manure management, but do not have the data to use a Tier 2 or Tier 3 approach for estimating emissions of N_2O from soils. Notwithstanding the above Ireland has integrated country specific research results into emission calculation in this submission.

5.5.2 Indirect N_2O Emissions from Managed Soils (3.D.2)

5.5.2.1 Category Description

Indirect N_2O Emissions from Managed Soils is a key category in Ireland. This category includes emissions from **atmospheric deposition** and **nitrogen leaching and run-off** from two indirect pathways: (i) following volatilisation of NH_3 and NOx from managed soils and the subsequent redeposition of these gases and their products NH_4^+ and NO_3^- to soils and waters; and (ii) after leaching and runoff of N, mainly as NO_3^-, from managed soils.

5.5.2.2 Methodological Issues

The Tier 1 approach in the 2006 IPCC Guidelines is used for *Indirect N_2O Emissions from Managed Soils.*

The IPCC methodology for indirect emissions is based on a simple approach that allocates emissions of N_2O due to nitrogen deposition resulting from NH_3 and NO_X emissions in agriculture and from nitrogen leaching to the country that generated the source nitrogen. The contributions from NH_3 and NO_X emission sources in other sectors, such as transport and stationary combustion, are excluded and the import of nitrogen from other countries through atmospheric transport and runoff is not considered.

Emissions from **atmospheric deposition** ($N_2O_{(ATD)}$) arise due to the volatilisation of nitrogen applied to soils in synthetic fertilisers and animal manures. The proportions of these fertilisers that are volatised are $Frac_{GASF}$ and $Frac_{GASM}$ respectively. The volatilisation rates for Ireland are determined in an elaborate NH_3 inventory for agriculture (Duffy et al, 2018). It is assumed that nitrogen lost as NO_X is negligible in comparison to NH_3. $Frac_{GASM}$ is split into $Frac_{GASM1}$ and $Frac_{GASM2}$ with $Frac_{GASM1}$ referring to NH_3-N losses from animal manures in housing, storage and landspreading and $Frac_{GASM2}$ being the proportion of nitrogen from sewage sludge applied to soils that is volatilised as NH_3. These values are presented in Table 5.7. Equation 11.9 in Volume 4, Chapter 11 of the 2006 IPCC Guidelines which is used to estimate the emissions:

$$N_2O_{(ATD)} - N = [(F_{SN} \times Frac_{GASF}) + \left((F_{ON} + F_{PRP}) \times Frac_{GASM1}\right) + (F_{ss}) \times Frac_{GASM2}] \times EF_4$$

Where:

$N_2O_{(ATD)}$–N = annual amount of N_2O–N produced from atmospheric deposition of N volatilised from managed soils, kg N_2O–N yr^{-1}

$Frac_{GASF}$ = fraction of synthetic fertiliser N that volatilises as NH_3 and NO_x, kg N volatilised (kg of N applied)$^{-1}$

$Frac_{GASM1}$ = fraction of applied organic N fertiliser materials (F_{ON}) and of urine and dung N deposited by grazing animals (F_{PRP}) that volatilises as NH_3 and NO_x, kg N volatilised (kg of N applied or deposited)$^{-1}$

$Frac_{GASM2}$ = fraction of applied sewage sludge N (F_{SS}) that volatilises as NH_3 and NO_x, kg N volatilised (kg of N applied or deposited)$^{-1}$

EF_4 = emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces, [0.01 kg N–N_2O (kg NH_3–N + NO_x–N volatilised)$^{-1}$]

Conversion of $N_2O_{(ATD)}$-N emissions to N_2O emissions for reporting purposes is performed by using the following equation:

$$N_2O_{(ATD)} = N_2O_{(ATD)} - N \times 44/28$$

Emissions from **leaching and run-off** are estimated using equation 11.10 in Volume 4, Chapter 11 of the 2006 IPCC Guidelines:

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

Where:

$N_2O_{(L)}$-N = annual amount of N_2O–N produced from leaching and runoff of N additions to managed soils in regions where leaching/runoff occurs, kg N_2O–N yr^{-1}

$Frac_{LEACH-(H)}$ = fraction of all N added to/mineralised in managed soils in regions where leaching/runoff occurs that is lost through leaching and runoff, kg N (kg of N additions)$^{-1}$

EF_5 = emission factor for N_2O emissions from N leaching and runoff, 0.0075 kg N_2O–N (kg N leached and runoff)$^{-1}$

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 $Frac_{LEACH-(H)}$ 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_2O Emissions from Managed Soils (3.D.2)

Parameter	Emission Factor	Emission Factor Reference
$Frac_{GASF}$	0.027	Calculated value for 2016
$Frac_{GASM1}$	0.085	Calculated value for 2016
$Frac_{GASM2}$	0.13	Table 11.3, Volume 4, Chapter 11 of the 2006 IPCC Guidelines
$Frac_{LEACH-(H)}$	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_2O Emissions from Managed Soils* are provided in Annex 2. The emission time series for agriculture 1990–2016 is consistent.

5.5.2.4 Category-specific QA/QC and verification

Standard QA/QC procedures have been applied to *Indirect N_2O Emissions from Managed Soils*. Details of Ireland's QA/QC process can be found in Chapter 1 of this report.

5.5.2.5 Category-specific Recalculations

Recalculations in this category are associated with the aforementioned adoption of Tier 2 nitrogen excretion rates for all cattle categories, in addition to adjustments to the periods of the year associated with housing for sheep and horses which has resulted in a 10.4 per cent average annual increase (20.9 kt CO_2 equivalent) in emissions from *3.D.2.1* Atmospheric Deposition and a 3.4 per cent (8.9 kt CO_2 equivalent) average annual increase in emissions from *3.D.2.2 Nitrogen Leaching and Run*-off.

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[2]. 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 in Ireland. In Ireland, emissions from liming only occur from **Limestone $CaCO_3$**, with no activities identified for **Dolomite $CaMg(CO_3)_2$** which is reported as Not Occurring (NO). Total emissions from *Liming* amounted to 425.60 kt CO_2eq in 2016.

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.

5.8.3 Uncertainties and Time-series Consistency

The uncertainties applicable to *Liming* are provided in Annex 2. The emission time series for agriculture 1990–2016 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

There are no recalculations in this category.

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_2 that was fixed in the industrial production process. Total emissions from these activities amounted to 35.80 kt CO_2eq in 2016.

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[2] http://www.agriculture.gov.ie/farmerschemespayments/crosscompliance/

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 1990–2016 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

There are no recalculations in this category.

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 1990-2015

			1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015
								Estimates in 2017 Submission (kt)							
3.A	Enteric Fermentation	CH_4	454.28	459.20	450.43	433.73	423.48	421.56	414.80	406.48	401.81	415.17	421.31	426.75	437.46
3.B	Manure Management	CH_4	53.69	53.51	52.05	50.54	48.82	48.65	48.13	47.36	47.06	49.20	49.64	50.19	51.38
3.B	Manure Management	N_2O	1.61	1.69	1.71	1.74	1.68	1.69	1.67	1.62	1.60	1.68	1.69	1.68	1.70
3.D.1	Direct em. from Managed Soils	N_2O	20.29	21.33	21.04	19.55	18.30	18.25	18.07	18.64	17.46	17.72	18.89	18.70	18.78
3.D.2	Indirect em. From Managed Soils	N_2O	1.75	1.84	1.82	1.69	1.57	1.59	1.60	1.65	1.52	1.52	1.62	1.60	1.62
3.G	Liming	CO_2	355.04	494.60	366.38	266.73	376.77	262.21	307.32	427.93	360.68	229.40	515.69	382.32	392.51
3.H	Urea Application	CO_2	44.47	39.68	42.25	27.90	23.36	30.76	40.93	45.16	32.32	21.32	21.66	25.09	28.31
3	Total Carbon dioxide	CO_2	399.51	534.28	408.63	294.63	400.12	292.97	348.25	473.10	393.00	250.72	537.35	407.40	420.81
3	Total Methane	CH_4	507.97	512.72	502.49	484.27	472.30	470.22	462.93	453.84	448.87	464.37	470.95	476.94	488.84
3	Total Nitrous oxide	N_2O	23.64	24.87	24.58	22.98	21.55	21.53	21.33	21.91	20.58	20.92	22.19	21.99	22.10
3	Total (CO_2 eq)	CO_2 eq	**20,144.82**	**20,762.83**	**20,295.16**	**19,248.76**	**18,629.40**	**18,464.63**	**18,278.60**	**18,349.23**	**17,748.11**	**18,094.93**	**18,923.95**	**18,882.56**	**19,227.36**
								Recalculated Estimates in 2018 Submission (kt)							
3.A	Enteric Fermentation	CH_4	454.28	459.20	450.43	433.73	423.48	421.56	414.80	406.48	401.81	415.17	421.31	426.24	436.95
3.B	Manure Management	CH_4	56.24	56.69	55.81	54.12	52.00	51.48	50.79	50.07	50.08	52.13	52.70	53.18	54.29
3.B	Manure Management	N_2O	1.67	1.74	1.75	1.77	1.71	1.72	1.70	1.64	1.62	1.71	1.73	1.71	1.75
3.D.1	Direct em. from Managed Soils	N_2O	17.77	18.98	18.88	17.45	16.18	15.99	15.53	16.69	15.48	15.96	17.34	16.84	16.80
3.D.2	Indirect em. From Managed Soils	N_2O	1.87	1.95	1.94	1.79	1.67	1.69	1.69	1.73	1.61	1.62	1.72	1.70	1.73
3.G	Liming	CO_2	355.04	494.60	366.38	266.73	376.77	262.21	307.32	427.93	360.68	229.40	515.69	382.32	392.51
3.H	Urea Application	CO_2	44.47	39.68	42.25	27.90	23.36	30.76	40.93	45.16	32.32	21.32	21.66	25.09	28.31
3	Total Carbon dioxide	CO_2	399.51	534.28	408.63	294.63	400.12	292.97	348.25	473.10	393.00	250.72	537.35	407.40	420.81
3	Total Methane	CH_4	510.52	515.89	506.24	487.84	475.48	473.05	465.59	456.56	451.89	467.30	474.01	479.42	491.23
3	Total Nitrous oxide	N_2O	21.31	22.68	22.58	21.02	19.56	19.39	18.91	20.06	18.71	19.29	20.79	20.26	20.28
3	Total (CO_2 eq)	CO_2 eq	**19,514.36**	**20,190.65**	**19,792.58**	**18,753.70**	**18,115.15**	**17,898.64**	**17,624.40**	**17,865.25**	**17,267.22**	**17,681.19**	**18,581.73**	**18,430.06**	**18,743.88**
								Percentage Change in Total Emissions due to Recalculations							
3.A	Enteric Fermentation	CH_4	-	-	-	-	-	-	-	-	-	-	-	-0.12	-0.12
3.B	Manure Management	CH_4	4.75	5.94	7.21	7.07	6.51	5.81	5.53	5.74	6.41	5.97	6.15	5.97	5.65
3.B	Manure Management	N_2O	3.91	2.97	2.30	2.20	1.69	1.68	1.70	1.08	1.57	2.12	2.28	1.93	2.79
3.D.1	Direct em. from Managed Soils	N_2O	-12.39	-11.01	-10.25	-10.74	-11.58	-12.38	-14.05	-10.48	-11.35	-9.96	-8.18	-9.93	-10.52
3.D.2	Indirect em. From Managed Soils	N_2O	6.94	5.99	6.38	5.94	6.25	6.01	5.67	5.16	5.88	6.23	6.27	6.14	6.49
3.G	Liming	CO_2	-	-	-	-	-	-	-	-	-	-	-	-	-
3.H	Urea Application	CO_2	-	-	-	-	-	-	-	-	-	-	-	-	-
3	Total Carbon dioxide	CO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	Total Methane	CH_4	0.50	0.62	0.75	0.74	0.67	0.60	0.57	0.60	0.67	0.63	0.65	0.52	0.49
3	Total Nitrous oxide	N_2O	-9.85	-8.79	-8.14	-8.53	-9.25	-9.92	-11.34	-8.45	-9.07	-7.81	-6.33	-7.85	-8.25
3	Total (CO_2 eq)	CO_2 eq	**-3.13**	**-2.76**	**-2.48**	**-2.57**	**-2.76**	**-3.07**	**-3.58**	**-2.64**	**-2.71**	**-2.29**	**-1.81**	**-2.40**	**-2.51**

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_2 emissions to, or removals from, the atmosphere are to be reported with respect to overall carbon gain or loss for up to five relevant carbon pools for the defined land categories. These pools are above-ground biomass, below-ground biomass, dead organic matter (litter and dead wood) and soils. For Convention reporting above-ground biomass and below-ground biomass are reported together as living biomass, and litter and deadwood are reported together as dead organic matter (DOM). The 2006 IPCC guidelines 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 2016 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands, where appropriate. Those emissions of N_2O and CH_4 associated with land management not reported under Agriculture are reported in the LULUCF sector including such activities as soil disturbance, and the drainage and rewetting of mineral and organic soils. Emissions of N_2O and CH_4 are reported for biomass burning.

6.2 Overview of LULUCF Sector

6.2.1 Sector Coverage

Complete coverage of the relevant gases has been achieved for the years 1990-2016 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 1990-2016. 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_2				CH_4	N_2O
	Biomass	DOM	Soils	Wood products		
A. Forest Land						
1. Forest Land remaining Forest Land	All	All	All, NA		All	Part, IE
2. Land converted to Forest Land	All	All	All, NA, NE		All	Part, IE
B. Cropland						
1. Cropland remaining Cropland	All	NO	All		NA	IE
2. Land converted to Cropland	NO	NO	NO		NA	NO
C. Grassland						
1. Grassland remaining Grassland	NO	NO	All, NO*		NO	All. IE
2. Land converted to Grassland	All	All	All		All	Part, IE
D. Wetlands						
1. Wetlands remaining Wetlands	All	NO	All		NO	IE
2. Land converted to Wetlands	All	All	All		All	All
E. Settlements						
1. Settlements remaining Settlements	NO	NO	NA		NO	IE, NE
2. Land converted to Settlements	All	All	All		All	Part, IE
F. Other Land						
1. Other Land remaining Other Land	NO	NO	NO*		NO	NO
2. Land converted to Other Land	All	All	All		All	All
G. Harvested wood products				All**		

Biomass - includes above and below ground biomass

DOM - dead organic matter (deadwood and litter)

All - all emission sources covered; NE - emissions not estimated; NO - activity not occurring; NA - not applicable (no emissions of the gas occur in the pool/source category); IE - emissions included elsewhere.

* Under the Tier 1 method, there is no carbon stock change in soil for these land categories, if there is no change in management

** HWP reported based on domestic production approach and excluding Harvest form deforested lands

The 1990-2016 inventory for LULUCF follows the same general approach and methodologies as those used for the submission for the 1990-2015 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 area 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 1990-2016 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 and/or horticultural use.

Annex 3.4.B 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 shown in Figure 6.1 illustrates how different data sources are used to derive land use categories in a hierarchal manner. Forest lands are initially derived using forest datasets and statistics. This is primarily based on the Forest Information and Planning System which used 1995 as the baseline (FIPS 95), afforestation and deforestation data (see section 6.3.1). The areas under forest land include open areas within forest boundaries. The submission includes biomass carbon stock change (CSC) for these areas using information obtained from the 2006 and 2012 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 industrial 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. However, these data may not have sufficient resolution, spatially or temporally, to allow land use tracking for all land use categories (see improvement plan, Section 6.11). Table 6.3 details the data sources used to estimate land use areas and soil types typical of each land use type.

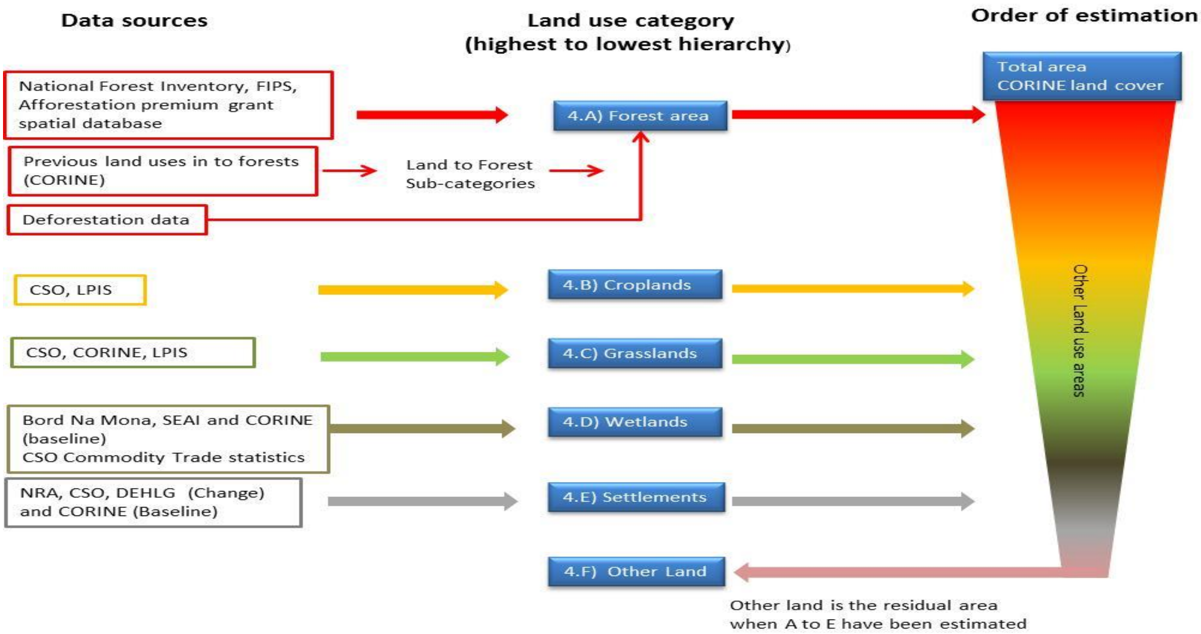


Figure 6.1 Methodologies and hierarchy of determining land use areas and transitions

See Table 6.3 for a detailed outline of data sources. Other Land is derived from the land not included in the forest, cropland, 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 2016. Grassland is the dominant land-use category in all years, accounting for 62.6 per cent of total area in 1990, followed by Wetland accounting for 18.4 per cent. Forest Land covered 6.5 per cent, followed by Cropland at 9.9 per cent and Settlements at 1.5 per cent. Other Land is the residual land use at 1.1 per cent. The major land-use changes since 1990 have been the conversion of Grassland and Wetland to Forest Land. In 2016, Grassland accounted for 61.0 per cent of land area, Wetland 16.1 per cent, Forest Land 10.7 per cent, Cropland at 9.5 per cent, with Settlement and Other Land accounting for 1.7 per cent and 1.0 per cent, respectively.

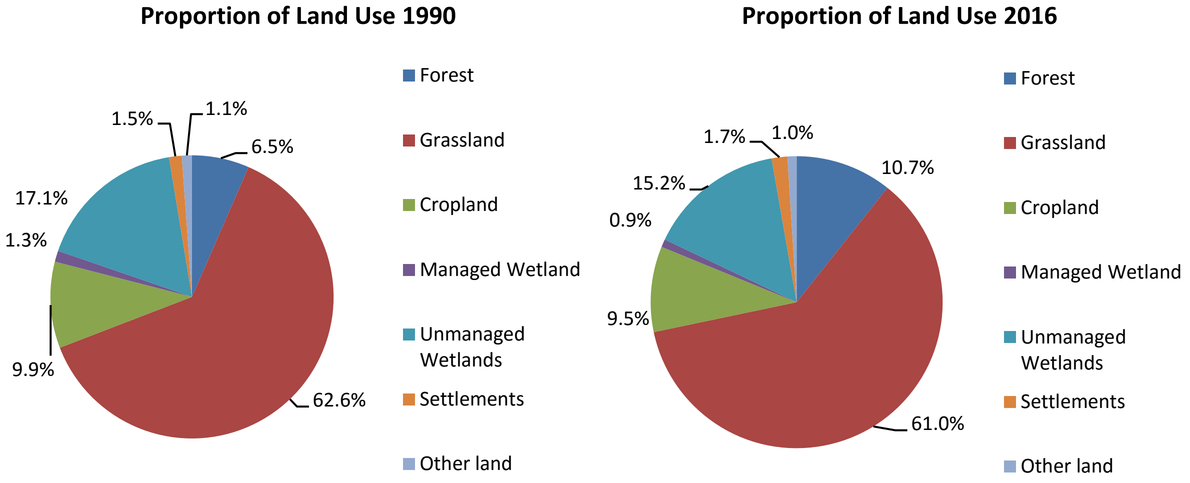


Figure 6.2 Overview of land use change between 1990 and 2016

Table 6.2 Emissions[a] and Removals[a] from Land Use Land-Use Change and Forestry 1990-2016 (kt CO2 eq)

LULUCF	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
4A Forestland	**-2540.95**	**-1782.33**	**-1702.02**	**-2809.24**	**-3274.44**	**-4662.22**	**-4751.69**	**-3844.74**	**-3749.46**	**-3171.42**	**-3424.06**	**-3165.70**	**-3577.87**	**-3630.15**
A. Forest Land CO_2	-2692.40	-1971.33	-1908.47	-3033.06	-3505.85	-4896.65	-4985.99	-4104.46	-3994.96	-3411.92	-3672.98	-3413.60	-3825.54	-3875.91
A. Forest Land CH_4	58.58	70.20	70.58	71.29	72.28	72.59	70.02	91.11	76.09	69.77	77.27	75.83	72.95	69.88
A. Forest Land N_2O	92.86	118.80	135.87	152.53	159.13	161.84	164.28	168.60	169.42	170.72	171.66	172.07	174.72	175.88
4B Cropland	**-16.17**	**-58.37**	**3.31**	**-150.23**	**29.42**	**64.70**	**-83.03**	**-197.19**	**-37.50**	**34.77**	**-31.72**	**-74.35**	**-92.69**	**-131.93**
B. Cropland CO_2	-16.23	-58.45	3.26	-150.39	29.41	64.69	-83.04	-197.21	-37.50	34.77	-31.72	-74.35	-92.69	-131.93
B. Cropland CH_4	0.04	0.06	0.04	0.12	0.00	0.01	0.01	0.01	0.00	0.00	NO	NO	NO	NO
B. CroplandN_2O	0.01	0.02	0.01	0.04	0.00	0.00	0.00	0.00	0.00	0.00	NO	NO	NO	NO
4C Grassland	**7626.95**	**6767.27**	**7199.14**	**7031.85**	**6837.18**	**7189.46**	**7246.65**	**7124.56**	**7118.64**	**7247.29**	**7108.07**	**7061.76**	**7102.95**	**7134.94**
C. Grassland CO_2	7343.33	6509.95	6951.79	6769.91	6589.57	6931.70	7004.44	6826.37	6860.76	6984.18	6841.38	6804.48	6842.59	6889.15
C. Grassland CH_4	267.95	234.07	244.05	254.07	242.42	234.34	237.28	290.84	244.70	238.88	246.22	242.61	240.73	240.02
C. Grassland N_2O	15.67	23.25	3.29	7.87	5.20	23.42	4.93	7.35	13.17	24.23	20.46	14.67	19.62	5.77
4D Wetlands	**1654.30**	**1909.25**	**1690.11**	**2759.34**	**2244.18**	**1862.02**	**1844.65**	**2351.73**	**2129.08**	**1784.10**	**1952.32**	**1955.61**	**2087.41**	**2137.23**
D. Wetlands CO_2	1487.42	1713.64	1543.98	2531.73	2120.59	1764.78	1746.04	2137.00	2001.61	1712.49	1847.99	1854.38	1984.36	2061.28
D. Wetlands CH_4	135.62	158.06	118.93	181.39	101.45	81.12	81.96	171.27	104.49	61.48	86.61	84.28	85.82	64.97
D. Wetlands N_2O	31.25	37.56	27.20	46.22	22.14	16.12	16.64	43.45	22.97	10.13	17.72	16.95	17.24	10.98
4E Settlements	**86.75**	**119.37**	**212.10**	**391.40**	**598.69**	**501.32**	**304.62**	**317.38**	**143.68**	**341.16**	**151.08**	**146.53**	**150.23**	**168.08**
E. Settlements CO_2	80.46	109.11	194.13	330.45	536.61	431.84	219.15	231.32	70.15	268.65	77.13	72.84	75.14	91.06
E. Settlements CH_4	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
E. Settlements N_2O	6.29	10.26	17.97	60.96	62.07	69.48	85.47	86.06	73.53	72.52	73.94	73.69	75.09	77.02
4F Other Land	**0.62**	**3.52**	**31.91**	**55.68**	**46.86**	**70.73**	**62.21**	**62.13**	**62.04**	**61.96**	**61.88**	**104.73**	**131.86**	**65.50**
F. Other Land CO_2	0.55	0.85	18.12	32.04	9.49	19.62	11.10	11.09	11.08	11.07	11.06	53.70	79.29	15.21
F. Other Land CH_4	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
F. Other Land N_2O	0.08	2.66	13.78	23.64	37.38	51.11	51.11	51.04	50.96	50.89	50.81	51.03	52.57	50.29
4G Harvested Wood Products	**-413.04**	**-679.70**	**-1123.25**	**-1129.67**	**-1198.40**	**-638.55**	**-710.84**	**-781.41**	**-743.18**	**-661.17**	**-686.28**	**-765.99**	**-731.46**	**-799.52**
G. HWP CO_2	-413.04	-679.70	-1123.25	-1129.67	-1198.40	-638.55	-710.84	-781.41	-743.18	-661.17	-686.28	-765.99	-731.46	-799.52
G. HWP CH_4	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
G. HWP N_2O	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Total LULUCF kt CO_2 eq	**6398.45**	**6279.02**	**6311.30**	**6149.13**	**5283.49**	**4387.46**	**3912.58**	**5032.44**	**4923.31**	**5636.68**	**5131.27**	**5262.58**	**5070.43**	**4944.15**

[a] positive values indicate emissions and negative values indicate removals

Table 6.3 Description of Land Use Categories

Land Use Category	Definition and Coverage	Area 1990 (ha)	Area 2016 (ha)	Percentage change 1990-2016	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 15% based on NFI statistics.	465,278	759.571	+63.3%	National Forest Inventory (NFI) 2006 and 2012 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.	700,656	673,949	-3.8%	Central Statistics Office (CSO), NFI Land Parcel Information System Indicative Soil Map of Ireland	Forest land, Settlement	Forest land
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.	4,452,550	4,340,585	-2.5%	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	1,218,453	1,079,970	-11.4%	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.	89,974	62,004	-31.1%	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	103,370	124,090	+20.0	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	NA	Grassland, Cropland, Forest land
Other Land	Residual when all other land use areas have been determined	81,506	71,615	-12.1%	CORINE, (includes, water bodies, bare rock etc.), NFI	Forest land	Forest land
Total Land	National territorial area (including inland water bodies and salt marshes and intertidal zones)	7,111,785	7,111,785		CORINE Land Cover		

6.3 Forest Land (Category 4.A)

6.3.1 Overall approach and activity data

Ireland adopts the gains and losses approach for reporting biomass carbon stock changes (CSC) using tier 3 models. The reporting of other C pools is done using a Carbon flow modelling framework. 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 and the second NFI inventory was completed in 2012. 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 CARBWARE model (Black, 2016; section 6.3.3.1 and Annex 3.4.A.5). Estimation of CSC in the forest lands before 2006 cannot be determined using the CARBWARE 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).

Figure 6.3 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 CARBWARE model has been subject to external validation and uncertainty analysis and is considered to more accurately represent CSC in Irish forests, when compared to the British Forestry Commission (BFC) based FORCARB model. 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). Therefore, the CARBWARE v 5 model, which has been used for KP LULUCF reporting since 2008, is now also used for convention reporting from 2007 onward. 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 CARBWARE 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. The vertical brackets show which activity data is used by different modelling frameworks FORCARB and CARBWARE. The red open box and yellow box in Figure 6.3 indicated interpolation and adjustment of the historic data against CARBWARE outputs to ensure a consistent representation of the entire time series.

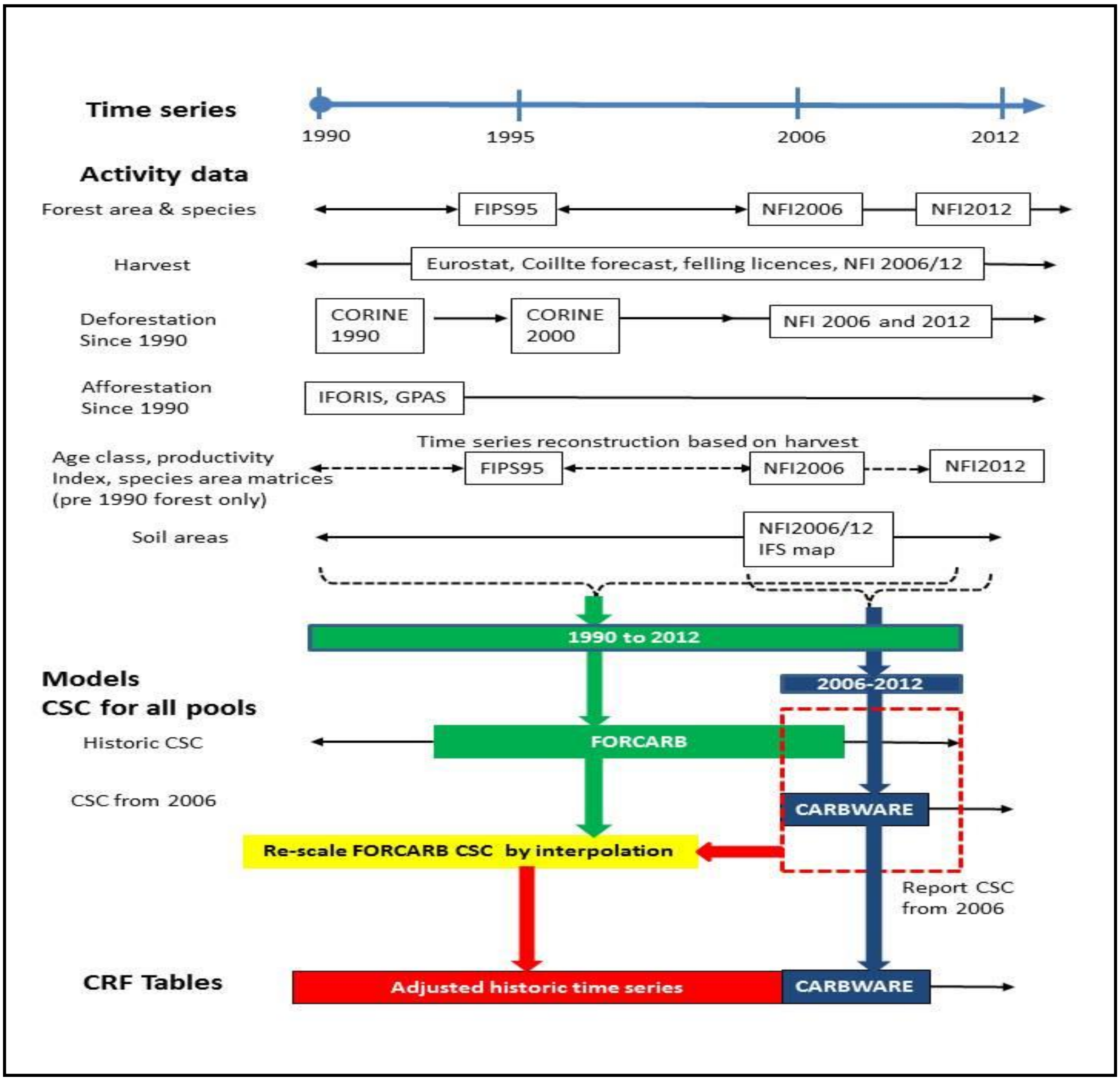


Figure 6.3 Activity data and models used to derive CSC for forest lands

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 new CARBWARE 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 CARBWARE model estimates (Figure 6.12 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). 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).

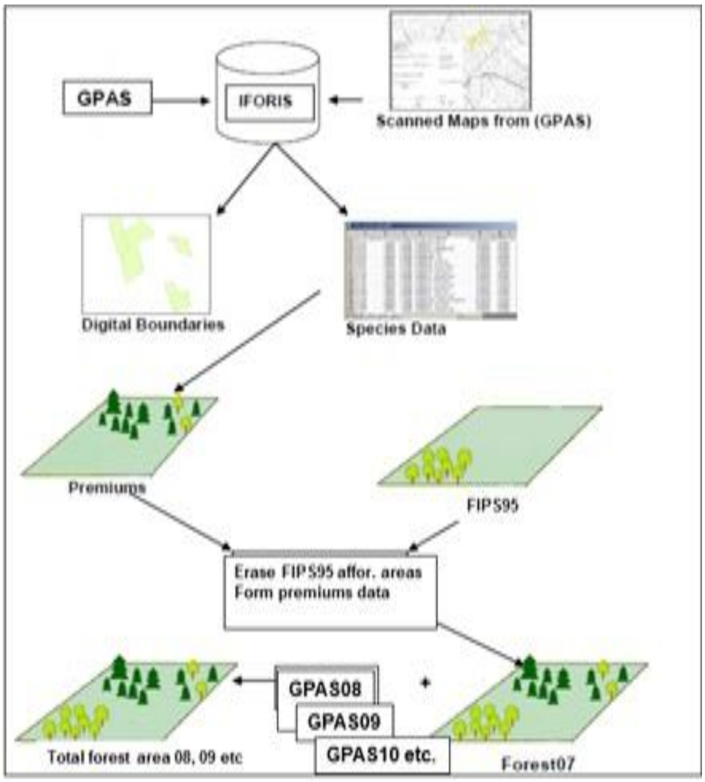


Figure 6.4 The process involved in deriving the total forest area and afforestation areas since 1990 using the IFORIS database

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 October of 2017 and it is envisaged that these results will be incorporated in to the greenhouse gas inventory in 2018. 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.

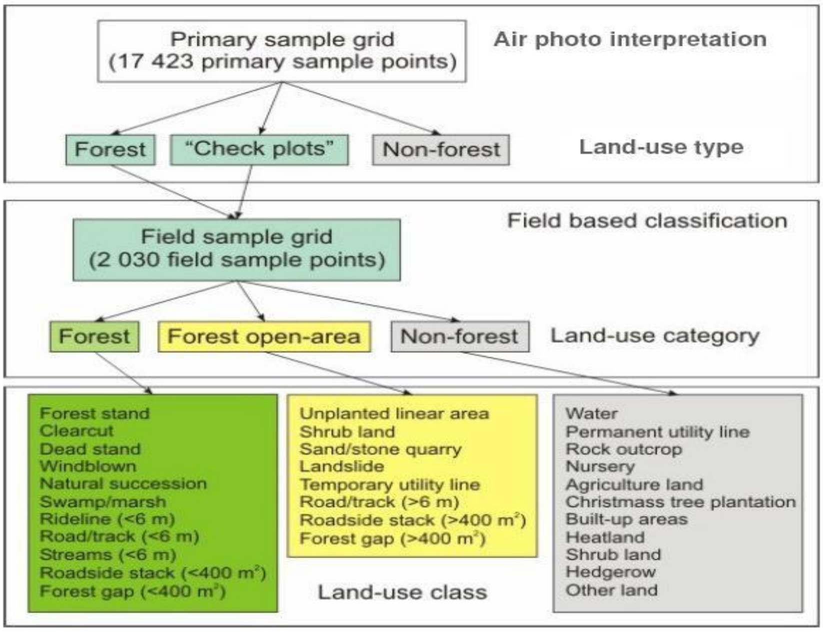
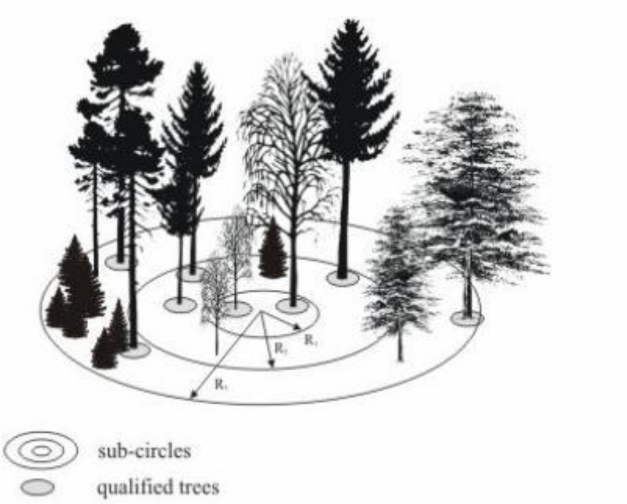


Figure 6.5 Overview of the NFI classification system (taken from NFI, 2007a)

The 2 km x 2 km grid is overlaid on the total land base map of the Republic of Ireland to facilitate land-use type (LUT) interpretation using colour aerial photographs (OSI, 2005, Bing 2011/12 and Global viewer). The primary focus of the interpretation is to identify forest land transitions. In tandem with this, other land-use types are identified for LULUCF reporting under the Convention. The grid is permanent and this allows for the re-assessment of primary sample points at future dates to monitor forest and other land-use change (i.e. afforestation and deforestation) when Ordnance Survey Ireland (OSI) produces the next range of ortho-rectified aerial photos (NFI, 2007).

Once a forest plot has been identified, field measurements are undertaken in established permanent plots. The exact location of the centre of ground survey plots is identified in the field by navigating to a six-digit Irish national grid co-ordinate using both GPS and electronic compass/laser technology. The total area of the circular sample plot is 500 m^2 (i.e. 25.24 m in diameter). Adjustments for slope are automatically made by the laser/range-finding equipment. The concentric circle approach, comprising three concentric circles with different radii is used for tree assessment. Trees of different dimensions are mapped and described on each plot (Figure 6.6). Individual trees in the plot are mapped and treemetric data are collected and archived in a GPS format. Forest mensuration measurements are made on selected individual trees within the plot based in 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 initiate the CARBWARE model.

Soil surveys were also conducted in permanent sample plots. The soil group classification used in the NFI was 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 had to be greater than 30 cm.



	R_1	R_2	R_3
Sub-circle radius (m)	3	7	12,62
Sub-circle area (m^2)	28,3	153,9	500
Treshold diameter (mm)	70	120	200

Figure 6.6 The concentric plot design and mapping of individual trees NFI, 2007a

Note: The concentric plot sampling approach used (see Fig 6.3.4) has implications for uncertainty (see validation and uncertainty sections).

Soil categories were aggregated into three major groups on the basis of their soil carbon characteristics, which can be used to estimate carbon stock change in soils. All mineral soils were grouped together. All organic soils with a depth greater than 30 cm were classified as peats soils. Mineral soils with an organic layer less than 30 cm were classified as mineral/peat soils.

6.3.2.4 Harvests and Deforestation

Harvest before 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 2016 were compiled using national data submitted to the FAO and EUROSTAT. For the 1990-2016 time series the FAO/EUROSTAT harvested volume was used to simulate harvest in the FORECARB model. 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 2012

The 2006 and 2012 NFIs were used to derive harvest data for the periods after 2005. 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 2006/12 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 2006 NFI and 2012 NFI and growth is interpolated between inventory years and extrapolated after the last available NFI (2012) using the CARBWARE 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^3 in 1990 to ca. 2.5Mm^3 by 2016 due to changes in the age class structure and clearfell of more crops at rotation age (

Table 6.8). 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 81,107 m^3 in 2007 increasing to 866,539 m^3 by 2014 and subsequently reducing to 583, 144 m^3 in 2015. The timber volume harvested in 2016 on afforested land was 667,000 m^3. Harvesting from the Coillte lands represented ca. 80 per cent of the total timber harvest from post-1990 forests (afforestation areas only). However, 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 70 per cent of stands, which are suitable for thinning, are not thinned.

Harvests since 2012

To derive harvest since 2012 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).

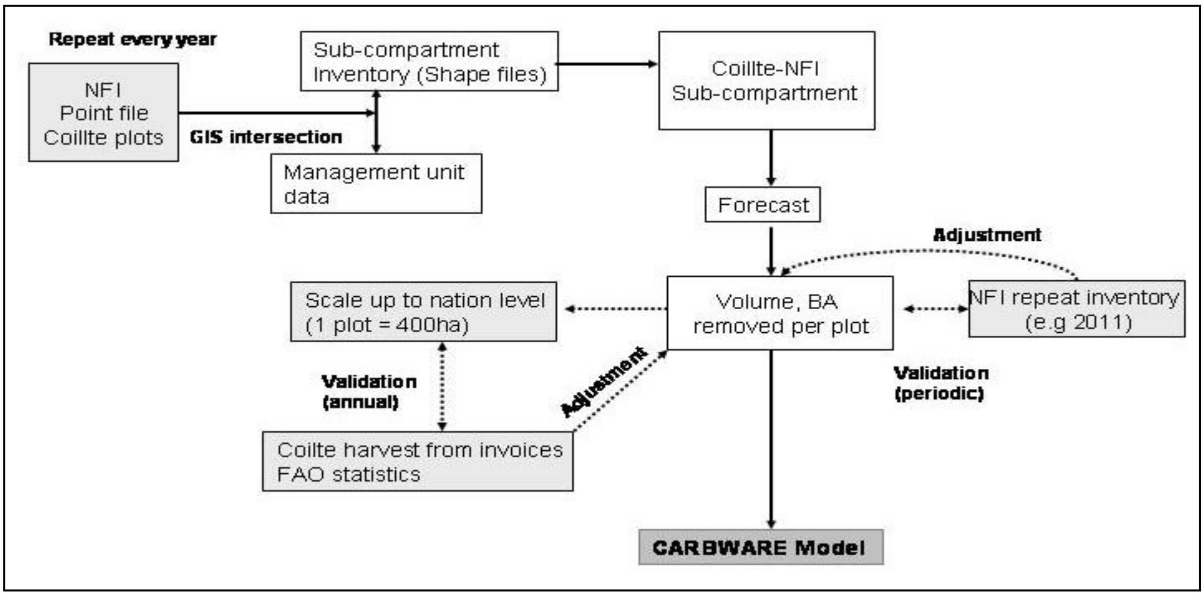


Figure 6.7 Methodology used to derive harvest information for post-1990 State Forests

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. An 'EventsTable' table for use in the CARBWARE database was created for input into the stand modification functions within the CARBWARE model to simulate the harvesting of trees. A final validation was performed on the individual tree tables (see Figure 6.10) to ensure adequate timber was removed during a thinning simulation. 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 Town land boundaries and names (OSI) and the GPAS layer compartments (see 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 Town land in question (as specified on felling licence application) contains a sample compartment.
ii. If there is a sample compartment in the Town land, 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. An 'EventsTable' table in the CARBWARE database was created for input into the stand modification functions within the CARBWARE model to simulate the harvesting of trees. A final validation was performed on the individual tree tables to ensure adequate timber was removed during a thinning simulation. It will be possible in the future to re-evaluate the 'ground truthed data' from repeat NFI inventories of harvested plots

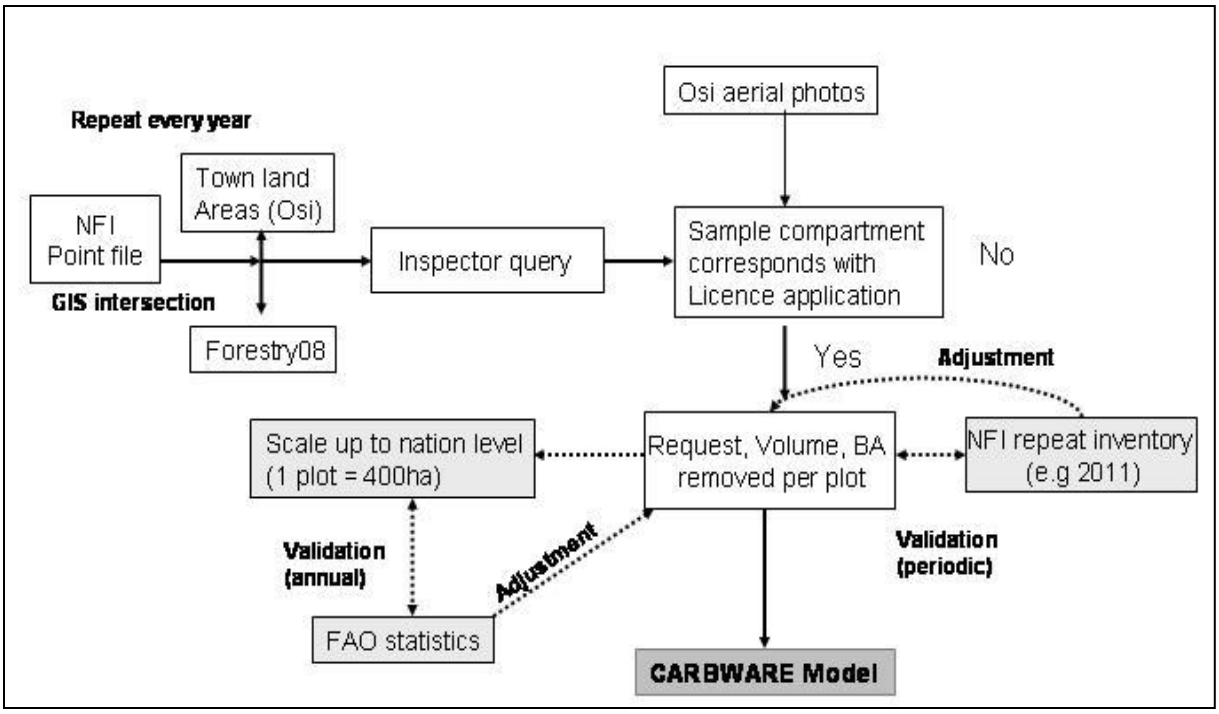


Figure 6.8 Procedure used to derive harvest activity data for private forested areas

Deforestation

Clear-felled areas, which were not restocked within 5 years between NFI's or if there was clear indication of land use change, were deemed to be deforested. The following approaches are used to determine deforestation areas. (see Annex 3.4.A):

1) Sampling approach: NFI grid points and aerial photography (see Annex 3.4.A.2)

This is a modification of 2006 IPCC guidelines approach 3, where the grids or centroids are sampled using a systematic sampling procedure adopted in the NFI. Assessment of 17,423 NFI point intersects with aerial photographs form 2000 and 2006 provides the opportunity to report deforestation for this period. This method identified 15 NFI PSP grid samples, which were deemed to be deforested between 2000 and 2006. The current land uses of these previously deforested lands were determined from photo interpretation using the 2006 images.

Assessments of deforestation from 1995 to 2000 were based on a GIS intersection of the 17,423 NFI plots with the FIPS 95 forest parcel polygon layer. This exercise produced 105 forest parcels, which were classified as forest in the FIPS 1995 dataset, but then re- classified as non-forest land in the NFI aerial photography 2000 interpretation. These 105 polygons were cross-checked with 1995 black and white aerial photographs to verify that they were forests in 1995. However, most of the sampled forest polygons were deemed to not be deforested or were originally other land uses in 1995. This was due to original FIPS 95 interpretation inconsistencies of photographs and mapping errors in the FIPS95 layer. Only 5 NFI sample points were identified to be deforested between 1995 and 2000. Although it is recognised that a grid based sample introduces a high level of uncertainty due to the poor resolution of detecting highly fragmented deforestation, this is the only available data set for this time series. Importantly these uncertainties should not introduce bias, because deforestation could be both over and 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 2006-2012 using the NFI

The NFI 2012 and previous NFI 2006 are used to derive deforestation data for the period 2006 to 2012. The NFI performs land use transition analysis based on a 2 x 2 km grid using aerial photography every 5 years. The first NFI was completed in 2006 with a follow up completed at the end of 2012. 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 national forest inventory programme will also continue to monitor whether clear felled forest land is replanted.

A QA exercise conducted in 2013 highlighted that the previously used felling licence record approach underestimated the areas and C stock of deforested land. Therefore, the NFI data is used to derive both the area and C stock activity data, derived directly from NFI permanent sample plots before deforestation occurred using the CARBWARE model.

The land use transitions due to deforested lands from 2006-2012 are derived from the corresponding NFI data. According to the deforestation definition, a total of 1600 ha of forests, which were clear-felled before the 2006 NFI and were not replanted by the repeat inventory in 2012, were classified as deforested to other land.

4) Deforestation records from 2013 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 2013 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 national forest inventory 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 see Figure 6.4 Activity data of land afforested since 2006 is derived from the NFI 2006 and 2012.

Activity Data for Afforestation Areas after 2012

Activity data of land afforested since 2012, after the completion of the second 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 productivity classes and individual tree height values based on CARBWARE growth models. These tables were used as inputs into the CARBWARE software to generate carbon gains and losses (Figure 6.10)

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.

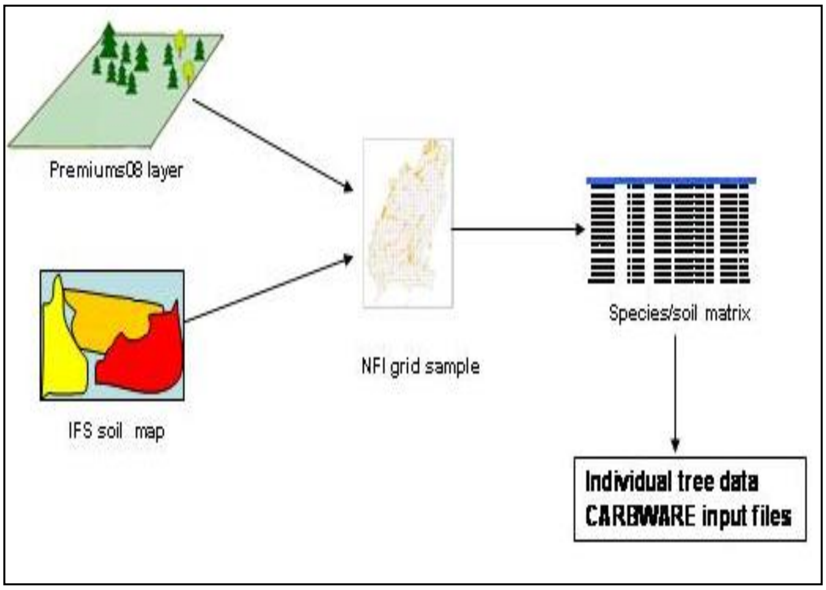


Figure 6.9 Procedure to derive activity data for Afforestation Areas after 2006

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 57 per cent of the total area; *4.A.2.2 Grassland Converted to Forest Land* account for 30 per cent of the total area; *4.A.2.1 Cropland Converted to Forest Land* account for 10 per cent of the total area; and *4.A.2.5 Other land Converted to Forest Land* account for 3 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 2012 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 45 per cent of the total area; *4.A.2.2 Grassland Converted to Forest Land* account for 45 per cent of the total area; *4.A.2.1 Cropland Converted to Forest Land* account for 8 per cent of the total area; and *4.A.2.5 Other land Converted to Forest Land* account for 2 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 2006-2016 time series. This resulted in a constant decline in wetland conversion to forest land by 1 per cent of the total annual afforestation area, and increase in annual afforestation of grasslands by 1.3 per cent of the total area, a decrease in annual afforestation of croplands by 0.6 per cent of the total area, and a decrease in conversion of other land to forests by 0.1 per cent of the 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[a]	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

[a]Note: For LULUCF reporting in the CRF table 4A1 and 4A2, litter pools are reported as IE under deadwood. This is because the FORECARB model used to estimate CSC for the historical time series does not differentiate between litter and deadwood pools.

6.3.3 Description of models used

6.3.3.1 CARBWARE

The CARBWARE model is used to derive net emissions/removals for all pools for all forest categories since 2006. The CARBWARE system is initialised using individual tree data from the NFI and other activity data (See Figure 6.3 and Figure 6.10). The growth and mortality model was developed using permanent sample plots established by Coillte in the 1950s. Following model parameterisation and extensive validation, software was developed to facilitate reporting of pools using model functions and input activity data (Figure 6.10). The software system was developed as part of a QC initiative to reduce calculation errors when input data is formatted and processed. When the software was developed extensive testing and validation of the code functionally on different operating systems was carried out by FERS Ltd and an independent validator (PTR Ltd) under the Council for Forest Research and Development (COFORD) funded CARBWARE project (2007-2012). The software is made available to the EPA and DAFM with a user manual.

The reporting system includes an on-going QA/QC system, whereby model outputs are validated against repeated NFI measurements on a 5 year rolling basis. Additional, external data checks on activity data are carried out by the data suppliers. The first repeat forest inventory on one-fifth of the forest area was completed 2011, with the remaining completed by the end of 2012.

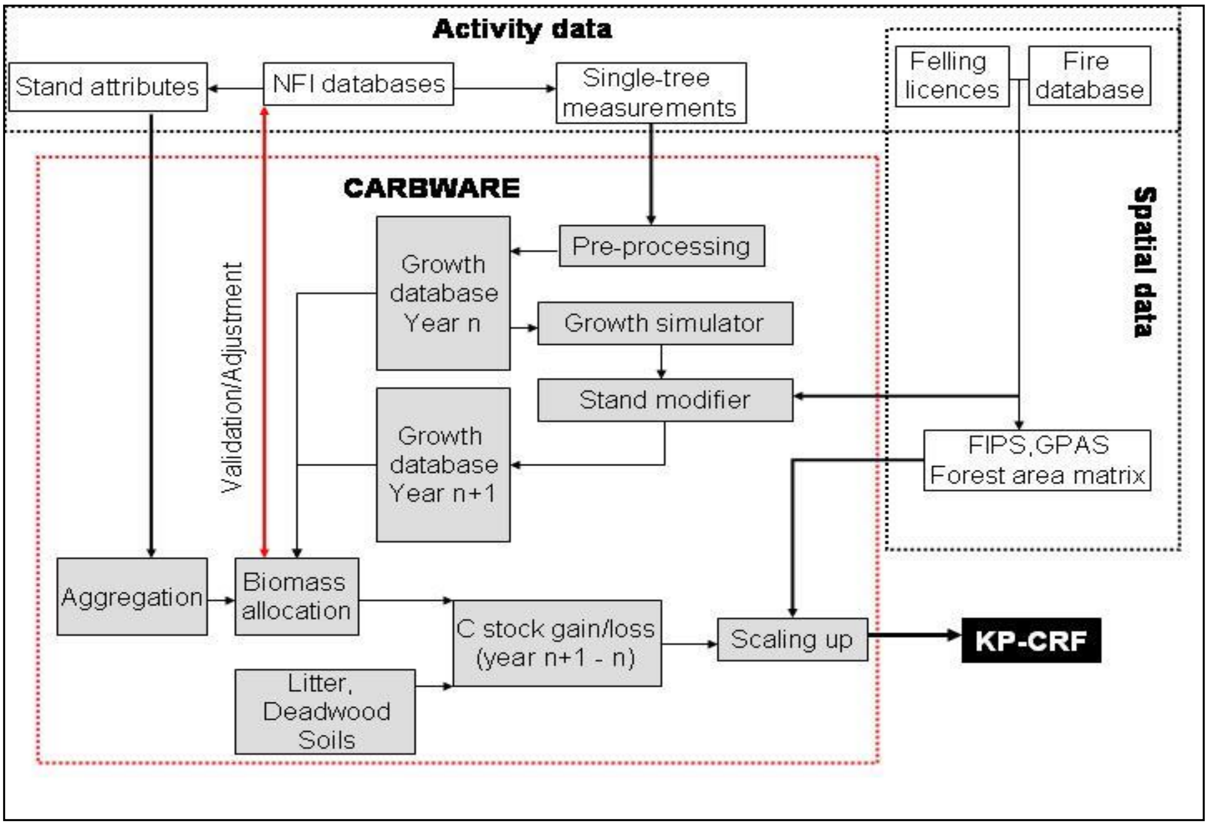


Figure 6.10 Schematic Overview of CARBWARE Functionality

The red box indicates the operational domain. The white boxes represent input data sources and data bases and the grey boxes indicate software modules which carry out different procedures.

6.3.3.1.1 Pre-processing, Growth Simulator and Stand Modifier Modules

The pre-processing module carries out formatting of NFI input files in the Microsoft Access environment to ensure that individual tree and stand information can be used by the growth simulator and stand modifier module. The model itself comprises of a growth simulator (DBH increment model see Annex 3.4.A.5), a modifier module (see Annex 3.4.A.5.2), which facilitates inclusion of natural mortality and harvests and a biomass allocation module which facilitates carbon flow between different pools.

6.3.3.1.2 The Carbon Flow Sub-model

The total carbon stock changes for a given forest plot is calculated as the sum of the gains and losses in the above-ground biomass (AB), below-ground biomass (BB), Litter (Li), deadwood (DW) and soil (So) carbon pools (Equation 2.3 Chapter 2 Volume 4 2006 IPCC guidelines):

$$\Delta C_{lu} = \Delta C_{AB} + \Delta C_{BB} + \Delta C_{Li} + \Delta C_{Dw} + \Delta C_{So} \quad (6.3.1)$$

Biomass estimates include biomass for trees only, non-tree vegetation is assumed to be in steady state following canopy closure. The definition of C pools is the same for Convention and Kyoto Protocol (KP) reporting. Below ground biomass includes all roots up to a diameter of 5cm. Litter is defined as deadwood with a diameter of less than 7cm. This includes abscised needles and leaves. The dead wood pool includes all lying and standing deadwood, dead roots and stumps with a diameter greater than 7cm. Organic and mineral/organic soils are reported.

a) Biomass Carbon gains and losses

Biomass carbon stock changes are calculated using a Tier 3 gain/loss method, corresponding to the process-based approach given by equation 2.4 Chapter 2, Volume 4 2006 IPCC guidelines, which gives the net carbon stock change as the sum of carbon gains and carbon losses for each NFI permanent sample plot

$$\Delta C = \Delta C_G + \Delta C_L \text{ ......(6.3.2)}$$

The biomass carbon gains (ΔC_G) for both above-ground biomass (AB) and below-ground biomass (BB) are calculated for each NFI permanent sample plot using

$$\Delta C_G = GTOTAL \times CF \text{ ......(6.3.3)}$$

where GTOTAL is the biomass gain (t dm. ha^{-1} yr^{-1}) in a PSP and CF is the carbon fraction of biomass dry matter, which is taken to be 50 per cent for all carbon pools (Black et al., 2007). GTOTAL is derived from the sum of all living individual tree components (i.e. AB or BB) within the NFI permanent sample plot, for example:

$$GTOTAL_{AB} = AB_n - AB_{n-1} \text{ ......(6.3.4)}$$

where n is the year of inventory. The GTOTAL value for each NFI permanent sample plot is normalised to 1 ha. The AB and BB of individual trees were calculated using biomass algorithms for different species cohorts based on national research (Annex 3.4.A.4, Table 3.4.A.4.a), where DBH and tree height (H) are used as dependent variables. These variables are input data in the NFI 'individual tree table' for the first NFI (2005/6, See Figure 6.6). The increases in DBH and H of individual trees between NFI years were simulated in the single tree growth models (See Annex 3.4.A.5.2). The stocking (number of trees in a plot) is adjusted after every growth simulation cycle using the stand modification module (Figure 6.6), which removes trees based on natural mortality models and harvest activity data (Annex 3.4.A.5.2).

Biomass carbon losses from the above-ground biomass pool ($\Delta C_{L(AB)}$) are calculated based on harvest (L_{timber}), harvest residue (L_{HR}), litter fall (L_{LF}), above-ground losses due to mortality ($L_{mort(AB)}$) and fire (L_{fire}):

$$\Delta C_{L(AB)} = L_{timber} + L_{HR} + L_{LF} + L_{mort(AB)} + L_{fire} \text{ ......(6.3.5)}$$

L_{timber} is calculated based on the above-ground biomass removed from harvest, simulated in the stand modification module (Annex 3.4.5.2). The allocation algorithms for timber based on harvested AB, H or DBH are derived from national research (see Annex 3.4.A.4, Table 3.4.A.4.a). L_{HR} includes the harvest residue representing all stems and branches with a DBH less than 7cm and litter left on site after timber is removed:

$$L_{HR} = AG - L_{timber} \text{ ......(6.3.6)}$$

L_{LF} reflects the transfer of carbon from the AB pool to the litter pool. This is calculated in the allocation module (Figure 6.7), based on nationally derived leaf/needle biomass (LB) and the foliage turnover rates (F_t) (Tobin et al., 2006):

$$L_{LF} = LB \times F_t \text{ ......(6.3.7)}$$

Allometric equations and coefficients used for the calculation of LB for different species cohorts, with either AB or DBH as dependent variables, are shown in Annex 3.4.A.4, Table 3.4.A.4.a. The F_t rate was assumed to be 6.7 years (i.e. F_t = 0.15) for conifer crops and 1 year for broadleaf crops (Tobin et al., 2006). The mortality of trees is based on nationally derived single tree mortality models (Annex 3.4.A.5.2.1).

The above-ground biomass loss from mortality ($L_{mort(AB)}$) was calculated using DBH and H as dependent variables in biomass algorithms (Annex 3.4.A.4, Table 3.4.A.4.a). The AB carbon losses associated with fires (L_{fire}) was determined as described in section 6.3.2. These losses are estimated in respect of total biomass burned and reported separately in CRF Table 4(V). The above-ground biomass gains in previously burned forest areas are assumed to be zero.

The biomass pools allocated to $L_{HR} + L_{LF} + L_{mort(AB)}$ pools are transferred to the litter and deadwood pools. Timber biomass harvested (L_{timber}) is assumed to be immediately oxidised in the year of harvest.

Biomass carbon losses from the below-ground biomass pool ($\Delta C_{L(BB)}$) is calculated as the sum of losses due to death of roots after harvest (L_{HRroot}), natural mortality of roots ($L_{mort(BB)}$) and root death following fire (L_{fire}):

$$\Delta C_{L(BB)} = L_{HRroot} + L_{mort(BB)} + L_{fire} \quad \text{...(6.3.8)}$$

L_{HRroot} is the root biomass transferred to the deadwood pool following harvest as is $L_{mort(BB)}$ following tree death. All roots are assumed to die and decompose following harvest. The mortality of roots is assumed to follow that for trees, as estimated from nationally derived single tree mortality models (Annex 3.4.A.5.2.1). The below-ground biomass loss from mortality ($L_{mort(BB)}$) is calculated using above-ground and total biomass algorithms (Annex 3.4.A.4, Table 3.4.A.4.a). The BB biomass losses associated with fires (L_{fire}) was determined in the same way as described above for AB losses due to fires and reported in Table 4(V). The below-ground biomass gains in burned forest are assumed to be zero.

Carbon stock changes associated with deforestation reported in CRF Tables 4(V) and KP tables 4(KP-II)4 include those for the total standing biomass of all trees, including roots, removed at clear fell (i.e. all biomass carbon is assumed to be immediately oxidised). Since activity data and methods used to derive deforestation estimates are now based on NFI measurements, AB, BB, litter and deadwood C losses are directly estimated using allometric equations and C flow models in CARBWARE (Annex 3.4.A.5.2, Table 3.4.A.4.a and following sections).

Where deforestation occurred after 2012 (i.e. harvested after the last NFI in 2012), there was no plot data for estimating C stock before harvest. Therefore, the carbon stock losses in the AB and BB pools for deforestation were calculated from an estimation of standing volume (V) of these NFI plots, as specified in the Coillte inventory, a basic density (D) in the range 0.35 to 0.55 (depending on tree species), a biomass expansion factor (BEF, total biomass to timber biomass see section 7) of 1.68 to 4 t/t^{-1} (Black et al., 2004), a carbon fraction (CF) of 0.5 and a root to shoot ratio R of 0.2 (Black et al., 2009b), as follows

$$TOTAL_{(AB)} = (V \times D \times BEF \times CF) \times 1/(1-R) \quad \text{...(6.3.9)}$$

$$TOTAL_{(BB)} = TOTAL_{(AB)} \times R \quad \text{..(6.3.10)}$$

The equations are similar to those presented in equation 2.8, Chapter 2, Volume 4 of the 2006 IPCC guidelines. However, the term (1-R) is included for above ground biomass because BEF is defined as the ratio of total biomass (including roots) to timber biomass. Similarly, the term R is included in the below ground biomass calculation.

There is no activity data for deforested areas before 2006, therefore the 2006-2012 mean AB (65.9.81 t C/ha), BB (17.2 tC/ha), litter and deadwood (16.4 tC/ha) C stock was applied as an IEF for these deforested areas.

b) Litter Carbon Stock Change

Net litter stock change (ΔC_{Li}) is calculated based on litter inputs (gains) due to litterfall (L_{LF}), as given by equation 6.3.7, harvest residue litter input (L_{HR}) in equation 6.3.6, mortality litter inputs (M_{li}), and losses associated with decomposition of the litter pool (L_{decomp}):

$$\Delta C_{Li} = (L_{LF} + L_{HR} + M_{Li}) - L_{decomp} \quad \text{(6.3.11)}$$

where M_{Li} is the input to the litter pool from natural mortality (i.e. all aboveground dead material with a diameter less than 7 cm). This is derived from the $L_{mort(AB)}$ minus the timber fraction of the new dead pool (L ($_{mort(tim)}$):

$$M_{Li} = L_{mort(AB)} - L_{mort(tim)} \quad \text{(6.3.12)}$$

The decomposition losses of the new input litter (L_{decomp}) and existing litter pool (L_{old}) are calculated using decomposition factors of 0.14 taken from national research (Saiz et al. 2007; Black et al. 2009b):

$$L_{decomp} = 1 - \left[\sum[L_{LF}, L_{HR}, M_{Li}, L_{old}]^{-D_{Lt}}\right] \quad \text{(6.3.13)}$$

$$L_{old} = \sum[\{(L_{LF}, L_{HR}, M_{Li})_{n-1,n-2,n-x}), L_{ini}\}]^{-D_{LI}} \quad \text{(6.3.14)}$$

where, L_{ini} is the initial litter pool estimated following the completion of the first NFI in 2006 using constructed lookup stand attribute tables based on the FORECARB model. The remaining litter from the newly input litter, harvest residue and mortality pools from the previous years (n-1, n-2 etc) were accumulated following decomposition.

The accumulated litter pool was assumed to be immediately oxidised when deforestation occurs (i.e. reported as an emission in both CRF Table (4(B-F) and KP table 4(KP-I)A.2):

$$\text{Deforested } \Delta C_{Li} = L_{old} \times -1 \quad \text{(6.3.15)}$$

The accumulated litter pool for these deforestation events is derived from the initial litter pool look up tables as described above.

c) Deadwood Carbon Stock Change

Net deadwood stock changes (ΔC_{DW}) are derived from carbon inputs associated with timber extraction residue (L_{tr}), timber from mortality (M_{timber}), dead roots from mortality ($L_{mort(BB)}$), roots from harvest (L_{HRroot}) and carbon loss due to decomposition of the new and previously existing deadwood pool (D_{DW}):

$$\Delta C_{DW} = (L_{tr} + M_{timber} + L_{mort(BB)} + L_{HRroot}) - D_{DW} \quad \text{(6.3.16)}$$

A small amount (approximately 4 per cent, Tarleton (PTR Ltd) personal communication) of harvested timber is assumed to be left on site following harvest and this is used to estimate L_{tr}:

$$L_{tr} = L_{timber} \times RF \quad \text{(6.3.17)}$$

The deadwood input from natural mortality (M_{timber}) is derived from allometric equations applied to the DBH and H of dead trees after mortality iterations (see Annex 3.4.A.5.2.1), while $L_{mort(BB)}$ and L_{HRroot}

are known from the analysis for the litter pool. The decomposition losses from the new input deadwood carbon pool, existing decaying logs (DL_{old}) and decaying stumps (DS_{old}) are calculated using equation 6.3.18 based on decomposition factors of 0.095 for stumps and 0.076 for roots (Tobin et al., 2006):

$$D_{DW} = 1 - \left[\sum[L_{tr}, M_{timber}, DL_{old}]^{-D_{\log}\times t} + \sum[L_{mort(BB)}, L_{HRroot}, DS_{old}]^{-D_{St}}\right] \text{… …….. (6.3.18)}$$

The volume and decay class of logs and stumps, measured in permanent sample plots during the NFI 2006, are used to calculate the carbon stocks in the decaying deadwood pools DL_{old} and DS_{old}, respectively. In the case of decaying logs

$$DL_{old} = \sum_i [VL_i \times DDC_i \times CF]^{-D_{\log}\times t} + \left[\sum(L_{tr}, M_{timber}\right]^{-D_{\log}}_{(n-1,n-2,n-x)} \text{…………………… (6.3.19)}$$

where VL is the log volume of the specific decay class (*i*, n=4), DDC is the density of the specific decay class (*i*) and CF is the carbon fraction (0.5). The density and decay classes described by Tobin et al (2006) were used to calculate the deadwood carbon pools in the NFI permanent sample plots (NFI, 2007b). L_{tr} and M_{timber} (n-1, n-2,..x) is the accumulated deadwood from the stand modifier functions (equation 6.3.16 and Figure 6.3.5) within the CARBWARE model for previous years (n). Similarly, decay class and volume functions are used to derive the carbon pool of decaying stumps in NFI sample plots (Tobin et al 2006, NFI, 2007b):

$$DS_{old} = \sum_j [VS_j \times DDC_j \times CF]^{-D_{St}\times t} + \sum\left[L_{mort(BB)}, L_{HRroot}\right]^{-D_{St}}_{(n-1,n-2,n-x)} \text{……………..(6.3.20)}$$

where VS is the stump volume of the specific decay class (*j*, n=4), DDC is the density of the specific decay class (*i*) and CF is the carbon fraction (0.5). The density and decay classes described by Tobin et al (2006) are used to calculate the deadwood carbon pools in the NFI permanent sample plots (NFI, 2007b). $L_{mort(BB)}$ and L_{HRroot} (n-1, n-2,..x) is the accumulated deadwood from the stand modifier functions (equation 6.3.16 and Figure 6.7) within the CARBWARE model for previous years (n). The carbon stock of the deadwood pool in NFI plots are attributed to each permanent sample plot using a deadwood look up function in the stand attribute table of CARBWARE (Figure 6.6). The decomposition emissions of the old and new deadwood carbon pools are then calculated using decay constant described by Tobin et al. (2006).

The accumulated deadwood and litter pools (DS_{old} and DL_{old}) are assumed to be immediately oxidised when deforestation occurs so that

Deforested $\Delta C_{DW} = (DL_{old} + DS_{old}) \times -1$ …………………………………………..(6.3.21)

The accumulated deadwood pool for these deforestation events is derived from the mean deadwood carbon pool of the forest category and age class, based on analysis of the NFI permanent sample plots.

d) Soils

Soils are classified into three major groups; mineral, peat and peaty/mineral soils. Peat soils are organic soils with a depth greater than 30 cm and peaty/mineral soils are a continuum between the peat and mineral categories. The IFS further defines mineral soils are classified into 14 sub-groups as reported in the NFI (see Section 6.3.2.3).

Mineral soils

Current research suggests that mineral soils in Ireland do not represent a source of carbon emissions following land use transition, so carbon stock changes are reported as NO (see Ch 11, section 11.3, Wellock et al., 2011). Prior to the first NFI in 2006, detailed methods were not available to historically track land use changes associated with the IPCC default, or our country specific, soil type classifications. This means that no soil type activity data is available to apply the tier 1 approach for mineral soils transitions of lands to forest land. Numerous national research projects are underway to develop these approaches (see section 6.11)

i) Forest remaining forest land

The Tier one approach for mineral soil carbon stock changes for forest land remaining forest land is applied (i.e. no stock change (NO) see 4.2.3.1 Ch4 Volume 4 of the 2006 IPCC guidelines)

ii) Cropland forest conversion

Application of Tier one approaches and country specific data (see table 11.4, Chapter 11) would suggest that cropland transitions to forestry would result in a net increase in carbon stocks of mineral soils. However, these cannot currently be estimated (NE, CRF 4(A-2.1) due to a lack of historical data on soil types for cropland transitions to forest land. However, the ability to identify these transitions will be investigated (see section 6.11).

Although justification is required if a pool is not estimated, based on the significance of exclusion of *emission* (see paragraph 37b of decision 24/CP.19), this only applies to emissions. Since cropland mineral soil stocks are likely to be a net removal of C, no justification is required.

iii) Grassland-forest conversions

Although Ireland does not have all required activity data, the stock change for grasslands will be zero if country specific and default approaches are applied to the Tier 1 approach outlined in Eq 2.25 in Chapter 2 Volume 4 of the 2006 IPCC guidelines. However, as seen in Figure 11.4 of Ch11, carbon stocks for mineral soils are not significantly different when forest and all grassland types are compared. If this data is applied to Eq 2.25 in Chapter 2 Volume 4 of the 2006 IPCC guidelines, the country specific stock change factors for land use (F_{LU}) and management (F_{MG}) are one. The F_{MG} categories are pasture and rough grazing (Fig 11.4, Ch11) and there are no additional input into these grassland types (i.e. medium level F_I =1, Table 6.2, chapter 6 Volume 4 of the 2006 IPCC guidelines). Therefore, the stock change for mineral soils would be zero for grassland forest transitions so and it is reported as NO in CRF table 4(A-2.2).

iv) Other-forests conversions

There are no mineral soils in the wetland category and no conversions from settlement or other land to forest land (reported as NO in CRF table 4(A-2)

Organic soils

On site emissions from peat soils given by equation 6.3.22 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.

$$\Delta C_{So} = \sum_i \left(A_i \times EF_{soil} \right) \text{...(6.3.22)}$$

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 0.58 t C/ha^{-1}.yr^{-1} for the first 50 years following afforestation and is zero thereafter. Emissions from peaty/mineral soils are calculated in the same way (equation 6.23), 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,

$$\Delta C_{So} = \sum_j \left(A_j \times EF_{soil} \times SD \right) \text{ ....(6.3.23)}$$

and

$$SD = \frac{depth(cm)}{30cm} \text{ ....(6.3.24)}$$

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/year 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 currently no research information on the partitioning of soil respiration between heterotrophic and autotrophic processes in peatland 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/year 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/year, the transition period is much longer than the previously used default periods. The accumulated default emission of 29.5 t/ha over 50 years is now more than 2 fold higher than the previously used methods (i.e. 13.6 t C/ha to Tier 1 and 14 t C/ha 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 tC/ha/year 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 simply 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.

6.3.3.1.3 Scaling and Aggregation of Permanent Sample Plots into Different Reporting Categories

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 (see Figure 6.56). Each tree in the sample is thus replicated a number of times equal to its expansion factor. This replication is allowed for when calculating variables derived at plot level, such as density, by incorporating the expansion factor into the equations. 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:

$$\frac{R_3^2}{R_i^2} \qquad \text{……(6.3.25)}$$

where R_i denotes the radius of the concentric circle associated with the *i* th diameter class.

In practice, the expansion factor, or weight, is used to estimate plot-level features, e.g. basal area. In such calculations, the number of trees of the *i* th diameter class that were not included in the sample is estimated by $\frac{R_3^2}{R_i^2}$ x n_i, where n_i is the number of trees of the *i* th class that are included in the sample.

The expansion factor therefore defines the relationship between each included tree and the estimated number of trees of the same class that were not included (Equation 6.3.25).

$$n_{ij} \times EF_{ij} = \hat{N}_{ij} \qquad \text{……(6.3.26)}$$

where n_{ij} _ EXF_{ij} is the product of the expansion factor for the *j* th tree in the *i* th class, and $\check{N}_{ij}$ is the corresponding estimate. In the terminology of the NFI, the RHS of Equation 6.3.26 is the representative tree number. With minor and obvious changes to the equation, we can calculate other tree-level estimates, including representative basal area, and individual-tree estimates can be aggregated for the entire plot to give plot-level estimates, including representative density. For example the aboveground biomass carbon of a plot (t C/ha) $GTOTAL_{(AB)}$ of a plot is calculated as:

$$GTOTAL_{(AB)} = \frac{\sum [ABij \times EXFij] \times 20}{1000} \qquad \text{……(6.3.27)}$$

where, 20 is the factor used to scale up to 1 ha and 1000 is used to convert kilogrammes of biomass carbon to tonnes.

For convention reporting the total gains or losses for each pool and soil category is calculated as the sum of the pool scaled up using the representative area of PSP within respective categories. 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 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:

New sub-category area (4.809 kha) $=(\frac{12}{650})\times 260.47$

These calculations are carried out automatically by the CARBWARE software and were subject to QA/QC checks during the coding of the software.

6.3.3.1.4 Datasets Used to Develop the CARBWARE Models

a) Permanent Sample Plot

The pre-processing, growth and mortality model was calibrated on data extracted from the permanent sample plot record system of Coillte Teoranta (the Irish Forestry Board state commercial forestry company). Broad and Lynch (2006b) provide details of the dataset in the context of modelling plot volume. The database consists of records of many silvicultural and thinning trials. These longitudinal trials were established from the 1950s onwards, and were initially established as replicated and blocked experimental designs (Broad and Lynch, 2006a).

b) Pre-processing functions

Raw data in the single tree tables and stand attributes are pre-processed by the CARBWARE software to provide variables used in the growth and modification models. In some cases, not all required variables, such as tree height (H) and crown ration (CR) are measured. These missing values are estimated using functions described in Annex 3.4.A.5.1.

c) Growth models

The availability of only one NFI cycle meant that that the CARBWARE model had to be developed and adapted to estimate carbon stock changes. This has been done by using diameter increment models for all trees with a DBH greater that 5cm and H increment models for trees with DBH less than 5cm (Annex 3.4.A.5.2). The generated DBH and H values, produced after each growth iteration, were then used to derive biomass estimates for a range of different biomass functions (Annex 3.4.A.4, Table 3.4.A.4.a).

d) Stand modification functions

The NFI permanent plots structure is modified at the end of each growth cycle to simulate the losses associated with natural mortality and harvest (see Annex 3.4.A.5.2).

6.3.3.2 FORCARB

The FORCARB model is used to calculate CSC for the historic time series from 1990 to 2006. This is then adjusted (see figure 6.3.1) to ensure a time series consistency. The FORCARB model uses a similar C flow modelling approach as described for CARBWARE, 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 6.5 Breakdown of species used in the pre-1990 and post-1990 forest categories

Cohort	**Species table**	**Proportion**
Spruce	Sitka spruce	0.593
Pine	Lodgepole pine	0.307

Larch	Japanese Larch	0.081
FGB	Sycamore, Ash, Birch	0.004
SGB	Beech	0.016

The yield class categories, silviculture and rotation age for each species within the pre-1990 and post-1990 categories for the period 1990-1999 were derived from the FIPS 95 dataset, modified from Gallagher et al, (2004, see Table 6.5). 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, see annex 3.4.A.4) 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 6.6 Yield class, silviculture and rotation criteria selected for periods 1990-1999 and 2000-2012

Species cohort	Yield class	Proportion of cohort	Silviculture	Rotation
Period :1990-1999 (Source FIPS 95)				
Spruce	10	0.37	No thinning	MMAI
	16	0.26	No thinning	MMAI
	20	0.20	Thin	MMAI less 20%
	24	0.17	Thin	MMAI less 20%
Pines	10	1.00	Thin	MMAI
Larch	10	1.00	Thin	MMAI
FGB	6	1.00	Thin	MMAI
SBG	6	1.00	Thin	MMAI
Period :2000-2012 (Source NFI-Coillte intersect)				
Spruce	10	0.37	No thinning	MMAI
	16	0.13	No thinning	MMAI
	20	0.20	Thin	MMAI less 20%
	24	0.17	Thin	MMAI less 20%
	16	0.13	No thinning	MMAI less 30%
Pines	10	0.30	No thinning	MMAI
	10	0.80	No thinning	30% less MMAI
Larch	10	1.00	Thin	MMAI
FGB	6	1.00	Thin	MMAI
SBG	6	1.00	Thin	MMAI

MMAI is maximum mean annual increment, which determines the age of clearfell.

Stand biomass (*St*) was expressed as:

$$St = Mt\left[\frac{1-e^{-k_s(k_t-t)}}{1-e^{-k_s k_t t}}\right] \quad \text{...(6.3.28)}$$

where:

$$Mt = \frac{Cm}{Rm}\ln\left[1+\frac{Co}{Cm}e^{Rmt}\right] \qquad (6.3.29)$$

where:

Mt is Monteith's function, *Cm* is maximum growth rate, *C*o is initial absolute growth rate and *R*m is the initial relative growth rate and *t* is time (years). Parameters *Cm, Rm, Co,* k_s and k_t were fitted using the least squares optimisation method to estimated stand biomass values.

The annual increment in above or below ground biomass for any given year was then calculated as:

$$\Delta C_b = St_{n+1} - St_n \qquad (6.3.30)$$

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. 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* and *4.A.2 Land Converted to Forest Land (see* section *6.3.4).*

Age class distributions were derived from afforestation records for the category *4.A.2 Land Converted to Forest Land.* 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 (see section 6.3.4).

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 CARBWARE 2006 to 2012 data (see section 6.3.4.1). Emissions form soils were not rescaled because this was derived directly using eq. 6.3.23 and 6.3.24 once areas on mineral, peaty mineral and peat soils were determined (see section 6.3.3.1.2).

6.3.4 Forest land remaining forest land (CRF 4.A.1)

Table 6.8 shows the net biomass, dead organic matter, soil C and CO_2 emissions/removals for the time series 1990-2016 for forest land remaining forest land (i.e. all forest established before 1990 reported in *4.A.1*). For the historical time series 1990 to 2006, the adjusted FORCARB estimates are reported. For the 2007 to 2016 time series, the CARBWARE model estimates are reported (Table 6.7)

The FORCARB model (see 6.3.3.2) 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 6.11). Figure 6.11 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 6.11).

It can be seen from Figure 6.11 that both the FORCARB and published age-class distributions (Black et al., 2012) show the same trends over the time series. There is 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. 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). These trends in combination with the increased harvest trends and higher emissions form harvest residues in the DOM pools over the time series appears to be the main driver of the observed decrease in removals by the pre-1990 forest category as suggested by Black et al., 2012.

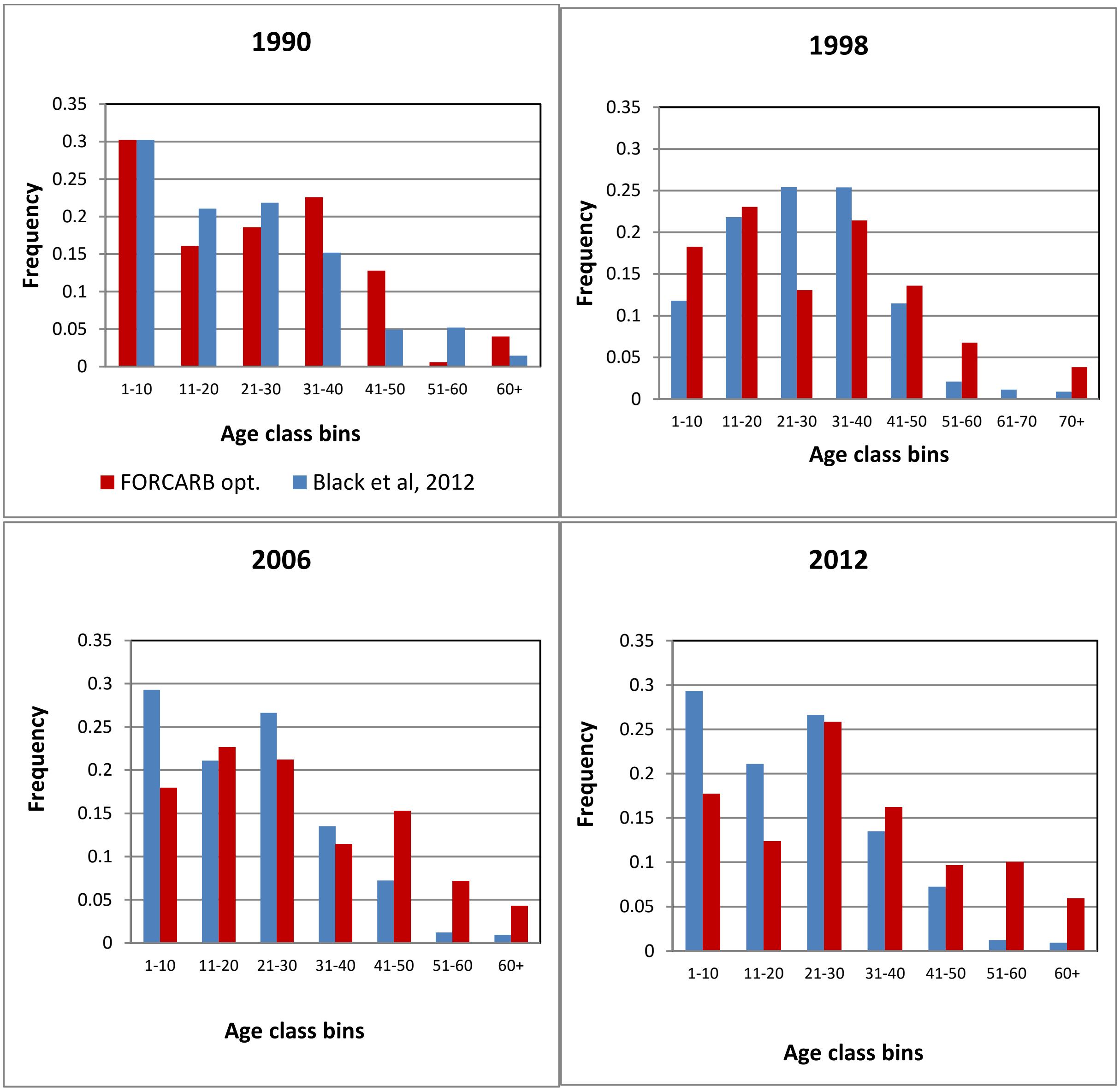


Figure 6.11 Validation of optimised age-class distributions

Table 6.7 Time series data for the forest category 4.A.1

Year	Area (kHa)		CSC (kt C)						Net CO_2 (kt CO_2)	Harvests[1] (M m^3)	
			Living biomass			DOM	Mineral Soils	Organic soils			
	Total	Organic	Gain	Loss	Net	Net	Net	Net	Total	EUROSTAT	Modelled
1990	465.26	277.87	2628.45	-1633.17	995.28	-74.46	NO	-151.44	-2821.05	1.78	1.68
1995	464.84	277.85	2724.43	-2016.14	708.29	-61.91	NO	-150.62	-1817.76	2.35	2.38
2000	462.65	277.62	2766.10	-2429.68	336.43	58.36	NO	-147.97	-905.00	2.76	3.00
2005	458.37	276.47	2767.79	-2526.01	241.78	103.95	NO	-143.40	-741.88	2.74	2.92
2007	454.77	273.67	2789.64	-2529.67	259.98	126.47	NO	-140.63	-901.33	2.48	2.86
2008	452.77	272.87	2816.55	-2229.10	587.45	74.22	NO	-138.19	-1919.42	2.16	2.21
2009	451.97	272.47	2831.88	-2320.25	511.63	99.55	NO	-137.26	-1737.71	2.24	2.68
2010	451.17	272.47	2864.00	-2668.44	195.56	149.08	NO	-135.55	-766.67	2.63	3.04
2011	449.57	272.07	2802.58	-2682.68	119.91	130.12	NO	-133.24	-428.20	2.60	2.73
2012	449.57	272.07	2749.39	-2881.78	-132.39	195.11	NO	-131.32	251.54	2.63	2.74
2013	449.53	272.07	2563.41	-2667.36	-103.95	231.26	NO	-129.78	9.07	2.81	2.83
2014	449.40	271.97	2452.82	-2574.05	-121.23	255.08	NO	-127.43	-23.55	2.22	2.22
2015	449.14	271.81	2431.40	-2594.04	-162.64	330.50	NO	-123.39	-163.04	3.22	2.59
2016	449.08	271.80	2372.97	-2462.22	-89.25	263.99	NO	-123.15	-189.17	2.46	2.47

[1] The harvest volumes show a comparison of the EUROSTAT and modelled harvest using FORECARB and the CARBWARE model. Note: the harvest volumes are calculated as total harvest (FAO/EUROSTAT) minus post-1990 forest harvests minus the deforestation harvest

6.3.4.1 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 2006 FORCARB series was adjusted (Figure 6.12) and rescaled using tier 1 2006 IPCC guidelines time series overlap approaches (Volume 1, Chapter 5):

a) Living biomass gains (*LBgian*, kt C) from the 2007 to 2012 time series for the CARBWARE and FORCARB model outputs were compared. The ratio (2.19) of the total CARBWARE and FORCARB LBgain values for 2007-2012 was used to adjust the time series:

$$LB\ gain_{adj} = LB\ gain_{ini.} \times 2.19 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots\ldots (eq\ 6.3.31)$$

where, $LBgain_{adj}$ is the adjusted living biomass gain value and $LBgain_{ini}$ is the initial FORCARB estimate. This method is consistent with eq 5.1 Chapter 5, Volume 1 2006 IPCC guidelines.

b) The adjusted biomass losses (*LBloss*) were scaled using the ratio of living biomass gains to living biomass losses, derived for each year in the 1990-2006 time series. For example the adjustment for 1990 is:

$$LB\ loss_{adj(1990)} = LBgain_{adj(1990)} \times \frac{LB\ loss_{ini(1990)}}{LBgain_{ini(1990)}} \ldots\ldots\ldots\ldots..\ldots\ldots (eq\ 6.3.32)$$

c) For dead organic matter (DOM), the ratio (-1.51) of the average CARBWARE to average FORCARB values for 2007-2012 was used to adjust the time series:

$$DOM_{adj} = DOM_{ini.} \times -1.51 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (eq\ 6.3.33)$$

d) There were no adjustments to the soil EF, since the FORCARB and CARBWARE estimates were identical.

Figure 6.12 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 6.8Table 6.. Both time series show the same trend but the adjusted values show a higher net removal of CO_2. This is due to fundamental differences in the model input variables and the spatial scale at with the FORCARB and CARBWARE 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 CARBWARE model imposes harvest when this is indicated in the NFI or felling licence records, as this gives a clear indication that the land owner intends to harvest a site. Also rotation ages as prescribed in the BFC are generally higher that those imposed under current management practice (Black et al., 2007; 2012);

b) Predefined stocking rates in the FORCARB model, which are generally under estimated, when compared to the real situation as evident from NFI data and national research (Black et al., 2007). This would result in an underestimation of LBgains when the FORCARB model is run;

c) Differences in the current annual increment when BFC yield table (as used in FORCARB) are compared to NFI (CARBWARE) and national research information;

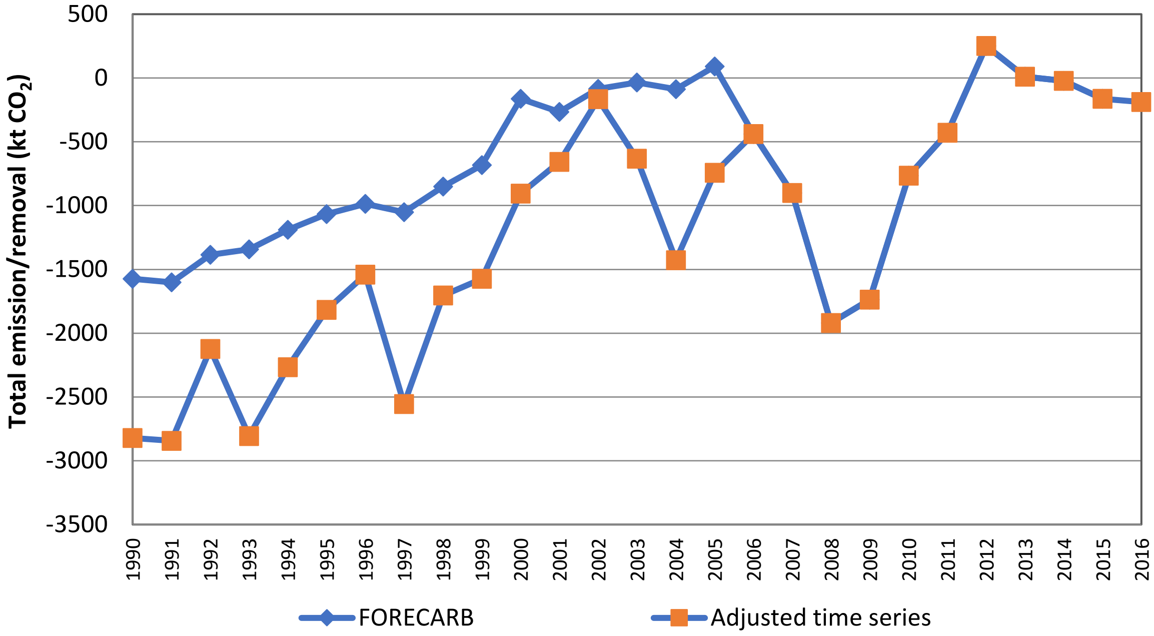


Figure 6.12 Adjusted time series for forest category 4.A.1

d) The CARBWARE 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 CARBWARE 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.

6.3.4.2 Mineral soils

The tier 1 approach is applied, which assumes that the carbon stock change (CSC) in mineral soil organic matter for category 4.A.1 Forest Land remaining Forest Land (FL-FL) is *zero.* Therefore, the notation key NO is reported for mineral soils under this land category in CRF Table 4.A.

6.3.4.3 Organic Soils

Emissions from the drainage of organic soils are reported using eq.6.3.23 and 6.3.24, described in section 6.2. 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 2012 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 (2006 and 2012) 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, 2007), 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 (see justifications in section 6.3.3.1.2, d) soils).

Table 6.8 Area (in kHa) and emissions from organic soils over the times series for forest land remaining forests

					Drained productive area		Sites < 50 years old (Drained productive area)		On-site emissions		Off-site DOC emissions		Total
Year	**Total Area[1]**	**Mineral**	**Organic**	**Open area [2]**	**Organic [3]**	**Organo-mineral[3]**	**Organic [4]**	**Organo-mineral[4]**	**Orgainic[5]**	**Organo-mineral[5]**	**Orgainic[6]**	**Organo-mineral[6]**	
	(kHa)								kt C				kt CO_2
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
2007	454.8	181.1	273.7	42.4	215.5	31.0	94.7	25.3	-55.9	-8.3	-66.8	-9.6	515.6
2008	452.8	179.9	272.9	42.7	214.3	30.8	91.9	24.3	-54.2	-8.0	-66.4	-9.5	506.7
2009	452.0	179.5	272.5	42.9	213.9	30.7	90.8	23.8	-53.6	-7.9	-66.3	-9.5	503.3
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	449.5	177.5	272.1	43.6	212.2	30.5	80.6	21.1	-47.5	-7.0	-65.8	-9.5	475.9
2014	449.4	177.4	272.0	43.6	212.1	30.5	77.6	19.6	-45.8	-6.4	-65.8	-9.5	467.2
2015	449.1	177.3	271.8	43.6	212.0	30.5	71.5	17.9	-42.2	-6.1	-65.7	-9.4	452.4
2016	449.1	177.3	271.8	43.6	212.0	30.5	71.2	17.6	-42.0	-6.0	-65.7	-9.4	451.5

[1] Total area includes open areas

[2] Open area within forest areas (roads, extraction routes, biodiversity etc).

[3] Area of drained organic (org.) and organo-mineral soils based in NFI 2006 and 2012 (excluding open areas). Organic soils include all soils with a > 20% C and an organic layer greater than 30 cm (e.g. Blanket peats, fens, cutaway peats. Organo-mineral soils are mineral soils with an organic overlay of < 30cm. These include peaty podsols and peaty gleys (Source NFI).

[4] No emissions from drained organic soils on sites older than 50 years old, (Data source NFI)

[5] 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 less than 50 years old.

[6] 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 estimates are recalculated in this submission based on new biomass, and DOM input estimates from the CARBWARE model for forest in 2012. In order to incorporate the effect of forest fires into CARBWARE, the following assumptions were made:

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 6.9Table 6.). 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 (GPG LULUCF 2003 Table 3 A 1.15). For nitrous oxide a C:N ratio of 0.01 is assumed. The overall implied emission factor for all GHGs as reported in CRF 4(V) is 290 t CO_2 eq/ha compared to an IEF of 39 t CO_2 eq/ha 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 ha 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 tC ha^{-1}, equivalent to 149,450 kg biomass d.wt ha^{-1}. The average C stock for litter and deadwood is estimated to be 14.1 tC ha^{-1}, equivalent to 28,263 kg biomass d.wt ha^{-1}. For the land converted to forest land category, the average aboveground biomass C stock of a 18 year old YC 16 crop is 45.3 tC ha^{-1}, equivalent to 90,526 kg biomass d.wt ha^{-1}. The average C stock for litter and deadwood is estimated to be 6.5 tC ha^{-1}, equivalent to 12,959 kg biomass d.wt ha^{-1};

5) Emissions from soils are assumed to negligible and are reported as not occurring (NO);

6) 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_2O from organic and synthetic fertilisers

Ireland does not report separately the emissions of N_2O due to nitrogen fertiliser use for *4.A Forest Land*. The amount of synthetic fertiliser used in forests is negligible compared to that used in Agriculture. N_2O emissions from fertiliser applications are based on national fertiliser sales data reported under Agriculture. The notation key IE is therefore used in CRF Table 4(I).

6.3.4.6 Emissions of N_2O and CH_4 from drainage and rewetted organic soils

a) N_2O from drained organic soils

Tier 1 estimates of N_2O emissions due to the drainage of organic soils in forest lands were first reported in 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), rich N organic (peaty-gleys or organo-mineral soils) and poor N 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 arterial drainage scheme 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 6.10). The productive drained areas of the 2 organic soil categories was used to estimate N_2O emissions using equation 11.1 in the 2006 IPCC Guidelines.

The 2013 IPCC Wetland supplement recommends only one EFs for drained temperate forest (2.8 kg N_2O-N per ha per year) 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 0.7kg N_2O per ha per year. Therefore, we have adopted to use the default EF for nutrient rich organic soils (2.8 N_2O-N per ha per year) and a country specific EF of 0.7 kg N_2O per ha per year for nutrient poor organic soils, since this is more reflective of national circumstances (Table 6.10). The decline in N_2O emissions from organic soils in the forest land remaining forest land category since 1990 is due to a reduction in drained areas due to deforestation activities (Table 6.10).

Table 6.9Area statistics and emission profiles over the time series 1990 to 2016 for wild fires in categories 4.A.1 and 4.A.2 and reported in table 4(V)

	F-F land (pre-1990)							F-L (post 1990)					
	Fire area	Prop area burned	Biom&DOM	CO_2	CH_4	N_20	CO_2 eq	Prop area burned	Biom&DOM	CO_2	CH_4	N_20	CO_2 eq
	Ha		t	kt					t	kt			
1990	389.00	1.00	69130.75	101.39	0.44	2.58E-03	113.22	NO	NO	NO	NO	NO	NO
1995	508.00	1.00	90278.72	132.41	0.58	3.37E-03	147.86	NO	NO	NO	NO	NO	NO
2000	334.00	1.00	59356.48	87.06	0.38	2.22E-03	97.21	NO	NO	NO	NO	NO	NO
2005	200.00	1.00	35542.80	52.13	0.23	1.33E-03	58.21	NO	NO	NO	NO	NO	NO
2007	224.83	1.00	39955.44	58.60	0.26	1.33E-03	65.44	NO	NO	NO	NO	NO	NO
2008	273.55	0.64	31056.17	45.55	0.20	1.49E-03	50.86	0.36	10223.96	15.00	0.07	3.82E-04	16.74
2009	154.48	0.63	17392.65	25.51	0.11	1.16E-03	28.49	0.37	5858.42	8.59	0.04	2.19E-04	9.59
2010	1013.09	0.63	113040.74	165.79	0.72	6.49E-04	185.14	0.37	39014.69	57.22	0.25	1.46E-03	63.90
2011	375.55	0.63	42047.05	61.67	0.27	4.22E-03	68.86	0.37	14379.80	21.09	0.09	5.37E-04	23.55
2012	95.00	0.63	10636.18	15.60	0.07	1.57E-03	17.42	0.37	3637.50	5.34	0.02	1.36E-04	5.96
2013	408.36	0.61	44268.20	64.93	0.28	3.97E-04	72.50	0.39	16480.97	24.17	0.11	6.15E-04	26.99
2014	328.47	0.60	34766.62	50.99	0.22	1.65E-03	56.94	0.40	13747.16	20.16	0.09	5.13E-04	22.51
2015	184.17	0.59	19340.62	28.37	0.12	1.30E-03	31.68	0.41	7796.27	11.43	0.05	2.91E-04	12.77
2016	37.41	0.59	3896.08	5.71	0.02	7.22E-04	6.38	0.41	1602.17	2.35	0.01	5.98E-05	2.58

b) CH_4 from drained lands and ditches

Estimation of CH_4 emissions from drained organic soils and forest drain ditches are based on the same activity data used for the determination of N_2O emissions with additional information on the fraction of land covered by drain ditches using Eq. 2.6 of Ch 2 of the IPCC Wetland Supplement 2013.

The default emission factors for $EF_{CH4land}$ (2.5 kg CH_4 per ha per year, Table 2.3 of the Wetland supplement 2013) and $EF_{CH4ditch}$ (217 kg CH_4 per ha per year, Table 2.4 of the Wetland supplement 2013) are used. The fraction of the total areas which is occupied by ditches ($Frac_{Ditch}$) was derived using country specific information (Forestry Scheme manual, 2003; Mulqueen et al., 1999) which specifies drain spacing's. For poor organic soils, such as blanket peats, these typically have 0.3m drains every 12m, which equates to a $Frac_{Ditch}$ of 0.0249. This derived country specific $Frac_{Ditch}$ for forest bogs are within the ranges reported for forest bogs and peats reported in Table 2A.1 in Annex 2A.2 of the IPCC Wetland supplement 2013. Richer organo-mineral soils, such as peaty gleys or peaty-podzols require drains every 80m, which is equivalent to a $Frac_{Ditch}$ of 0.00375.

The decline in CH_4 emissions from organic soils in the forest land remaining forest land category since 1990 is due to a reduction in drained areas due to deforestation activities (Table 6.10).

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_2O emissions from mineral soils as a result of land use change of management (F_{SOM})

Emissions of N_2O 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 6.10 The activity data and N_2O and CH_4 emissions from drainage of forest land remaining forest land

	Area (kHa)				kt N_2O			kt CH_4		
Year	Total Area	Open area	Organic N-poor	Organic N-rich	Organic N-poor	Organic N-rich	Total N_2O	Drained lands	Ditches	Total CH_4
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	462.7	41.3	220.2	31.7	0.15	0.14	**0.29**	0.62	1.22	**1.83**
2005	458.4	42.0	217.7	31.3	0.15	0.14	**0.29**	0.61	1.20	**1.81**
2007	454.8	42.4	215.5	31.0	0.15	0.14	**0.29**	0.60	1.19	**1.79**
2008	452.8	42.7	214.3	30.8	0.15	0.14	**0.29**	0.60	1.18	**1.78**
2009	452.0	42.9	213.9	30.7	0.15	0.14	**0.28**	0.60	1.18	**1.78**
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	449.5	43.6	212.2	30.5	0.15	0.13	**0.28**	0.59	1.17	**1.76**
2014	449.4	43.6	212.1	30.5	0.15	0.13	**0.28**	0.59	1.17	**1.76**
2015	449.1	43.6	212.0	30.5	0.15	0.13	**0.28**	0.59	1.17	**1.76**
2016	449.1	43.6	212.0	30.5	0.15	0.13	**0.28**	0.59	1.17	**1.76**

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. If no estimates were available expert judgement was applied (Table 6.12). Some uncertainties cannot be quantified due to a lack of validation data. These include uncertainties associated with mortality models. However, mortality factors are selected where a tree has a 95 per cent probability of being dead (Annex 3.4.A.5).

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 and litter pools are derived from DBH increment models and biomass equations. However, the simple tier 1 method is adopted until the capacity to develop Monte Carlo approaches is developed and reported in future submissions.

The percentage input uncertainties in the various methodological parameters used for the analysis of carbon stock change in the relevant carbon pools and for the emissions of non-CO_2 gases are listed in Table 6.13. The combined uncertainties of the products of the respective parameters associated with each component pool are calculated using equation 6.3.34 (equation 3.1, Chapter 3, Vol 1, 2006 IPCC guidelines)

$$U_{total} = \sqrt{U_1^2 + U_2^2 + U_3^2 + U_n^2} \quad \text{..........(6.3.34)}$$

Where:

U_{total} is the combined uncertainty of the product of the input values U_1, U_2, U_3 and U_n given in Table 6.11, which also indicates the associated input parameters whose uncertainties have been combined. The uncertainties in the reported carbon stock changes reported in the CRF tables are calculated in Table 6.18 as the sum of the uncertainties for carbon pools using equation 6.3.35 (equation 3.2 Chapter 3, Vol 1, 2006 IPCC guidelines):

$$U_{total} = \frac{\sqrt{(U_1 \times x_1)^2 + (U_2 \times x_2)^2 + (U_n \times x_n)^2}}{|x_1 + x_2 + x_n|} \quad \text{..........(6.3.35)}$$

Where:

U_{total} is the combined uncertainty, U_1, U_2 and U_n are the uncertainties of pool estimates (Table 6.13) and x_1, x_2 and x_n are the mean values for the respective pools reported in the CRF tables.

For deriving uncertainties for code C in Table 6.12, CARBWARE DBH and H growth models were validated using repeated NFI permanent sample plot data taken in 2012. These represent repeat measurement of 1150 plots taken at a 3-6 year interval. Since modelling errors include NFI measurement and sampling errors, specific consideration was focused towards identifying sampling errors associated with the methodology employed by the Forest service (NFI data providers) and assessing model error (both sources of error in assessing biomass stock changes):

Table 6.11 Uncertainty estimates for individual activity and area data sets for forest land remaining forest land

Code	Component	Sub-category	% Uncertainty	Source
A	Biomass algorithms	AB and BB	12.0	Black et al., 2007
B	C fraction	All biomass pools	0.9	Black et al., 2007
C	DBH and H Increment	AB and BB	11.9	Black et al., 2007, Black 2008, Black et al., 2009 section 6.3.2
D	Area data	GPAS data	0.6	Derived from Black et al 2009a Table 2 Comparison of NFI and GPAS data
E	Litter	Li	3.1	Tobin et al, 2006
F	Deadwood	DW	22.0	Tobin et al, 2007
G	Peat soils	So	90.0	Assume same as Tier 1 (Table 2.3,2.3.1 Ch2, 2006 IPCC Guidelines)
H	Fire C stocks	fire	15.0	95 % confidence interval for biomass stocks (NFI)
I	Areas burned	fire area	50.0	Expert Judgement
J	re-scaling of FORECARB	LB	3.1	% sd of ratio of CABWARE/FORECARB
K	re-scaling of FORECARB	DOM	28.5	% sd of ratio of CABWARE/FORECARB
L	N_20	N_20 and CH_4 area	12.3	Conf. interval of NFI analysis
M	N_20 EF	N_20 emissions drained	119.0	Wetland supplement Table 2.5 and Yamulki et al., 2013
O	CH_4 LAND EF	CH_4 emissions drainage	87.2	2013 Wetland supplement Table 2.4
P	CH_4 DITCH EF	CH_4 emissions drainage	126.0	2013 Wetland supplement Table 2.3
Q	Soils DOC	So	43.5	2013 Wetland supplement Table 2.1

Table 6.12 Combined uncertainty estimates for forest land remaining forest land pools

	Component	Equation in NIR	% uncertainty	Uncertainty of combined products (code)
LB net	Biomass	Eq6.3.2	17.2	A+B+C+D+E+J
DOM	DOM	6.3.16 and 6.3.11	36.2	D+E+F+K
SO	Soils	6.3.24	100.0	D+G+Q
Fires	Fire	Section 6.3.3.4	59.4	H+I
N_20	Drainage of soils	2006 IPCC Guidelines	119.6	L+M
CH_4	Drainage of soils	2006 IPCC Guidelines	153.7	L+O+P

a) Accuracy of repeated DBH measurements

An infield validation check was used to ensure the corresponding tree was measured in the repeat inventory based on a spatial query of mapped trees. Measurement error of diameter and height was not checked infield or validated before entry into the data base. This resulted in a significant occurrence of negative increment data (5 to 12 per cent of data) which was removed prior to model validation. In addition, trees with a DBH increment > 15 cm over the NFI 5 year cycle and with increment values higher than 2 times the plot standard deviation were removed from the database. Zero increments from harvested trees were also removed from the database to ensure Wilcoxon ranked tests could be interpreted properly. However, no further attempts were made to clean data with erroneous measurements in the remaining data.

b) Partial sampling of trees within a plot

Data on trees within three diameter classes (<12, 12-20 and >20 cm) are recorded if they are observed within a certain distance from the plot centre in three concentric plots within the 0.5 ha plot. This represents an additional sampling area and increases the probability of a lower representative sample of smaller, compared to larger trees. Performance of model calibration was assessed using root mean squared error (RMSE), accuracy (a measure of bias), precision and theoretical excess error.

Data were further stratified to investigate reasons for the large variation in growth increment prediction residuals across different species cohorts, DBH size classes, forest types and management regimes. Comparisons of model accuracy, bias and precision across different species cohorts and size classes show poor performance of the model in some cases (Table 6.12). Stratified cohort groups all had lower empirical excess error (Table 6.13), when compared to the theoretical excess error except for the SGB cohort, suggesting that the variation in the NFI model residuals is smaller than the random theoretical expected variation in the calibration dataset.

For all DBH categories, Spruce, Pines, Other conifers (OC) and Slow growing broadleaves (SGB) shows good agreement with the model with no significant difference between observed and simulated values ($P > 0.05$). In contrast, Fast growing broadleaves (FGB) and Larch showed poor agreement with the model predictions showing significant differences between observed and predicted values (Table6.13). Larch and FBG showed a 27 per cent lower and 128 per cent higher growth rate than the model prediction, respectively.

This analysis (Table 6.13) and the uncertainty of biomass equations (annex 3.4.A.4) show that the largest uncertainty is associated with broadleaf cohorts. Current national research is being conducted to improve biomass gains and loss estimated for these cohorts.

Table 6.13 NFI external validation of CARBWARE models

Cohort	<12 cm	12-20 cm	20-30 cm	30-40 cm	>40 cm	All classes
Spruce						
Accuracy	-0.42	0.09	0.28	0.09	-0.73	0.17 (4.8%)
Precision	1.94	1.9	1.86	1.91	2.09	2.04
P-value	<0.01	0.37	0.14	0.55	0.03	0.36
E_{imp}						9.80%
N	204	1234	1092	226	48	2804
Pines						
Accuracy	-0.3	0.13	0.14	-0.59	ND	-0.21 (-9.4 %)
Precision	1.37	1.62	1.61	3.17	ND	2.25
P-value	0.037	0.23	0.52	<0.01	ND	0.29
E_{imp}						0.40%
N	56	342	379	44	6	827
Larch						
Accuracy	ND	-1.59	0.48	ND	ND	-0.88 (-27.8 %)
Precision	ND	2.13	1.38	ND	ND	2.14
P-value	ND	<0.001	0.05	ND	ND	<0.001
E_{imp}						7.90%
N	8	54	36	4	0	102
OC						
Accuracy %	ND	-0.21	-0.53	-1.14	ND	-0.51 (-21.4 %)
Precision	ND	1.34	1.69	1.83	ND	1.65
P-value	ND	0.544	0.05	0.02	ND	0.06
E_{imp}						14.70%
N	5	77	66	31	19	198
FGB						
Accuracy	<0.001	1.44	3.06	4.19	ND	2.0 (128.1 %)
Precision	1.49	1.85	1.87	2.47	ND	2.28
P-value	0.2	<0.001	<0.0001	<0.0001	ND	<0.0001
E_{imp}						8.70%
N	64	194	183	35	19	495
SGB						
Accuracy	ND	-0.28	-0.23	-0.67	-1.24	-0.50 (-30.5 %)
Precision	ND	1.27	1.73	1.7	1.91	1.68
P-value	ND	0.37	0.75	0.17	<0.001	0.11
E_{imp}						55.10%

Tier 1 time series trend analysis was also conducted. The increased uncertainty in the trends based on the 1990 base year are associated with increase harvests and age class distribution shifts over the time series, as described in text relating to

Table Table 6.5 and Figure 6.6.

Table 6.14 Uncertainty analysis for forest land remaining forest land since 1990 [3]

Year	Category	Year (kt CO_2 eq)	Base year (kt CO_2eq)	Combined uncertainty in year (±%)	Contribution to total variance in year (fraction)	Mean trend in relation to base-year (% mean trend)
1990	CRF 4A.1	-2821.0	-2821.0	29.9	0.8	na
	CRF 4 (II)	134.0	134.0	78.5	0.1	na
	CRF4(V)	113.2	113.2	59.4	0.1	na
	Total	-2573.8	-2573.8	33.2	1.0	**na**
1995	CRF 4A.1	-1817.8	-2821.0	39.3	0.8	-35.6
	CRF 4 (II)	133.9	134.0	78.5	0.1	-0.1
	CRF4(V)	147.9	113.2	59.4	0.1	30.6
	Total	-1536.0	-2573.8	47.4	1.0	-40.3
2000	CRF 4A.1	-905.0	-2821.0	64.9	0.8	-67.9
	CRF 4 (II)	133.2	134.0	78.5	0.1	-0.6
	CRF4(V)	97.2	113.2	59.4	0.1	-14.1
	Total	-674.5	-2573.8	88.9	1.0	-73.8
2005	CRF 4A.1	-741.9	-2821.0	76.1	0.8	-73.7
	CRF 4 (II)	131.7	131.7	78.5	0.1	0.0
	CRF4(V)	-58.2	113.2	59.4	0.0	-151.4
	Total	-668.4	-2576.1	104.1	1.0	-74.1
2010	CRF 4A.1	-766.7	-2821.0	68.6	0.7	-72.8
	CRF 4 (II)	129.1	134.0	78.5	0.1	-3.7
	CRF4(V)	185.1	113.2	59.4	0.1	63.5
	Total	-452.5	-2573.8	120.9	1.0	-82.4
2011	CRF 4A.1	-428.2	-2821.0	118.0	0.8	-84.8
	CRF 4 (II)	128.5	134.0	78.5	0.2	-4.1
	CRF4(V)	68.9	113.2	59.4	0.1	-39.2
	Total	-230.8	-2573.8	224.0	1.0	-91.0
2012	CRF 4A.1	251.5	-2821.0	204.3	0.8	-108.9
	CRF 4 (II)	128.5	134.0	78.5	0.2	-4.1
	CRF4(V)	17.4	113.2	59.4	0.0	-84.6
	Total	397.5	-2573.8	131.8	1.0	-115.4
2013	CRF 4A.1	9.1	-2821.0	5687.5	0.8	-100.3
	CRF 4 (II)	128.4	134.0	78.5	0.2	-4.2
	CRF4(V)	72.5	113.2	59.4	0.1	-36.0
	Total	209.9	-2573.8	251.2	1.0	-108.2
2014	CRF 4A.1	-23.5	-2821.0	2195.4	0.8	-99.2
	CRF 4 (II)	128.3	134.0	78.5	0.2	-4.3
	CRF4(V)	56.9	113.2	59.4	0.1	-49.7
	Total	161.7	-2573.8	326.4	1.0	-106.3
2015	CRF 4A.1	-163.0	-2821.0	329.0	0.8	-94.2
	CRF 4 (II)	128.2	134.0	78.5	0.2	-4.3
	CRF4(V)	31.7	113.2	59.4	0.0	-72.0
	Total	-3.1	-2573.8	17476.2	1.0	-99.9
2016	CRF 4A.1	-189.2	-2821.0	266.0	0.8	-93.3
	CRF 4 (II)	128.2	134.0	78.5	0.2	-4.3
	CRF4(V)	6.4	113.2	59.4	0.0	-94.4
	Total	-54.6	-2573.8	940.7	1.0	-97.9

Table 6.14 shows that the uncertainty of estimates for forest land remaining forest land was 25 per cent in 1990, increasing to 54.6 per cent by 2016. This is because the net emission in 2016 was closer

[3] Note that uncertainties for category 4A(II) and 4A(V) include land in the forest remaining forest land category

to zero, which makes the percentage uncertainty higher when the absolute uncertainty is much lower, when compared to other years.

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

Table 6.15 shows the net biomass, dead organic matter, soil C and net CO_2 emissions/removals for the time series 1990-2016 for lands converted to forest land (i.e. all forest established after 1990 reported in category 4.A.2). For the data time series pre 2006, the adjusted FORCARB estimates are reported. For the data time series 2007 to 2016, the CARBWARE model estimates are reported (Table 6.15). 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 2008-2016 (see chapter 11).

The increase in removals by the post 1990 forest is due to an increase in forests area and productivity as new established forests mature. The slight decrease in the slope of the change in removals from 2007 onward is due to thinning harvests in productive forests at age 17 years old and older.

6.3.5.1 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 2006 FORCARB series was adjusted (Table 6.15) and rescaled using tier 1 2006 IPCC guidelines time series overlap approaches:

- Living biomass gains (*LBgian*, kt C) from the 2007 to 2012 time series for the CARBWARE and FORCARB model outputs were compared. The ratio (1.586) of the total CARBWARE and FORCARB LBgain values for 2007-2012 was used to adjust the time series:

$$LB\ gain_{adj} = LB\ gain_{ini.} \times 1.58 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots\ldots (eq\ 6.3.36)$$

where, $LBgain_{adj}$ is the adjusted living biomass gain value and $LBgain_{ini}$ is initial FORCARB estimate. This method is consistent with eq 5.1 Chapter 5 of the 2006 IPCC guidelines;

- The adjusted biomass losses (*LBloss*) were also determined using equation 6.3.36 but using a ratio of 1.585 scaled using the ratio of living biomass losses of the total CARBWARE and FORCARB LBloss values for 2007-2012. The ratio of gains to losses (as applied to forest land remaining forest land) was not used because there are no harvest losses for the FORCARB time series 1990-2007;
- For dead organic matter (DOM), the ratio (1.911) of the average CARBWARE to average FORCARB values for 2007-2012 was used to adjust the time series:

$$DOM_{adj} = DOM_{ini.} \times 1.911 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (eq\ 6.3.37);$$

- There were no adjustments to the soil EF, since the FORCARB and CARBWARE estimates were identical.

Table 6.15 Time series for forest category 4.A.2

	Area (kHa)		CSC (kt C)						Net CO_2 kt	Harvests[1] (M m3)	
			Living biomass			DOM	Min. Soils	Organic soils	Total		
Year	Total	Organic	Gain	Loss	Net	Net	Net	Net		Thinnings	Modelled
1990	15.82	9.92	0.00	-0.26	-0.26	0.01	NO	-7.19	27.26	NO	
1995	110.83	64.51	123.65	-8.66	114.99	11.38	NO	-48.38	-285.97	NO	
2000	184.54	106.88	367.71	-36.13	331.58	41.85	NO	-76.02	-1090.53	NO	
2005	243.99	139.46	757.80	-95.81	661.99	78.65	NO	-101.56	-2343.31	NO	
2007	259.20	146.39	954.36	-238.41	715.95	116.08	NO	-105.72	-2663.12	0.08	0.08
2008	265.45	149.23	1073.96	-262.76	811.20	125.00	NO	-107.72	-3037.77	0.02	0.02
2009	272.10	152.25	1185.35	-350.33	835.02	170.73	NO	-110.55	-3282.39	0.21	0.22
2010	280.41	156.04	1285.32	-383.79	901.53	182.52	NO	-112.92	-3560.80	0.14	0.15
2011	287.06	159.07	1347.64	-438.09	909.55	201.97	NO	-116.20	-3649.53	0.18	0.18
2012	292.91	161.73	1377.42	-461.09	916.33	207.18	NO	-118.68	-3684.39	0.11	0.11
2013	299.07	164.50	1406.22	-462.92	943.30	205.02	NO	-119.82	-3771.15	0.21	0.19
2014	305.16	167.69	1502.11	-757.20	744.91	321.31	NO	-122.26	-3461.20	0.87	0.87
2015	311.13	171.30	1536.90	-691.24	845.66	287.89	NO	-125.27	-3697.03	0.58	0.53
2016	317.48	175.04	1664.93	-777.91	887.02	248.49	NO	-127.84	-3694.81	0.67	0.67

The harvest volumes show a comparison of the EUROSTAT and modelled harvest using FORECARB and the CARBWARE model.

Figure 6.13 shows the initial FORCARB estimates (blue symbols) and the time series adjustment as (red symbols) reported in CRF table 4.A.2 and Table 6.15. Both time series show the same trend but the adjusted values show a higher net removal of CO_2. This is due to fundamental differences in the model input variables and the spatial scale at with the FORCARB and CARBWARE models operate. There are also known underestimated biases in the FORCARB model introduced when BFC yield tables are used. These are introduced by the same factors as those discussed under the forest land converted to forest land. The final adjusted time series comprises of adjusted FORCARB estimates for the period 1990-2006 and CARBWARE estimated for the period 2007-2016.

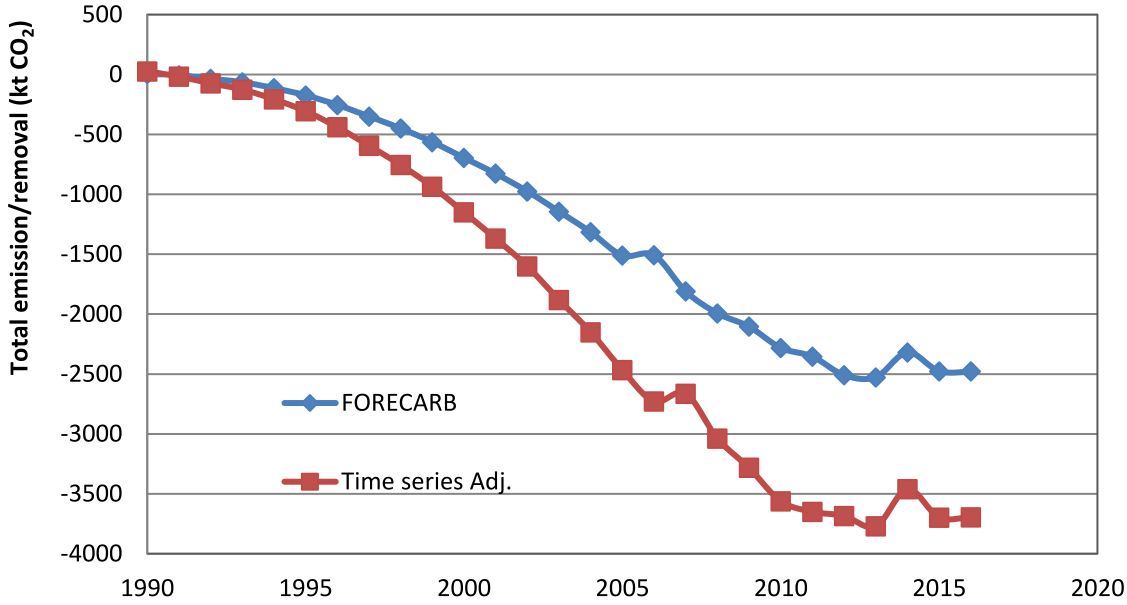


Figure 6.13 The adjusted time series for land converted to forest land (4.A.2)

6.3.5.2 Mineral Soils

Grassland converted to forest land (L-FL since 1990) on mineral soils are demonstrated to have no significant change in SOC CSC due to afforestation (see chapter 11.3 and section 6.3.3.1). Although national data shows conversions form crop to forest result in an increase in mineral soil CSC, this is not estimated (NE, see CRF Table 4.A.2) due to a lack of activity data.

6.3.5.3 Organic Soils

The same approaches as described for forest land remaining forest land were used to estimate emissions from organic soils in lands converted to forest land 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 6.16). The allocation of emission estimates for the sub-categories *4.A.2. 2.1* to *2.5* are based on the proportion of lands converted to forests.

Table 6.16 Area (in kha) and emissions from different organic soil types over the times series for land converted to forests

					Drained productive area		On-site emissions		Off-site DOC emissions		Total
Year	**Total Area[1]**	**Mineral**	**Org.**	**Open area [2]**	**Org. [3]**	**Org.-mineral[3]**	**Org.[4]**	**Org.-mineral[4]**	**Org.[5]**	**Org.-mineral[5]**	
	(kHa)						**kt C**				**kt CO_2**
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	46.3	64.5	13.2	43.0	16.0	-25.4	-4.7	-13.3	-5.0	177.4
2000	184.5	77.7	106.9	22.0	67.2	25.7	-39.6	-7.6	-20.8	-8.0	278.7
2005	244.0	104.5	139.5	29.0	88.6	36.0	-52.3	-10.6	-27.5	-11.2	372.4
2007	259.2	112.8	146.4	32.5	90.1	41.4	-53.1	-11.8	-27.9	-12.8	387.7
2008	265.4	116.2	149.2	33.4	90.8	43.7	-53.6	-12.4	-28.2	-13.6	395.0
2009	272.1	119.8	152.3	34.4	92.2	45.7	-54.4	-13.4	-28.6	-14.2	405.3
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	299.1	134.6	164.5	38.6	98.3	50.5	-58.0	-15.7	-30.5	-15.7	439.3
2014	305.2	137.5	167.7	39.5	101.0	50.5	-59.6	-15.7	-31.3	-15.7	448.3
2015	311.1	139.8	171.3	40.4	103.1	52.4	-60.8	-16.3	-32.0	-16.3	459.3
2016	317.5	142.4	175.0	41.4	105.3	53.4	-62.1	-16.5	-32.6	-16.5	468.8

[1] Total area includes open areas

[2] Open area within forest areas (roads, extraction routes, biodiversity etc).

[3] Productive area of drained organic (org.) and organo-mineral soils based in NFI 2006 and 2012 (excluding open areas). Organic soils include all soils with a > 20% C and an organic layer greater than 30 cm (e.g. Blanket peats, fens, cutaway peats. Organo-mineral soils are mineral soils with an organic overlay of < 30cm. These include peaty podsols and peaty gleys (Source NFI).

[4] On-site emissions are calculated using Eq 6.3.23 and 6.2.24 and areas of productive and rained organic and organo-mineral soils less than 50 years old.

[5] Off-site emissions are calculated using and EF of -0.31 tC /ha and the area of drained productive organic and organo-mineral soils using Eq 2.4 and Table 2.2, Ch2 of the 2013 IPCC Wetlands supplement.

6.3.5.4 Emissions from Biomass Burning

The methodology for estimating emissions from biomass burning is discussed in category *4.A.1* (see section 6.3.4.4). 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 6.9). Fires on land afforested since 1990 represent 36 per cent to 41 per cent of the total fire areas over the period 2008 to 2016 (Table 6.9).

6.3.5.5 Emissions of N_2O from Fertilization

Ireland does not report separately the emissions of N_2O due to nitrogen fertiliser use for *4.A Forest Land*. The amount of synthetic fertiliser used in forests is negligible compared to that used in agriculture and therefore all N_2O emissions from fertiliser applications are reported under agriculture. The notation key IE is therefore used in CRF Table 4(I).

6.3.5.6 Emissions of N_2O and CH_4 from drainage and rewetted organic soils

The methodology for estimating N_2O and CH_4 emissions from drainage of organic soils are discussed section 6.3.4.6.

a) N_2O from drained organic soils

The increase in N_2O emissions from organic soils in the land converted to forest land category since 1990 is due to an increase in afforestation of organic soils under the grants and premiums scheme (Table 6.17).

b) CH_4 from drained lands and ditches

The increase in CH_4 emissions from organic soils in land converted to forest land category since 1990 is due to an increase in afforestation of organic soils under the grants and premiums scheme (Table 6.17)

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 6.17 The area activity data and N_2O and CH_4 emissions from drainage of land converted to forest land

	Area (kHa)				kt N_2O			kt CH_4		
Year	**Total Area**	**Open area**	**Organic N-poor**	**Organic N-rich**	**Organic N-poor**	**Organic N-rich**	**Total N_2O**	**Drained lands**	**Ditches**	**Total CH_4**
1990	15.8	1.9	6.6	2.1	0.00	0.01	**0.01**	0.02	0.04	**0.06**
1995	110.8	13.2	43.0	16.0	0.03	0.07	**0.10**	0.14	0.25	**0.39**
2000	184.5	22.0	67.2	25.7	0.05	0.11	**0.16**	0.23	0.38	**0.61**
2005	244.0	29.0	88.6	36.0	0.06	0.16	**0.22**	0.31	0.51	**0.81**
2007	259.2	32.5	90.1	41.4	0.06	0.18	**0.25**	0.32	0.52	**0.84**
2008	265.4	33.4	90.8	43.7	0.06	0.19	**0.26**	0.33	0.53	**0.86**
2009	272.1	34.4	92.2	45.7	0.06	0.20	**0.27**	0.34	0.54	**0.87**
2010	280.4	35.6	94.3	47.7	0.07	0.21	**0.28**	0.35	0.55	**0.90**
2011	287.1	36.6	96.1	49.1	0.07	0.22	**0.28**	0.36	0.56	**0.92**
2012	292.9	37.6	97.8	50.2	0.07	0.22	**0.29**	0.36	0.57	**0.93**
2013	299.1	38.6	98.3	50.5	0.07	0.22	**0.29**	0.37	0.57	**0.94**
2014	305.2	39.5	101.0	50.5	0.07	0.22	**0.29**	0.37	0.59	**0.96**
2015	311.1	40.4	103.1	52.4	0.07	0.23	**0.30**	0.38	0.60	**0.98**
2016	317.5	41.4	105.3	53.4	0.07	0.23	**0.31**	0.39	0.61	**1.00**

6.3.5.7 N_2O emissions from mineral soils as a result of land use change of management (F_{SOM})

Emissions of N_2O from mineral soils are based on mineralisation rates due to loss of organic C from mineral soils (Eq 11.8 Ch11, Vol 4 of the 2006 IPCC guidelines). We report that the 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).

6.3.5.8 CO_2 emissions from urea application to soils

All fertiliser application related emissions, including CO_2 emissions from urea application are reported under *3. Agriculture* because these are based on national sales data (IE).

6.3.5.9 Uncertainty Analysis for Category 4.A.2

The same uncertainty analysis was carried out for lands converted to forest land as was undertaken for forests remaining forest land (Table 6.18). The only different sources of uncertainty in this analysis (see Table 6.11 and Table 6.12) was the uncertainty due to re-adjustment scaling factor uncertainty for biomass (LB), litter and dead wood (DOM), i.e. Codes J and K Table 6.12Table 6.1), which were 3.7 and 9.0 per cent for lands converted to forest land.

Table 6.Table 6.18 shows that the uncertainty of estimates for land converted to forest land was 96.6 per cent in 1990, decreasing to 20.7 per cent by 2016. 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 6.18 Uncertainty analysis of lands converted to forest land as reported in CRF 4.A.2

Year	Category	Year emission/ removals (kt CO_2 eq)	Base year emission/ removals (kt CO_2eq)	Combined uncertainty in year (±%)	Contribution to total variance in year (fraction)	Mean trend in year in relation to base-year (% mean trend)
1990	CRF 4A.2	27.3	27.3	96.6	0.8	na
	CRF 4(II)	8.7	8.7	88.4	0.2	na
	CRF4(V)	0.0	0.0	0.0	0.0	na
	Total	**35.9**	**35.9**	**96.6**	**1.0**	**na**
2000	CRF 4A.2	-1090.5	27.3	32.2	0.8	-4101.0
	CRF 4(II)	92.9	8.7	90.6	0.2	
	CRF4(V)	0.0	0.0	0.0	0.0	
	Total	**-997.6**	**35.9**	**32.2**	**1.0**	**-4101.0**
2005	CRF 4A.2	-2343.3	27.3	24.2	0.8	-8697.3
	CRF 4(II)	124.7	124.7	91.3	0.2	
	CRF4(V)	0.0	0.0	0.0	0.0	
	Total	**-2218.7**	**151.9**	**24.2**	**1.0**	**-8697.3**
2010	CRF 4A.2	-3560.8	27.3	20.4	0.8	-13164.2
	CRF 4(II)	141.9	8.7	94.0	0.1	
	CRF4(V)	62.9	0.0	52.2	0.0	
	Total	**-3355.9**	**35.9**	**20.7**	**1.0**	**-9439.5**
2011	CRF 4A.2	-3649.5	27.3	20.3	0.8	-13489.7
	CRF 4(II)	145.2	8.7	94.1	0.2	
	CRF4(V)	23.2	0.0	52.2	0.0	
	Total	**-3481.1**	**35.9**	**20.4**	**1.0**	**-9787.9**
2012	CRF 4A.2	-3684.4	27.3	20.3	0.8	-13617.6
	CRF 4(II)	148.0	8.7	94.2	0.2	
	CRF4(V)	5.9	0.0	52.2	0.0	
	Total	**-3530.5**	**35.9**	**20.4**	**1.0**	**-9925.3**
2013	CRF 4A.2	-3771.2	27.3	20.3	0.8	-13935.9
	CRF 4(II)	148.8	8.7	94.2	0.1	
	CRF4(V)	72.5	0.0	52.2	0.0	
	Total	**-3549.9**	**35.9**	**20.3**	**1.0**	**-9979.3**
2014	CRF 4A.2	-3461.2	27.3	20.5	0.8	-12798.8
	CRF 4(II)	151.5	8.7	93.9	0.2	
	CRF4(V)	35.1	0.0	52.2	0.0	
	Total	**-3274.6**	**35.9**	**20.5**	**1.0**	**-9213.1**
2015	CRF 4A.2	-3697.0	27.3	20.3	0.8	-13664.0
	CRF 4(II)	155.5	8.7	94.1	0.2	
	CRF4(V)	12.8	0.0	52.2	0.0	
	Total	**-3528.8**	**35.9**	**20.3**	**1.0**	**-9920.5**
2016	CRF 4A.2	-3694.81	27.26	20.71	0.84	-13655.88
	CRF 4(II)	158.66	8.68	94.03	0.16	
	CRF4(V)	2.58	0.00	52.20	0.00	
	Total	**-3,533.57**	**35.93**	**20.71**	**1.00**	**-9933.90**

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[4] .

The NFI data for 2012 allowed the recalculation of forest areas for 2006 to 2012. The development of the new methodology resulted in an increase in the reported area of deforestation from 1.38 to 12.512 kha in 2008, with a further 0.8 kha being deforested in 2009, 0.8 kha in 2010, 1.6 kha in 2011 and 0.8 kha in 2012. In 2013, the limited felling licence records and lands taken out database identified deforested areas of 0.129 kha to grasslands and settlements (see chapter 11 and Table 6.19). The increase in conversion of forest land to other lands after 2005 is associated with clearfelled forest land which was not replanted within a 5 year period as determined using the 2006 and 2012 NFI. The lands have not been converted to any known land use but are classified as deforestation and reported as forest converted to other land.

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 2012 NFI. The 2013, to 2016 data is based on felling licence information and the lands taken out database (see 6.3.2.4).

Table 6.19 Land use change and soil type matrix showing annual deforestation areas (kha/ year) associated with different land uses and soil type

	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
2007	10.512	4.202	3.776	0.373	2.679	1.200	1.424	1.084	2.633	1.544
2008	12.512	5.002	4.176	0.373	3.879	2.000	1.424	1.084	3.033	1.544
2009	13.312	5.402	4.576	0.373	3.879	2.000	1.824	1.484	3.033	1.544
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	16.640	6.615	6.640	0.374	4.744	2.812	2.224	1.884	3.033	1.544
2014	16.836	6.771	6.681	0.392	4.765	2.824	2.224	1.884	3.166	1.671
2015	17.423	7.096	6.777	0.393	4.878	2.883	2.224	1.884	3.544	1.936
2016	17.630	7.165	6.928	0.418	4.900	2.893	2.229	1.889	3.572	1.964

* No transition from forests to croplands were detected

[4] http://life04.raisedbogrestoration.ie/index.html

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):

$$C_{L(Total)} = C_{L(AB)} + C_{L(BB)} = TOTAL_{(Biomass)} lost \quad \text{(6.3.38)}$$

The carbon stock **losses (C_L)** 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 section 6.3.3.1.2 above.

2) Where plots were clearfelled before 2006 from the standing volume (V) of the forest stand, as specified by Coillte plot queries, a basic density (D) in the range 0.35 to 0.55 (depending on tree species), a biomass expansion factor (BEF) of 1.68 to 4 t/t^{-1} (Black at al., 2004) a carbon fraction (CF) of 0.5 and a root to shoot ratio R of 0.2, as described in Eq 6.3.9 and 6.3.3.1 above). A list of plot data from Coillte provided information of deforestation area (including open areas), species, age, standing volume before clearfell.

3) There is no activity data for deforested areas before 2006, therefore the 2006-2013 mean AB (65.9.81 t C/ha), BB (17.2 tC/Ha), litter and deadwood (16.4 tC/Ha) C stock was applied as an IEF for these deforested areas. (see section 6.3.3.1.2).

It is important to note that many deforested lands are not fully stocked before clearfell and land use change, with the exception of:

- Clearfelled non-regenerated land within a 5-year period (1600 ha since 2006 with a mean biomass stock of 230 t C ha^{-1}),
- EU LIFE bog restoration projects in 2007 (400 ha, biomass stock of 176 t C ha^{-1}),
- Wind farm conversions in 2007 (400 ha, biomass stock of 230 t C ha^{-1}),
- Grassland conversion in 2009. (400 ha, biomass stock of 97 t C ha^{-1})

All other deforestation events over the period 2006-2012, representing 6400 ha of the total 9600 ha had a lower biomass stock ranging from 1.1 to 112 t C ha^{-1}. These were younger aged crops, which were prematurely clearfelled for deforestation or scrub land forests converted to settlements.

The accumulated litter and DOM pool were 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 1st rotation crops.

i. Organic soils emissions due to rewetting are estimated using the 2013 IPCC Wetland supplement (see section 6.3.6.1.1). Biomass gains after conversion to rewetted and regenerating wetlands are included in on-site removals (see section 3.2.1 of the 2013 Wetland supplement) and are therefore reported as 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). 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 6.20 Deforestation carbon stock changes and harvest over the time series 1990-2016

Area (kHa)		CSC (kt C)						Net CO_2 kt	Harvests (m3)
		Living biomass			DOM	Mineral Soils	Organic soils	Total	
Year	Total	Gain	Loss	Net	Net	Net	Net		Modelled
1990	0.02	0.06	-1.64	-1.58	-0.50	-0.01	-0.02	7.79	4040
1995	0.44	1.81	-27.71	-25.89	-4.41	-0.14	-0.11	112.04	65364
2000	2.63	2.72	-71.24	-68.52	-10.85	-0.69	-0.44	295.15	168068
2005	6.91	2.72	-71.24	-68.52	-13.63	-1.94	-2.09	316.00	168068
2006	8.91	0.00	-392.16	-392.16	-39.79	-2.38	-3.53	1605.52	936429
2007	10.51	0.00	-177.56	-177.56	-8.12	-2.82	-4.44	707.48	417156
2008	12.51	2.72	-102.81	-100.09	-17.40	-3.70	-5.16	463.32	232740
2009	13.31	2.72	-92.44	-89.72	-6.16	-3.70	-6.40	388.62	222262
2010	14.11	5.44	-45.69	-40.25	-6.01	-3.69	-6.40	206.62	111220
2011	15.71	8.16	-56.57	-48.41	-28.58	-3.68	-6.59	319.96	114959
2012	16.51	0.00	-42.22	-42.22	-12.80	-3.66	-7.31	241.98	101250
2013	16.64	0.44	-5.88	-5.45	-0.79	-3.71	-7.33	63.32	13925
2014	16.84	0.28	-13.10	-12.82	-1.79	-3.72	-7.52	94.80	32109
2015	17.42	0.65	-19.64	-18.99	-6.01	-3.82	-7.81	134.31	30465
2016	17.63	1.03	-6.57	-5.54	-3.37	-3.76	-7.95	75.62	18592

6.3.6.1.1 Mineral soils

Ireland has chosen not to account for carbon stock changes in mineral soils converted to grasslands. Verifiable information demonstrating that deforested grassland mineral soils are not a source of anthropogenic GHG is provided in chapter 11. The notation key NO is therefore used for mineral soils under this land category in CRF Table 4.C.

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^{-1} was used based on best available soil data (see Figure 11.3, Ch 11). 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_2 form mineral soils because there is no activity data to determine the percentage green area in urban areas.

Mineralisation emissions of N_2O due to the loss of SOC (F_{som}) due to deforestation to 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.

6.3.6.1.2 Organic soils

Drained organic soils

Grasslands (4C): Emissions of CO_2 from deforested grasslands are assumed to occur because lands are likely to be shallowly drained because they are temperate rich organic soils. The default on-site emission factor on 3.6 t C/ha (Table 2.1 of the 2013 IPCC Wetland Supplement), and off-site EF_{DOC} of 0.31 t C /ha 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_4 emissions from deforested grasslands (Eq. 2.6 of 2013 IPCC Wetland Supplement). For CH_4-land emissions the default $EF_{CH4\text{-}land}$ of 39 kgCH4/ha and $FRAC_{ditch}$ of 0.05 is used for shallow drained grasslands (Tables 2.3 and 2.4 of the 2013 IPCC Wetland Supplement). The emission factor from shallow drains EF_{drain} of 527 kg CH_4/ha is used (Table 2.4 of the 2013 IPCC Wetland Supplement).

Default emission factors (1.6 kg N-N_2O/ha, Table 2.5 of the 2013 IPCC Wetland Supplement) and methods (Eq. 2.7) for temperate shallow drained nutrient rich organic soils are used for N_2O emissions from deforested grasslands.

Settlements (4E) and other lands: The 2013 IPCC Wetland Supplement and 2006 IPCC Guidelines provide no methodology for drained organic soils under settlement. Therefore, emissions from organic soils converted to settlement and other land are assumed to continue using the on-site and DOC EFs and methods outlined in reported using eq. 6.3.23 and 6.3.24, described in section 6.3.3.1.2 (Soils). Emissions of CH_4 and N_2O 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_2 emissions, default on-site $EF_{\text{-}land}$ 2.8 tC /ha and the $EF_{\_DOC}$ of 0.31 t C/ha is used (Table 2.1 and 2.2 of the the 2013 IPCC Wetland Supplement).

Wetlands (4D): For CH_4, CH_4-$_{land}$ emissions the default $EF_{CH4\text{-}land}$ of 6.1 kgCH4/ha and $FRAC_{ditch}$ 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_{drain} of 542 kg CH_4/ha is used (Table 2.4 of the 2013 IPCC Wetland Supplement).

Default emission factors (1.6 kg N_N_2O/ha, Table 2.5 of the 2013 IPCC Wetland Supplement) and methods (Eq. 2.7) for temperate shallow drained nutrient rich organic soils are used for N_2O emissions from deforested grasslands.

Rewetting of organic soils

Emissions from organic soils following forest conversion back to wetlands (4D i.e. rewetting of organic soils) include on-site emission/removals (i.e. C-composite) and off-site DOC emissions (section 3.2.1 of the 2013 wetland supplement). On site removals, due to non-woody vegetation/organic soils bio-geochemical reactions are assumed to not occur (NO) because peat soils are re-saturated since drainage does not occur on regenerated wetlands (as part of EU LIFE peatland regeneration projects). On-site emissions are estimated based on the area of rewetted soils, the default emission factor EF_{CO_2} of -0.23 (Table 3.1 and Eq 3.4 of the 2013 IPCC Wetland Supplement). Off-site DOC emissions are estimated using Eq. 3.5 and the default $EF_{DOC\text{-}rewetted}$ of -0.24 (Table 3.2 of the 2013 IPCC Wetland Supplement). EF for CH_4 due to rewetting is 92 kg CH_4 per ha per (Eq 3.8 and table 3.3 of the 2013 IPCC Wetland Supplement).

6.3.6.1.3 Uncertainty 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 6.21). 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 6.21 Uncertainty estimates for individual activity and area data sets for deforested lands

Code	Component	Sub-category	% Uncertainty	Source
A	Biomass algorithms	AB and BB	12.00	Black et al 2007
B	C fraction	All biomass pools	0.87	Black et al 2007
C	Volume to biomass	Defor losses	38.50	Felling licences and BEF uncertainty, Black 2004
D	Area deforestation	NFI, OSI aerial photos	46.70	Sample strata uncertainly analysis/ new deforestation methods
E	Litter	Li	3.10	Tobin et al, 2006
F	Deadwood	DW	22.00	Tobin et al, 2007
G	Peat soils and DOC	So	90.00	Assume same as Tier 1 (Table 2.3,2.3.1 CH2, 2006 IPCC Guidelines)
I	Drained area	N_20 and CH_4 drained	12.30	Conf. interval of NFI analysis
J	N_20 emission factors drainage	N_20 emissions	119.00	Wetland Supplement Table 2.5 and Yamulki et al., 2013
K	CH_4 EF ditches	CH_4 emissions	87.20	Wetland Supplement Table 2.4
L	CH_4 EF lands	CH_4 emissions	126.00	Wetland Supplement Table 2.3
M	N_20 EF mineralisation	N_20 emissions	66.00	2006 IPCC Guidelines Eq 11.8
N	DOC emissions from drained soils	So	43.50	Wetland Supplement Table 2.1
O	Mineral soil EF to settlement	So	50.00	Review of NIRs from other countries e.g. Finland and Sweden
P	Peat extraction EF CO_2	So	69.81	Wetland Supplement Table 2.1 and 2.2
Q	Rewetting CO_2	So	125.36	Wetland Supplement Table 3.1and 3.2
R	Rewetting CH_4	CH4 emissions	240.00	Wetland Supplement Table 3.3

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 6.12 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	187.78	D, G, N, O, P, Q
N_2O	N_20 drainage	Wetland Supplement	128.43	D, I , J
CH_4	CH_4 drain and rewetting	Wetland Supplement	285.01	I, K, L, R

Table 6.23 Uncertainty estimates for deforested land

Year	Category	Year emission/ reductions (kt CO_2 eq)	Base year emission/ reductions (kt CO_2eq)	Combined uncertainty in year (±%)	Contribution to total variance in year (fraction)	Mean trend in year in relation to base-year (% mean trend)
1990	CRF 4B-E	8.06	8.06	48.91	0.93	na
	CRF 4 (II)	0.01	0.01	197.87	0.01	na
	CRF4 (III)	0.43	0.43	66.00	0.07	na
	Total	**8.50**	**8.50**	**47.61**	**1.00**	**na**
1995	CRF 4B-E	112.04	8.06	53.14	0.95	1290.23
	CRF 4 (II)	0.07	0.01	197.87	0.00	400.00
	CRF4 (III)	4.42	0.43	66.00	0.05	937.10
	Total	**116.52**	**8.50**	**47.71**	**1.00**	**1271.12**
2000	CRF 4B-E	295.15	8.06	53.31	0.91	3562.46
	CRF 4 (II)	0.63	0.01	223.63	0.01	4562.82
	CRF4 (III)	21.42	0.43	66.00	0.08	4930.65
	Total	**317.20**	**8.50**	**47.75**	**1.00**	**3632.61**
2005	CRF 4B-E	316.00	8.06	50.87	0.77	3821.17
	CRF 4 (II)	3.45	3.45	226.22	0.04	0.00
	CRF4 (III)	60.71	0.43	66.00	0.19	14156.45
	Total	**380.15**	**8.50**	**53.66**	**1.00**	**4373.40**
2010	CRF 4B-E	205.21	8.06	55.48	0.56	2446.44
	CRF 4 (II)	9.52	0.01	151.56	0.07	70226.15
	CRF4 (III)	115.23	0.43	66.00	0.37	26959.68
	Total	**329.96**	**8.50**	**83.98**	**1.00**	**3782.74**
2011	CRF 4B-E	318.55	8.06	45.70	0.61	3852.85
	CRF 4 (II)	10.75	0.01	164.05	0.07	79286.60
	CRF4 (III)	114.80	0.43	66.00	0.32	26859.68
	Total	**444.10**	**8.50**	**68.20**	**1.00**	**5125.86**
2012	CRF 4B-E	240.57	8.06	51.51	0.57	2885.18
	CRF 4 (II)	11.86	0.01	154.56	0.08	87522.61
	CRF4 (III)	114.38	0.43	66.00	0.35	26759.68
	Total	**366.81**	**8.50**	**78.04**	**1.00**	**4216.34**
2013	CRF 4B-E	61.89	8.06	120.10	0.44	667.96
	CRF 4 (II)	11.88	0.01	154.43	0.11	87664.71
	CRF4 (III)	115.74	0.43	66.00	0.45	27079.84
	Total	**189.51**	**8.50**	**140.13**	**1.00**	**2130.02**
2014	CRF 4B-E	93.37	8.06	85.97	0.44	1058.58
	CRF 4 (II)	12.12	0.01	153.17	0.11	89394.32
	CRF4 (III)	116.28	0.43	66.00	0.45	27207.66
	Total	**221.77**	**8.50**	**121.43**	**1.00**	**2509.60**
2015	CRF 4B-E	134.31	7.79	68.51	0.49	1623.05
	CRF 4 (II)	12.57	0.01	150.14	0.10	92744.19
	CRF4 (III)	119.32	0.43	66.00	0.42	27919.74
	Total	**266.20**	**8.23**	**121.43**	**1.00**	**3132.78**
2016	CRF 4B-E	75.62	7.79	108.44	0.46	870.10
	CRF 4 II	12.70	0.01	150.13	0.11	93693.72
	CRF4III	117.46	0.43	66.00	0.43	27484.40
	Total	**205.78**	**8.23**	**131.92**	**1.00**	**2399.06**

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 IPCC supplementary guidance for the Kyoto protocol. The approach adopted is broadly consistent with the 2013 Revised 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 2016. The FAO/EUROSTAT data is used to calibrate the FORCARB and CARBWARE model harvests as described in section 6.3.2.4. The domestic harvest, imported and exported timber flows from 1961 to 2016 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 f_{irw} and f_{pulp} ratios to derive the volume of SW, WBP and PPB (see Table 6.24).

a) Volumes of the SW and WBP HWP from domestic harvest are converted to tC using default conversion factors. The aggregate value of 0.458 and 0.595 Mg/m^3 is used for SW and WBP, respectively (Table 2.8.1 2013 IPCC supplement). A carbon fraction of 0.5 is used for SW and a C fraction of 0.454 for WBP (Table 2.8.1 of the 2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol). The final inflows of different domestically produced HWP are shown in Table 6.24

b) Harvest product data was further extrapolated back to 1900 using regression equations using exponential function for each wood product (WP$_j$):

$$WPj = e^{0.015(year-1961)\times tC1961j} \qquad (6.3.39)$$

where *year* is the specific year before 1961 and $tC1961_j$ is the tC feedstock for the wood product j in 1961. Historic consumption rates from 1900-1960, using a growth rate of 1.15 per cent y^{-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 6.15 and Table 6.20 in the sections above. All harvests for deforested land are assumed to be immediately oxidised, so CSC in the CRF under HWP are reported as IE under sub categories 4.C.2, 4.D.2, 4.E.2 or 4.F.2 as part of biomass losses.

d) The estimation of the annual amount of HWP being produced from domestic harvest, which is related to the 3 different forest activities is then determined using Eq. 2.8.4 of the 2013 IPPC Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol.

Table 6.24 Annual 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)
	(eq2.81 IPCC 2013)	m3	m3	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	0.878	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	717766	167494	193079	NO	0
2011	0.954	726243	701943	166310	188823	NO	0
2012	0.916	715888	644570	163938	173389	NO	0
2013	0.899	741236	664612	169743	178781	NO	0
2014	0.902	817857	697548	187289	187640	NO	0
2015	0.894	809425	687536	185358	184947	NO	0
2016	0.906	895309	701515	205026	188707	NO	0

a) The tier 2 first order decay model Forestry production and trade data from 1961-2016 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:

$$C_{i+1} = e^{-k} \times C_i + \left[\frac{(1-e^{-k})}{k}\right] \times Inflow_i \qquad (6.3.40)$$

$$\Delta C_i = C_{i+1} - C_i \qquad (6.3.41)$$

Where:

i = year

C_i = the carbon stock in the particular HWP category from a particular forest activity at the beginning of year *i*, kt C

k = decay constant of first-order decay for HWP category given in units yr^{-1} (*k* = ln(2)/HL, where HL is half-life of the HWP pool in years (see below).

$Inflow_i$ = the inflow to the particular HWP category (*HWP_j*) during year *i*, kt C yr^{-1}

ΔC_i = carbon stock change of the HWP category during year *i*, kt C yr^{-1}

Default half-lives of two years for paper, 25 years for wood-based panels, and 35 years for saw[n] wood[5] were used to estimate emissions resulting from products coming out of use.

The final HWP data for lands converted to forest land and land remaining forests is shown in Table 6.25 and Table 6.26.

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 6.27Table 6.). 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 form category *4A1* (or FM) and *4A2* (AR, Table 6.27) 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 6.27). Therefore, the mean trend change for the category (expressed as a percentage) is undefined (divided by zero).

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

Table 6.25 Detailed inflows and CSC for different HWP categories from harvested forest land (including deforestation)

Year	Sawn wood (kt C)			kt CO_2	WBP (kt C)			kt CO_2	Paper (kt C)			kt CO_2	Total
	Gain	Loss	Net	In use	Gain	Loss	Net	In use	Gain	Loss	Net	In use	kt CO_2
1990	86.69	-18.20	68.49	-251.12	63.32	-18.76	44.56	-163.37	0.00	-0.40	-0.40	1.45	-413.04
1995	151.12	-28.53	122.59	-449.49	87.97	-25.12	62.85	-230.47	0.00	-0.07	-0.07	0.26	-679.70
2000	195.23	-40.35	154.88	-567.89	192.39	-40.91	151.48	-555.41	0.00	-0.01	-0.01	0.05	-1123.25
2005	211.02	-55.35	155.67	-570.78	213.69	-61.26	152.43	-558.90	0.00	0.00	0.00	0.01	-1129.67
2010	167.49	-67.83	99.66	-365.43	193.08	-79.63	113.45	-415.98	0.00	0.00	0.00	0.00	-781.41
2011	166.31	-69.77	96.54	-353.96	188.82	-82.67	106.15	-389.22	0.00	0.00	0.00	0.00	-743.18
2012	163.94	-71.64	92.29	-338.41	173.39	-85.36	88.03	-322.76	0.00	0.00	0.00	0.00	-661.17
2013	169.74	-73.51	96.23	-352.85	178.78	-87.84	90.94	-333.43	0.00	0.00	0.00	0.00	-686.28
2014	187.29	-75.57	111.72	-409.64	187.64	-90.45	97.19	-356.35	0.00	0.00	0.00	0.00	-765.99
2015	185.36	-77.74	107.62	-394.59	184.95	-93.07	91.87	-336.87	0.00	0.00	0.00	0.00	-731.46
2016	205.03	-80.05	124.98	-458.26	188.71	-95.64	93.07	-341.26	0.00	0.00	0.00	0.00	-799.52

Table 6.26 Detailed inflows and CSC for different HWPs from category 4A

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 6.27 Uncertainty of HWP estimates for all forest harvests

Year	Year emission/reductions (kt CO_2 eq)	Base year emission/reductions (kt CO_2eq)	Combined uncertainty in year (±%)	Mean trend in year in relation to base-year (% mean trend)
1990	-413.04	-413.04	24.86	na
1995	-679.70	-413.04	25.47	64.56
2000	-1123.25	-413.04	24.24	171.95
2005	-1129.67	-413.04	24.24	173.50
2007	-1198.40	-413.04	24.24	190.14
2008	-638.55	-413.04	24.60	54.60
2009	-710.84	-413.04	24.24	72.10
2010	-781.41	-413.04	24.29	89.18
2011	-743.18	-413.04	24.24	79.93
2012	-661.17	-413.04	24.25	60.07
2013	-686.28	-413.04	24.25	66.15
2014	-765.99	-413.04	24.25	85.45
2015	-731.46	-413.04	24.30	77.09
2016	-799.52	-413.04	24.31	93.57

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 6.14 shows the long term historic record in areas under crops since 1847. The historic data and more recent data are based on different survey methodologies, but common, under lying, trends are evident. The most notable trend is the long-term reduction in the area under cropland with increased production of crops seen during the first world war (1914-1918) and second world war (1939-1945).

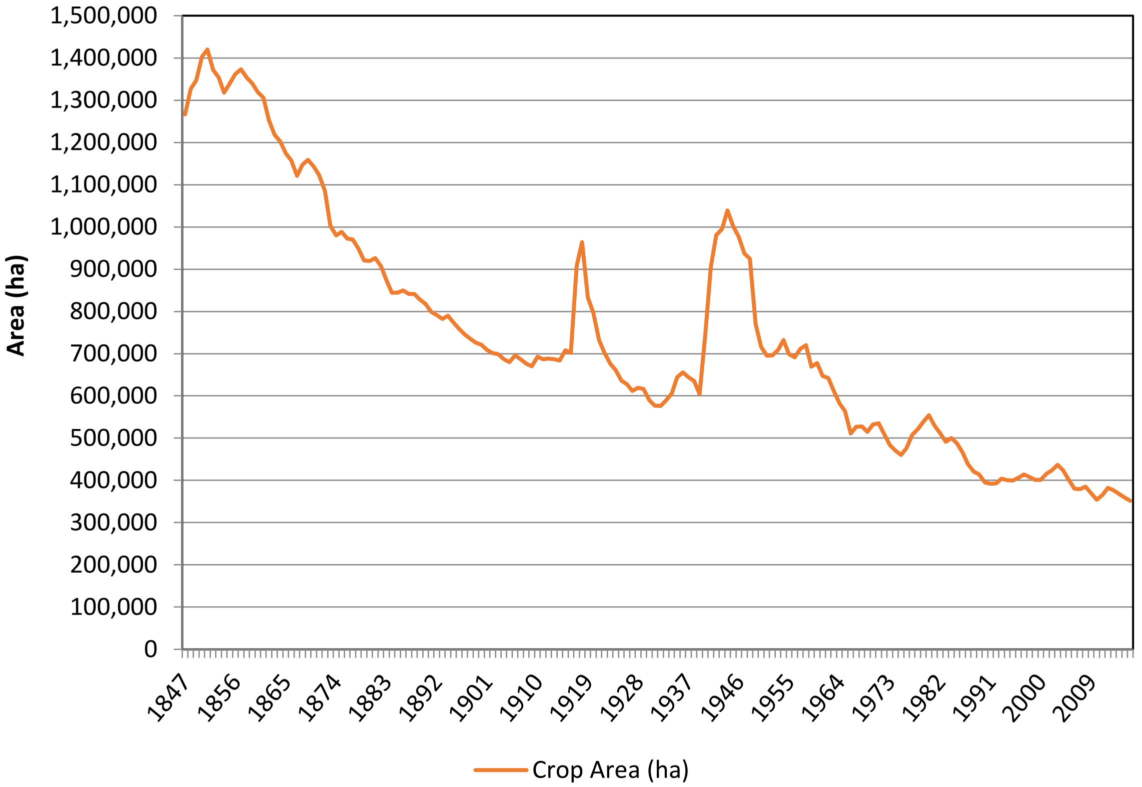


Figure 6.14 Long term time series of areas under crops in Ireland since 1847

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 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)."*

The revised approach for the 2016, 2017 and 2018 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. This effectively covers all agricultural lands in Ireland. 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 6.29 shows a number of 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, the definition of Cropland has been revised for reporting purposes as those lands which are have been cultivated in the reporting year, and those lands which are under temporary grassland, but have been recorded as having been also used to cultivate a crop 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. At this time, no distinction is made between crop types, and it is assumed that the main factor influencing changes in long term carbon profile is 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.

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

An analysis of historical areas under crops shows a significant decline in crops over a sustained period of decades (Figures 6.14 and 6.15). 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 6.16 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.

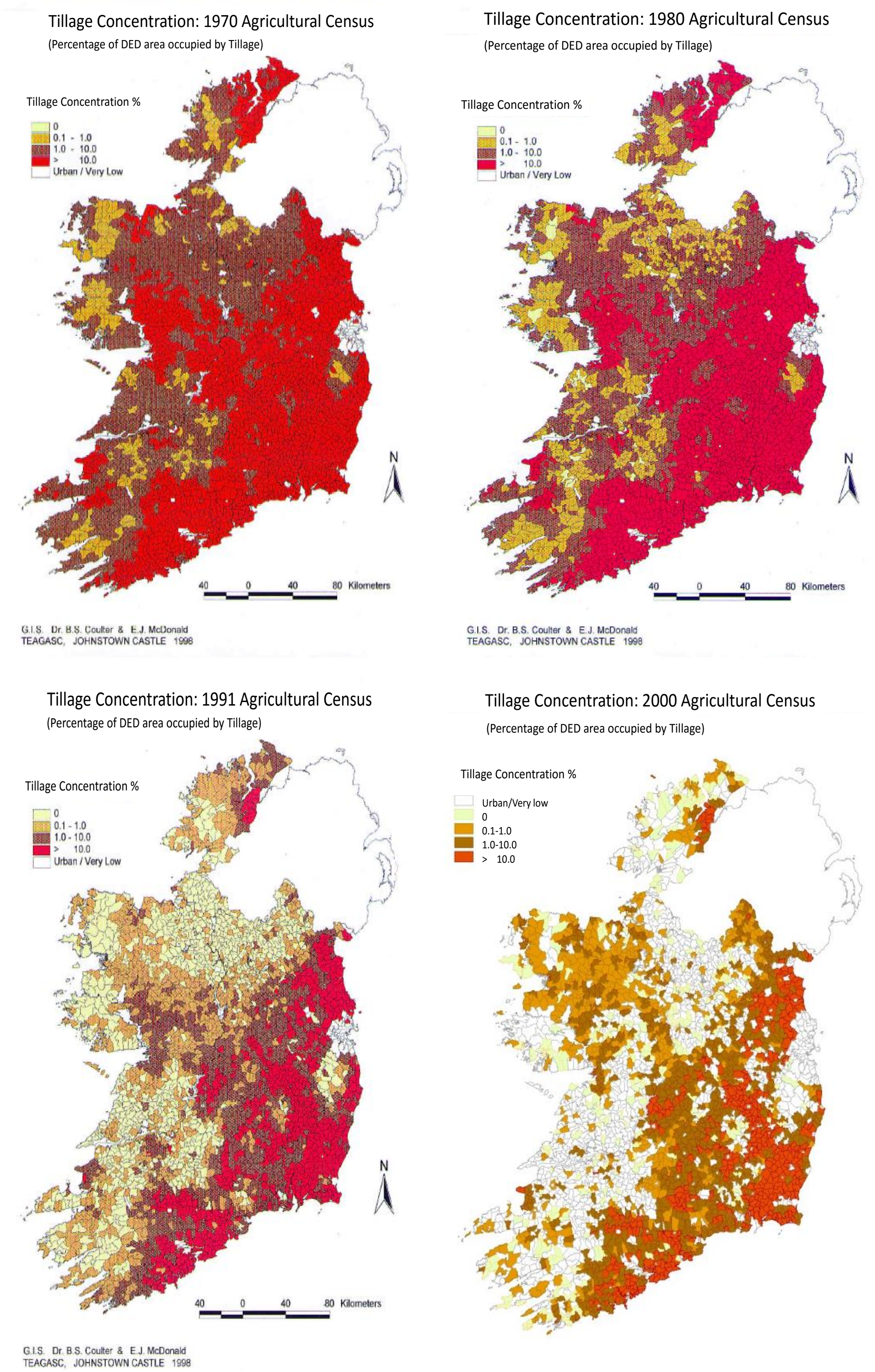


Figure 6.15 Spatial pattern of long term consolidation of tillage activities in well defined regions of Ireland

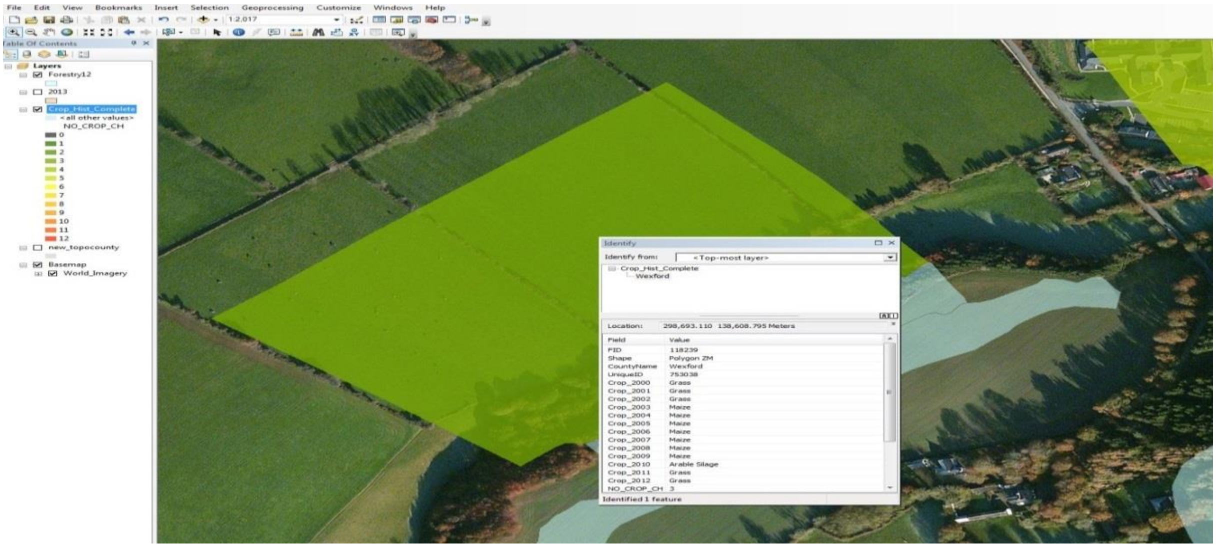


Figure 6.16 GIS layers showing attribute data for an individual land parcel associated with Land Parcel Information System

There is no evidence, 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 in many cases to define parcel boundaries. There is anecdotal evidence of hedgerow removal to facilitate access and traffic of machinery; however, recent hedgerow surveys across Ireland suggest the removal has not occurred on the same scale as other parts of Europe. Additional work is required to quantified change 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.

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 under native vegetation is established from the soil type and the default reference soil organic carbon stocks (SOC_{ref}) for cold, temperate moist regions (Tables 2.3, Chapter 5 Volume 4 of the 2006 IPCC guidelines, and the relevant sections of the 2013 Wetlands Supplement). The Indicative Soils Map of Ireland (Fealy and Green, 2009) is the base soil data source used in this analysis for soil type information in Ireland. Mineral soils as identified from the soil map are allocated to the HAC (high activity clay), LAC (low activity clay), sandy and humic soil classes used by the IPCC, while drained peats/organic soils are allocated to the IPCC wetlands class as shown in Table 6.28, based on detailed national assessment of soil carbon stocks in Ireland (Tomlinson et al., 2005). The values of SOC_{ref} appropriate to each soil association may then be assigned using the correspondence to IPCC classes given in Table 6.. The distribution of CORINE Land Cover over IPCC soil classes was established in the same way to facilitate complete correspondence between land use, soil and SOC_{ref}.

Choice of Methods

Ireland has adopted a Tier 1 approach to reporting greenhouse gas emissions associated with those areas defined as Cropland land use.

Activity data

The primary sources of activity data for Cropland used for the 2018 submission are:

- Central Statistics Office annual statistics of Utilised Agriculture Area (1980-2016);
- Land Parcel Information System data (2000-2016) Maintained by the DAFM. the LPIS is integrated with the forestry, IFORIS data system;
- EPA/Teagasc Indicative Soil Map (2008);
- Activity within the Construction Sector from DEHLG (1990-2016);
- Fire Information for Resource Management System (FIRMS) NASA;
- National forest fire statistics see Table 6.9;
- Expert opinion [6]was sought on the use of histosols for crops in Ireland.

Table 6.28 Soil Class Coverage and Soil Organic Carbon

General Soil Map Soil Association	Proportion of IPCC Soil Class					Proportion of Soil Association in Area of Ireland
	HAC	LAC	Peaty/ Humic	Sandy Soil	Wetlands Soil	
basin peat					0.34	0.06
brown earth		0.19				0.13
brown podzolic		0.21				0.15
Gley		0.30			0.02	0.22
grey brown podzolic		0.30				0.21
Lithosol			0.22	1.00		0.04
lowland blanket peat					0.31	0.05
Podzol			0.78			0.08
Renzinas	1.00					0.01
upland blanket peat					0.33	0.06
Proportion of IPCC Soil Class in Area of Ireland	0.01	0.71	0.10	0.01	0.17	
SOC_{ref} (t C/ha)	95	85	115	71	NA	

6.4.3 Cropland Areas

The area of cropland in a given year is the sum of the area of crops and the area of temporary grassland. The sum can be viewed as the areas of land 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 statistics.

[6] Expert opinion was elicited from the delegates to a one day workshop:- “GHG fluxes in terrestrial ecosystems in Ireland - Grasslands, croplands, peatlands and forests “ held on 20th September 2007 http://www.ucc.ie/en/hydromet/celticflux/#Anchor1

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.

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 2016 provides robust identification of all parcels used for crops in this period. In total there are 181,228 parcels included in the Cropland cohort. Figure 6.177 shows the spatial distribution of croplands. They are clearly concentrated within the 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.

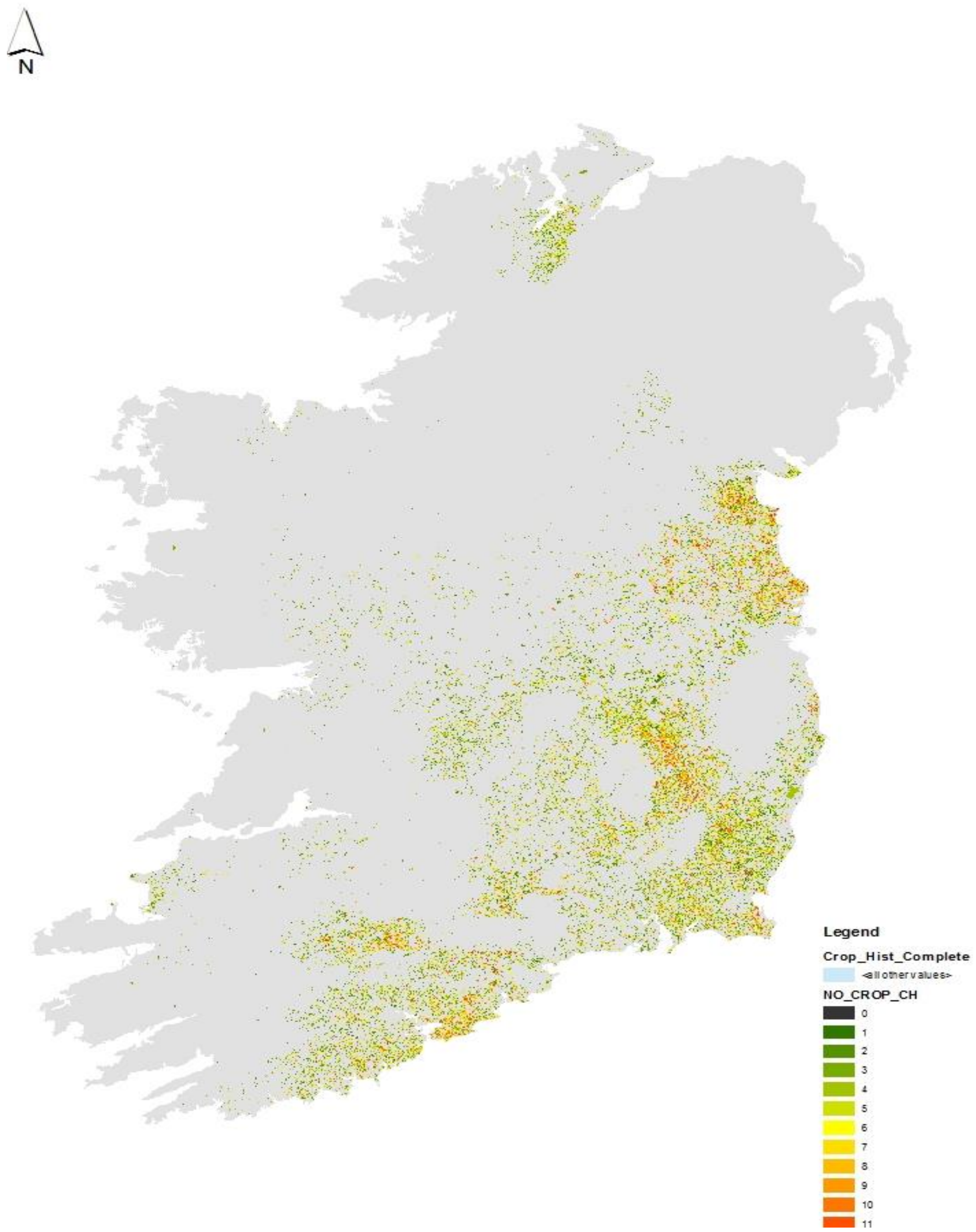


Figure 6.17 Spatial distribution of all Cropland land parcels.

During the period 2000-2016, 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 cohort to accommodate the known incidences of conversion of Cropland to Forest land and Settlement. The details on the estimate of Cropland to Forest land conversion is given in Section 6.3. In order to meet this demand, the cohort of Cropland in 1990 must include those lands which are later converted to forest. During this period to 1999, although the geographic location of afforestation areas are known, the previous land use at each site can only be inferred. Therefore, during the period 1990-1999, the exact location of cropland to forest conversion cannot be determined from existing analysis.

Analysis of the conversion of Cropland to Settlement has not been completed to the same level of spatial detail. The demand for settlement on croplands is currently based on estimates of activities in the construction sector which is disaggregated based on proportion of national land use in other lands uses. 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. Preliminary exploration of the LPIS data, postal service geodirectory data and contemporary aerial and satellite imagery largely confirms this assumption. However, additional analysis is required.

There is an important consequence of using this approach for Cropland, which includes all crop and temporary grassland land parcels identified within the 2000-2016 LPIS data, and extrapolation of this area back to 1990 on the basis of known conversion to Forest land or 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 CRF tables.

All changes in emissions and removals are associated with short term transitions between crops and temporary grasslands, and reported as occurring in the Cropland remaining Cropland land use category.

The analysis of the LPIS provides the history of each land parcel. However, it is not feasible to produce estimates of emissions and removals for each parcel. Therefore it is necessary to devise a consistent approach to summarise the spatial data. To undertake this anslysis, the crop types were aggregated into two broad classifications: Crop or Grass. For ease of analysis these where further codified into “0” for Crop and “1” for Grass. This allows the compression of the history of each parcel into a binary code, and for grouping of parcels based on similar patterns of land use history. The total of 181,228 identified cropland parcels were condensed to 5,411 management patterns, plus one pattern of continuous cropping. Table 6.29 shows some examples of this coding and grouping and how it is successful in condensing the spatial data into a more manageable form. Figure 6.18 shows the time series of the inferred proportion of land parcels within the Cropland category which are temporary grassland in a given year.

Table 6.29 Examples of binary coding of cropland parcel history

Pattern Id	Code	Number of Parcels	Sum Area (ha)	Number of years of Grass
A	0000000000000	35897	159930.6	0
B	0000011111111	3558	11180.48	8
C	1101111111111	1511	7695.15	12
D	1100000000000	1431	5569.52	2
E	1111111100111	899	3159.8	11
F	1100111111111	840	3317.04	11
G	1110011111111	824	2880.86	11
H	0000000000100	211	636.19	1
I	1111100000111	127	416.92	8
J	0000011000000	93	295.82	2
K	0000000111100	83	300.05	4
L	1111000000001	83	299.76	5
M	0010000000000	81	341.9	1
N	0001011111111	79	373.34	8
O	0000101111111	77	474.12	7
P	0000001011111	75	210.82	6
Q	0011000000000	73	309.55	2

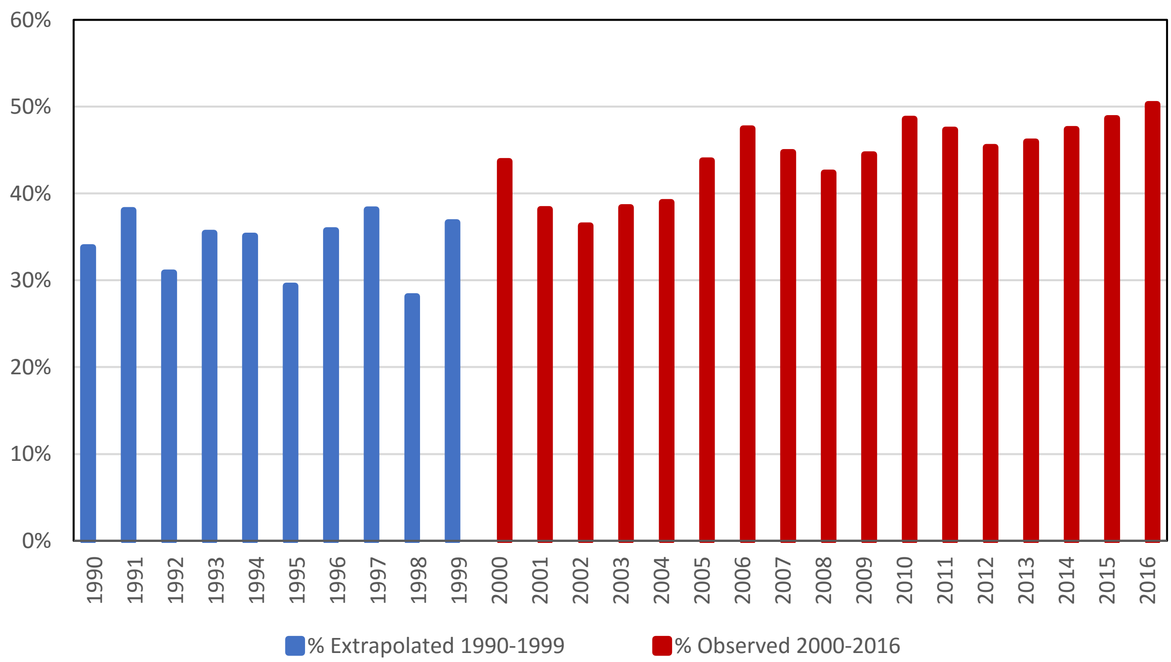


Figure 6.18 Proportion of Cropland cohort which is under temporary grassland each year

It is interesting to note the difference in histories of crop parcels and temporary grassland parcels, shown in Table 6.29. Not surprisingly, if in 2012 a parcel was identified under a crop, then it is more likely to have been under crops in previous years, and spent relatively less time under temporary grass, and vice versa. This reflects the situation that tillage farmers in Ireland will concentrate their efforts on the lands they own, and therefore these lands will spend more time under crops. While, temporary grassland will include a high proportion of lands which are rented or leased for crops on an ad hoc, demand driven, basis, and therefore are less intensively used for crops.

Land parcel data is available for the period 2000-2016. For the period from 1990-1999 the land use pattern is estimated based on a Monte Carlo analysis whereby for each land use pattern 500 simulated times series are constructed for the period 1900 to 1999, constrained by the probability of observed crop/temporary grass for these parcels during the known period from 2000-2016. 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 -2016. 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 2000-2016. The Monte Carlo lacks reference to external drivers of activity within the sector. This may be an area for further development work.

The LPIS and Indicative Soil Map 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.

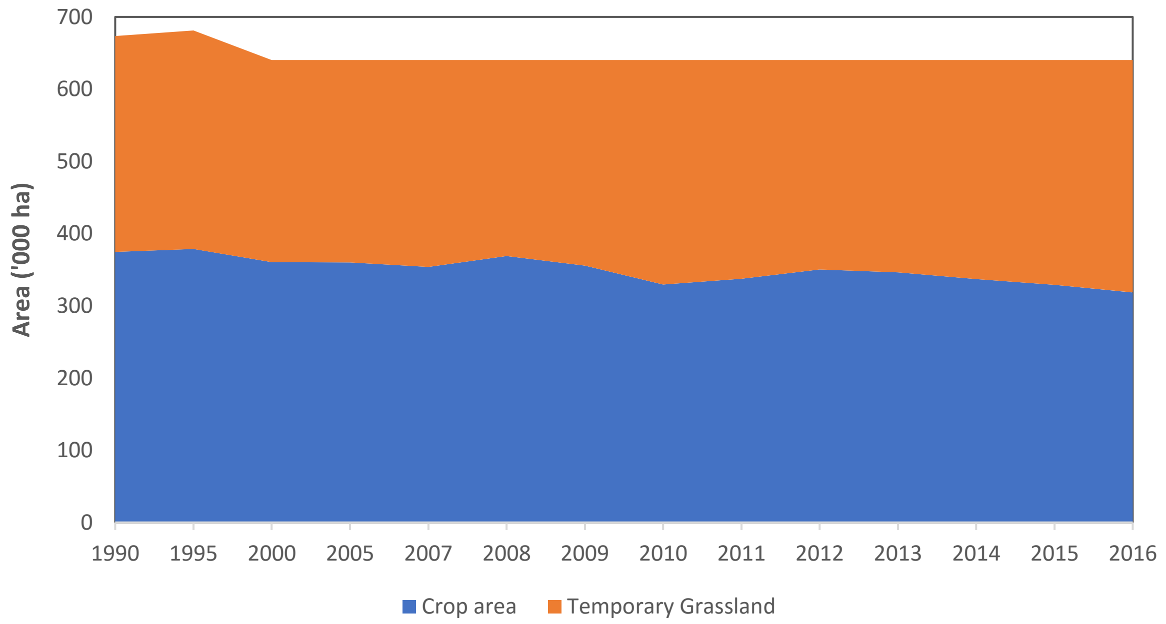


Figure 6.19 Time Series of Cropland from 1990-2016

Figure 6. shows the time series of Cropland area from 1990 – 2016, split between area under crops in a given year, and temporary grassland. The total area decreases slightly over time, reflecting on-going conversion of Cropland to Forest Land and Settlement.

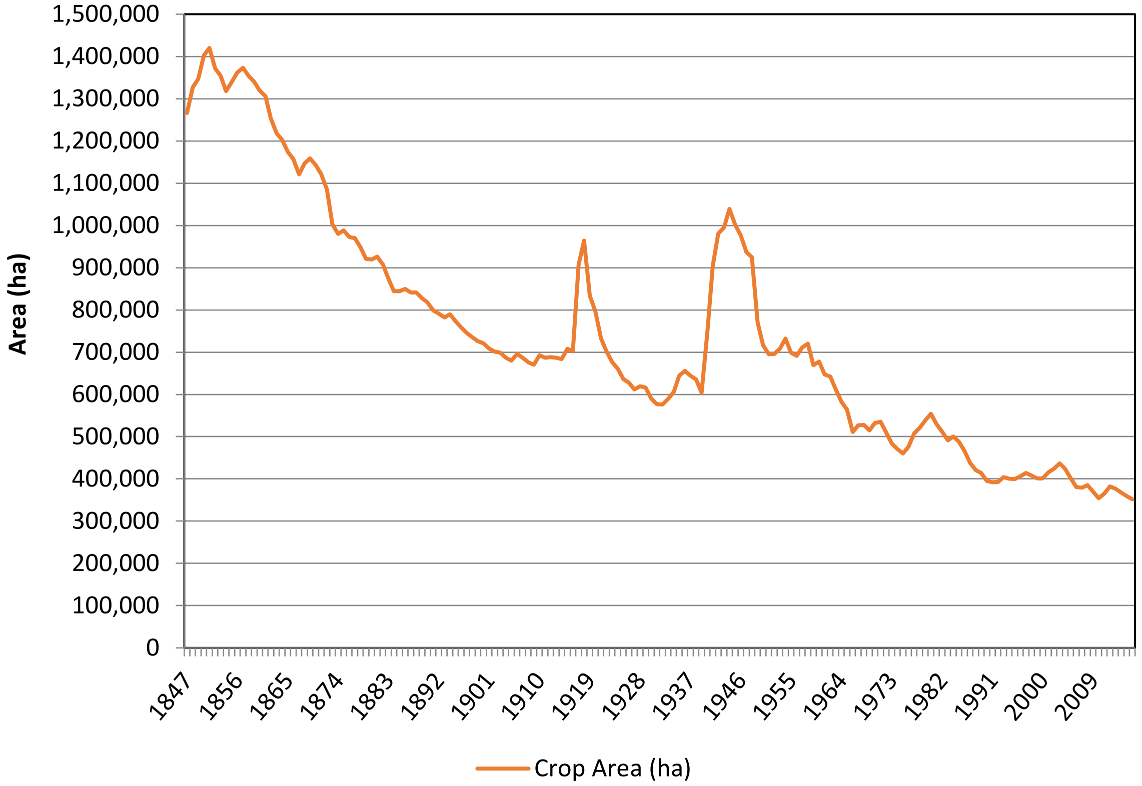


Figure 6.14 shows analysis of the long-term trend in croplands in Ireland over the last one and a half centuries shows a steady decline in tillage area (with temporary reversals associated with exceptional measures to address food security concerns during World War I and World War II), and the consolidation of cropping activity to the most suitable soil types and local climate zones. From the graph, 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 Forest land and Settlement, the Cropland cohort, identified from the analysis of the LPIS from 2000-2016, 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 2000-2016, 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 2000-2016 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 2000-2015 has been assumed as representative for years 1900-1999. This approach results in an unrealistically stable pattern of biomass removal/uptake during this period. Alternative approaches may be explored for future submissions.

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 of crops. 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 and the carbon content of dry matter is 0.5 per cent. The default value of 5 t dry matter/ha 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 eq 6.4.2, derived from eq 2.15 from Chapter 2 Vol 4 of the 2006 IPCC guidelines as follows:

$$\Delta C = A * [(C_{after} - C_{before}) + DC_{growth}] \qquad (6.4.2)$$

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

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 6.30 and Figure 6.20 provide an example of the application of this approach for a specific example of crop and temporary grassland rotation pattern. In total there were 5,411 rotation patterns and plus one pattern of continuous cropping identified, representative of activity on 181,228 parcels of land.

Table 6.30 Example of crop and temporary rotation pattern

Year	2000	2001	2002	2003	2004	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Code	0	0	0	0	0	0	1	1	0	1	1	0	0	0	0	1

* Where "0" represents crop and "1" represents temporary grassland

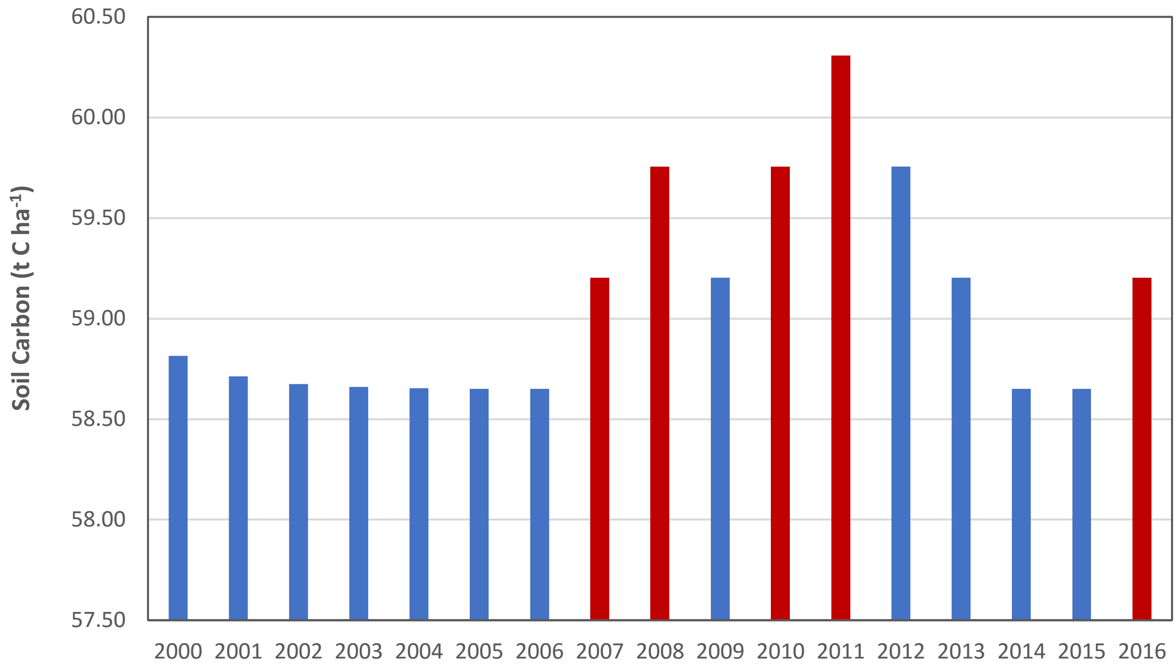


Figure 6.20 Estimated Soil Carbon per hectare based on the crop rotation pattern outline in Table 6.30 for period 2000-2016.

Perennial Woody Crops

The area of woody crops and bioenergy crops (including Christmas trees and Mischantus) 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 are 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 at the present time. Christmas trees are defined as a horticultural crop, and so 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. In 1997, O'Reilly et al 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[7] 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 [8]currently estimates the market

[7]http://www.intertradeireland.com/media/A%20Review%20of%20the%20All-Island%20Horticulture%20Industry.pdf
[8]http://www.bordbia.ie/industry/manufacturers/insight/publications/MarketReviews/Documents/Export-Performance-and-Prospects-2015.pdf

for Christmas trees from Irish producers to be between 500,00 and 700,000 plants. Typically trees are grown at a density of between 4,500 and 7500 plants per hectare. This implies an annual demand for the 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 the total area of Christmas tree plantations can be estimated at between 475 ha and 1,440 ha, with an average of 960 ha. Therefore, Christmas tree plantations in Ireland may cover between 1,000 and 4,000 hectares, with a best estimate of 1,500 ha. 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 6.21).

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 and 2012.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 6.21). The estimated annualise areas for years between censuses data has been based on linear interpolation between data points.

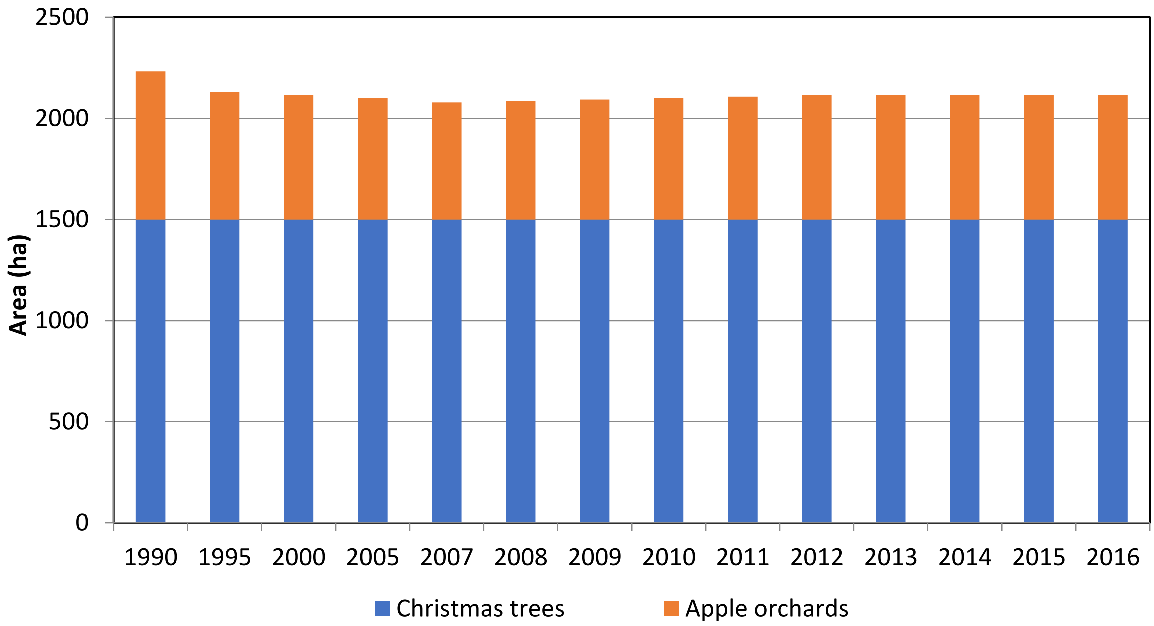


Figure 6.21 Estimated area under Perennial woody crops 1990-2016

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

$$\Delta C_B = \Delta C_G + \Delta C_{conversion} - \Delta C_L \qquad 6.4.3$$

Where DC_B = annual change in biomass stock in perennial crops

ΔC_G=annual increase in carbon stocks in biomass under perennial crops. This is assumed to be zero for well-established perennial crop areas. For lands in transition, the accumulation rate is given by the reference carbon stock (63 tC ha^{-1}) divided by a default 30 year period it is assumed it takes for woody crop to reach maturity/equilibrium.

$\Delta C_{conversion}$ = the initial decrease in biomass from perennial woody crops to annual crops. This is equal to the net change due to a loss of 63tC ha^{-1} in the year of transition, from Table 5.1 Chapter 5 Vol 4 of the 2006 IPCC Guidelines, and a gain in biomass due to subsequent growth of crops in the year of transition. This is equal 5.0 tC yr-1, from Table 5.8 of Chapter 5 Vol 4 of the 2006 IPCC Guidelines.

ΔC_L= is the annual loss due to harvesting, fuel wood gathering and disturbance. This is assumed to be zero for well-established perennial crops.

Figure 6. shows the time series of estimated carbon stock change in biomass based on this analysis.

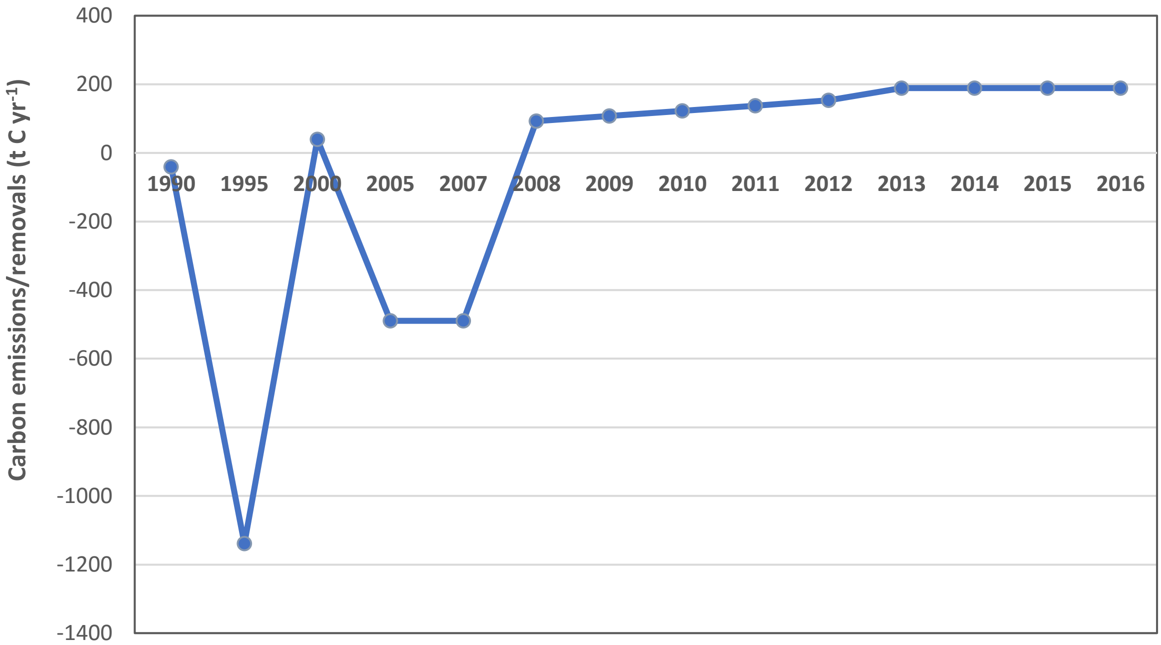


Figure 6.22 Carbon Stock change in Biomass of Perennial Crops

Negative is a source of emissions to the atmosphere

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 2004 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 and that no other land categories are converted to croplands. The research noted in 6.4.5 will also analyse the validity of this assumption.

6.4.7 Estimation of Emissions from Soils

Mineral 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. From which the carbon emissions or removals for the various land-use conversion categories from equation 2.25 in the guidelines, as follows:

$$\Delta C = A * (SOC_0 – SOC_{0\text{-}T}) / T \qquad (6.4.1)$$

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

where

- ΔC = annual change in carbon stocks
- A = area of land converted from a former land use
- SOC_0 = soil organic carbon stock for current land use
- $SOC_{0\text{-}T}$ = 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 6.31 shows 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 6.4.1 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 6.4.1. 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. In line with expert option it is assumed that no cultivation occurs on organic soils, as discussed in 6.4.2.

Table 6.31 Adjustment Factors for SOC

Land Use	F_{LU}	F_{MG}	F_I	Adjustment factor, AF
Cropland	0.69	1.0	1.0	0.69
Improved grassland	1.0	1.0	1.14	1.14
Unimproved grassland	1.0	1.0	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 is to estimate changes in soil carbon stocks is based on the pattern of cropland rotation allowing carbon uptake to soil in years when the parcel is under temporary grassland, and carbon loss for years under crops. The maximum carbon uptake under grassland is limited to the reference level for improved grassland, while the minimum carbon removal is limited to the reference level for permanent croplands. The initial level of carbon associated with a given pattern of land use is estimated from the average carbon content arising from the Monte Carlo simulation of 500 instances of the pattern populated with random binominal probability equal to the observed proportion of crop years in the period from 2000-2016. In this way, parcels which have a history of mostly temporary grassland will tend to start with high soil carbon stocks, whereas those with a history of mostly crops will tend to start with low soil carbon stocks.

Table 6.32 shows the average carbon stocks for crop and temporary grass parcels based on years spent under grass. Clearly, the more years a parcel spends under a crop, the closer its carbon content is to the reference level for continuous cropping. Likewise, the more years a parcel spend under grass, the closer the carbon levels are to the reference content for permanent grassland.

The incorporation of parcel history into the approach for estimation of soil carbon emissions and removals successfully reflects rotational crop management practices, which developed over time to maintain soil condition and fertility.

Table 6.32 Carbon content of cropland soils as a function of 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

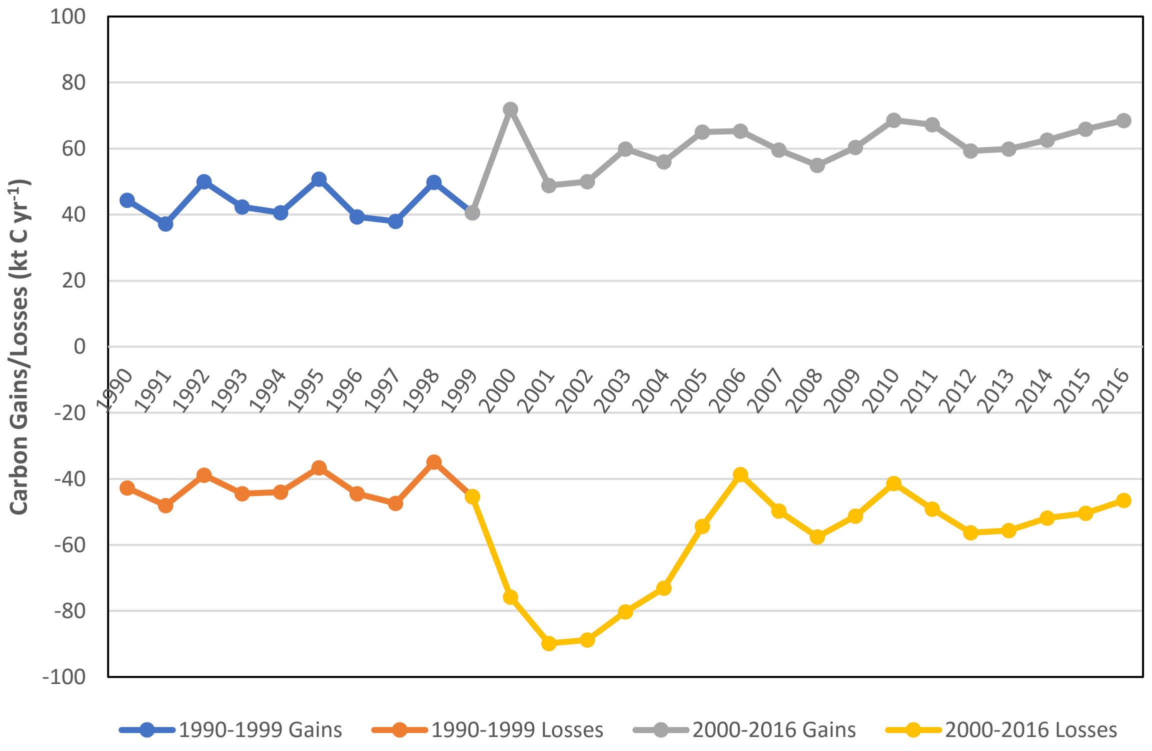


Figure 6.23 Time Series of estimated Soil Carbon Gains and Losses associated with rotational patterns of crop production

6.4.8 Cropland emissions due to Biomass Burning

Activity data on the occurrence of fire on cropland is limited but recently developed remote sensing products may yield a better understanding of the occurrence of fires on cropland in the future. Similar to previous submissions The NASA Fire Information for Resource Management System (FIRM) data set for the region of Ireland was interrogated to establish the occurrence of fires on cropland. When overlayed with the CORINE datasets for the years 2000, 2006 and 2012, it has identified that on average approximately 5 per cent (Table 6.33) of the recorded fire events in any one year coincide with cropland locations. There are however, significant limitations to this approach mainly related to the relatively low spatial resolution and high probability of cloud interference in any signal over Ireland.

Based on the overlay of the NASA FIRMS dataset with CORINE a table of the probability of fire on each land use type for each year 2001 to 2016 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 and 2012

Table 6.33 Land Cover/Use associated with NASA FIRMS instances of fires and the average proportion of fires detected.

Land Use	Proportion of All Fires Detected
Forest	11.4%
Cropland	4.7%
Grassland	20.8%
Wetlands	62.4%
Settlement	0.7%
Other	0.0%

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 to provide a review[9] 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 1km² fire cannot be associated with a distinct land-parcel.*

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[9] 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

Considering these limitations, any estimate GHG emissions caused by this activity would show high uncertainties."

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 "NO" 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_4 and N_2O only.

Emissions of CH_4 and N_2O are calculated using eq 2.27 from Chapter 2 Vol 4 of the 2006 IPCC Guidelines, and shown here:

$$L_{fire} = A \cdot M_B \cdot C_f \cdot G_{ef} \cdot 10^{-3} \qquad \text{eq 6.4.4}$$

Where L_{fire} = amount of greenhouse gas emissions from fire, in tonnes of gas (CH_4, N_2O),

A = area burnt, ha,

M_B = mass of fuel available for combustion, tonnes ha^{-1}. This includes biomass, litter and DOM. For Tier 1 Litter and DOM are assumed zero for croplands remaining croplands.

Cf = combustion factor, dimensionless,

The default value for M_B .C_f is 4.0 from Table 2.4in 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 CH_4= 2.7 g kg^{-1} dm_{burnt}, N_20 =0.07 g kg^{-1} dm_{burnt}.

6.4.9 Uncertainties and time-series consistency in Cropland

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 2000-2016 was used in the analysis presented in this submission Figure 6.4.6 shows crop and temporary grass areas for this period. 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 in previous submission, the CSO data only captures net transitions between crop and grassland and back again.

Uncertainty in Area

The uncertainty in areas for the period 2000-2016 can be estimated from the requirements for submission of data to the DAFM under the various farm payment schemes associated with LPIS. 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 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

There are no QA/QC or verification procedures specific to the Cropland category

6.4.11 Cropland recalculations and impact on 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 6.24 shows a comparison between 2017 and 2018 submissions of estimated total emissions associated with Croplands. The difference is driven by the impact of the complete 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. This variability requires additional analysis to ensure it does not result from an artefact of the methodological approach for assessing activity data (areas), but is reflective of actual potential emissions and removals. A revised table of probability of fires based on NASA FIRMS data was produced for this submission leading to a revision in the estimates associated with biomass burning. The net effect of these recalculation is a 77 percent reduction in emissions/increase in removals across the timeseries.

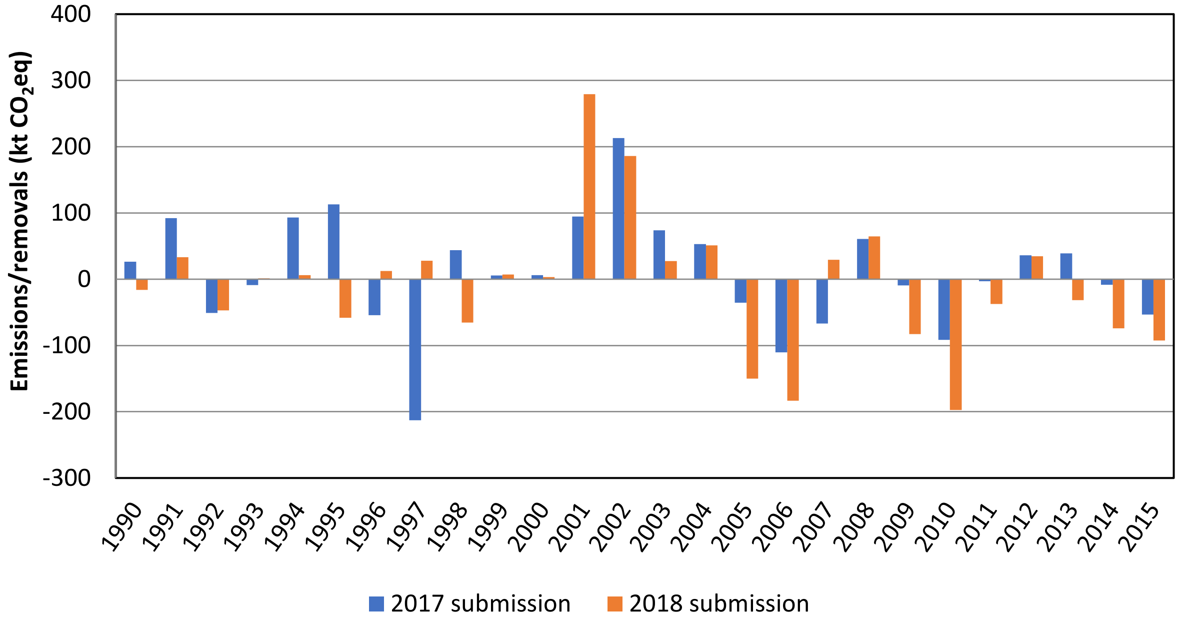


Figure 6.24 Comparison between 2017 and 2018 submissions of estimated total emissions and removals associated with Cropland

6.4.12 Cropland Category-specific planned improvements

A major project on Irish soils, the Irish Soils Information System, has recently published its data and produced a new, complete map of soils in Ireland. It is proposed to revise the attribution of soil type and soil carbon, and land use, based on this new, comprehensive dataset through a recently funded research project. It is hoped this will lead to the adoption of Tier 2 country specific value for reference soil carbon stock and management factors.

The 2015 submission was the first step towards incorporation of the Land Parcel Information System into the reporting methodologies. The stock change approach adopted in this first instance indicated large inter-annual variability in carbon stocks. This was re-evaluated for the 2016, 2017 and this the 2018 submission in the context of a relatively stable Cropland cohort area. Additional development is required to establish country specific management factors associated with specific soil and crop types.

The current activity data for perennial woody crops is limited. Additional data discovery and analysis is required to be undertaken to improve these data.

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 continues to discuss with a number of other agencies in this regard.

The EPA is funding research into the remote sensing technologies and analytical techniques for the quantification of non-forest wood biomass in the landscape. In the context of Cropland, this refers to primarily hedgerows. 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. The aim of the research is to exploration cost effective measurement and monitoring systems to quantify the impact of such policy incentives on biomass and carbon.

6.5 Grassland (4.C)

Definition: 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 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 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 the management and use of grassland through the 20th century leading to increased productivity.

In recent decades, changes in agriculture, have been driven by measures under the Common Agriculture Policy, where for example the "headage payment" subsidy lead to a very dramatic increase in sheep numbers from 3.5 million animals in the early 1980s to 8.9 million by 1990. This had a severe environmental impact due to over-grazing on hill sides. Reform of the scheme, in the mid-1990s, led to a sharp decline in sheep numbers, and a corresponding decline in the reported area of rough grazing. Similarly, production quotas on milk effectively led to the compression and stagnation of the dairy sector in Ireland.

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 2016 submission:

- Central Statistics Office annual statistics of Utilised Agriculture Area (1990-2016);
- Land Parcel Information System data (2000-2016) 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 Department of Environment, Community and Local Government (1990-2016);
- Fire Information for Resource Management System (FIRMS) NASA;
- National forest fire statistics see Table 6.9;
- National Forest Inventory 2006 and 2012.

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 spatial data used to estimate the remaining grasslands.

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. Analysis of the National Forest Inventory for 2006 and 2012 includes estimates of hedgerows and non-forest wooded areas in the agricultural landscape. However, further research is required to complete a robust time series of hedgerow extent and condition in Ireland. Preliminary studies to this construct this time series have been funded by the EPA.

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 2009. This resulted in a stepwise break point in the CSO 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. 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. The research noted in section 6.4.2 will explore the LPIS database to refined analysis of this topic further.

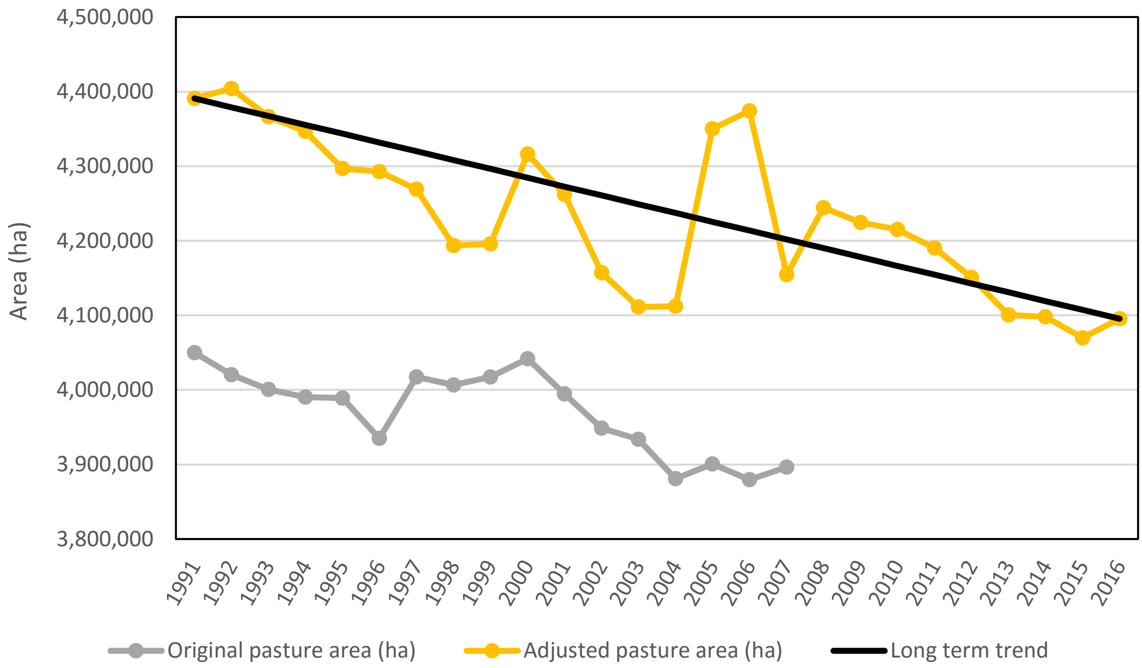


Figure 6.25 Plot of original CSO data for Grassland areas and adjusted data for 1991-2007 based on extrapolation of long term trends from 1991 to 2007 and 2008-2016

It is important to note that both improved and unimproved grassland areas are estimates of grasslands *in use* for agricultural purposes. 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. 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 other land uses.

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.. 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 report 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 in recent years has 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. 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.

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 "in use" 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 good economic return.

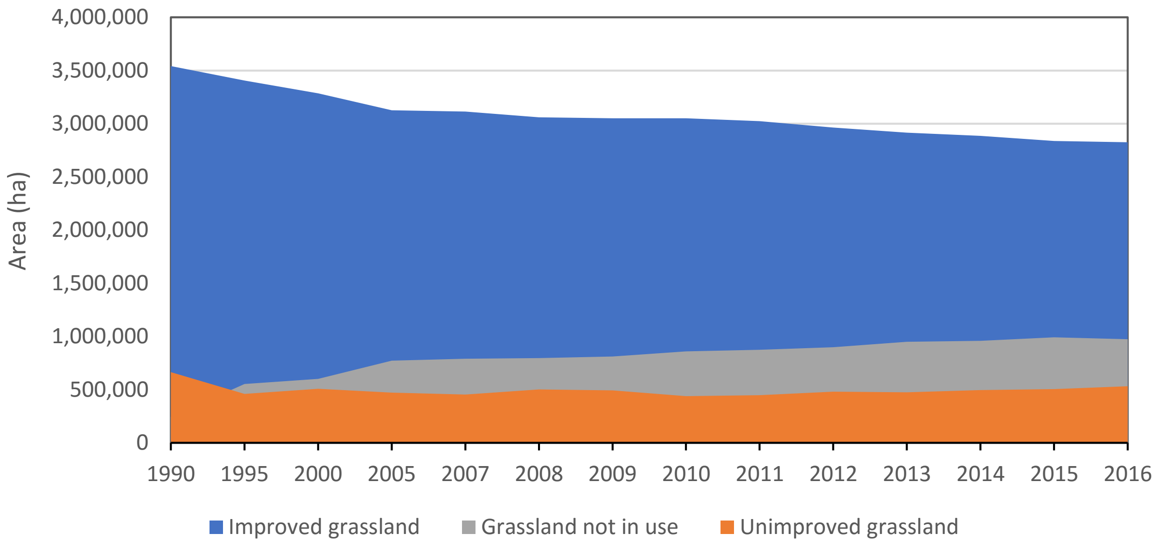


Figure 6.26 Trends in Grassland use 1990-2016

Hedgerows are maintained as an integral system of grassland systems to control the movement of livestock, manage grazing fodder stock, and in many cases to define parcel boundaries. There is anecdotal evidence of hedgerow removal to facilitate access, traffic of machinery and deploying alternative methods to management of grazing intensity. However, recent hedgerow surveys across Ireland suggest the removal has not occurred on the same scale as has occurred in other parts of Europe. Additional work is required to quantified change over time in hedgerows in Ireland, both in terms of extent and condition, and the EPA has funded a number of research initiatives on this topic. At present, a consistent time series of changes in hedgerow extent or condition is not available.

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 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. However, as Grassland is the dominant land use category for Ireland, the 2006 IPCC Guidelines suggest it is appropriate to develop national specific data to estimate the impact of management and disturbance. Ireland has funded a number of studies to achieve this, and the country specific analysis will be incorporated into the methodology as appropriate.

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 1990 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 grassland not in use 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_4 and N_2O associated with drainage activity.

The Tier 1 methodology from the 2006 IPCC Guidelines, described in Section 2.3.3.1, and eq 2.26 in the guidelines (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 per year 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.

$L_{organic} = A \cdot EF$ 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 yr^{-1}.

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. Figure 6. shows the time series of carbon losses from drained organic soils under agricultural grassland.

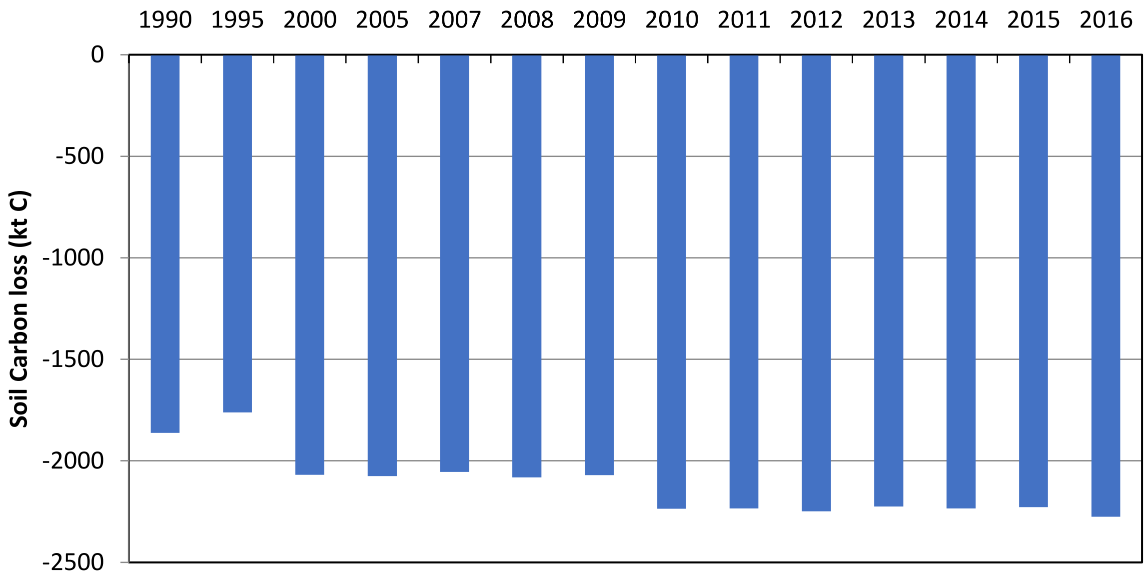


Figure 6.27 Time Series of carbon losses from drained organic soils under grassland

New estimates have been provided for forest conversion to grassland organic soils for the period 1990 to 2009. Emissions from peaty mineral soils are adjusted according to peat depth as described in equation 6.3.2.

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 involves natural rewetting 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_2 removals from the atmosphere due to uptake to soil;
2. CO_2 losses in the form of dissolved organic carbon into the water system;
3. CH_4 emissions due to rewetting.

$$CO_2 - C_{rewetted\ organic\ soil} = CO_2 - C_{composite} + CO_2 - C_{DOC} + L_{fire-}CO_2 - C$$

Where $CO_2 - C_{\text{rewetted organic soil}}$ =CO_2 as C removals and emissions from rewetted organic soils, tC yr^{-1}.

$CO_2 - C_{composite}$ = emissions and removals from soil and non-tree vegetation tC yr-1

$CO_2 - C_{DOC}$= emissions from dissolved organic carbon exported from rewetted organic soils, tC yr-1

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

CO_2 removals from the atmosphere due to uptake to soil ($CO_2 - C_{composite}$)

From simplified version of Eq 3.4 in the 2013 Wetlands Supplement

$$CO_2 - C_{composite} = A.EF_{CO_2}$$

Where A = area of nutrient poor rewetted organic soils, and EF $_{CO2}$ = emission factor for nutrient poor, soils in temperate climate zone and is equal to -0.23 tC ha^{-1}, from Table 3,1 in the 2013 Wetlands Supplement. The minus sign indicate a sink of carbon.

CO_2 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.

$$CO_2 - C_{DOC} = A \cdot EF_{DOC\ rewetted}$$

Where $CO_2 - C_{DOC} =$ off-site emissions of CO_2 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_2-C ha^{-1} yr^{-1}.

CH_4 emissions/removals due to rewetting

Rewetting or organic introducing anaerobic conditions to the soil, which leads to decomposition of organic matter with the release of CH_4. Eq 3.7 in the 2013 Wetlands Supplement provides the basis for Tier 1 approach to estimation of these emissions.

$$CH_4{-}C_{rewetted\ org\ soil} = CH_4{-}C_{soil} + L_{fire}$$

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

$$CH_4{-}C_{soil} = A_{rewetted\ org\ soil} \cdot EF_{NP,T}$$

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 kg CH_4-C ha^{-1} yr^{-1}.

6.5.2.5 CH_4 emissions due to drainage of grasslands on organic soils

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

$$CH_{4\_organic} = \left(A_{T,NP,O} \cdot \left((1 - Frac_{ditch}) \cdot EF_{CH_{4_{land}}} + Frac_{ditch} \cdot EF_{CH_{4}\_ditch}\right)\right) \text{ eq 6.5.5}$$

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_{CH4_land} = emission factor for methane emissions from nutrient poor soils serviced by drainage ditches in temperate zone. The default value for EF_{CH4_land} is 1.8 kg CH_4 ha^{-1} yr^{-1} from table 2.3 of the 2013 Wetlands Supplement for shallow drained soils, which is typical drainage for Ireland.

EF_{CH4_ditch} = emission factor for methane emissions from ditches in temperate zone, draining nutrient poor soils. The default value for EF_{CH4_land} is 527 kg CH_4 ha^{-1} 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.

Figure 6.28 Estimate of area drained and CH4 emission estimates in grasslands.presents the time series of estimated area of nutrient poor grassland drained for use as agricultural grassland and associated CH_4 emissions.

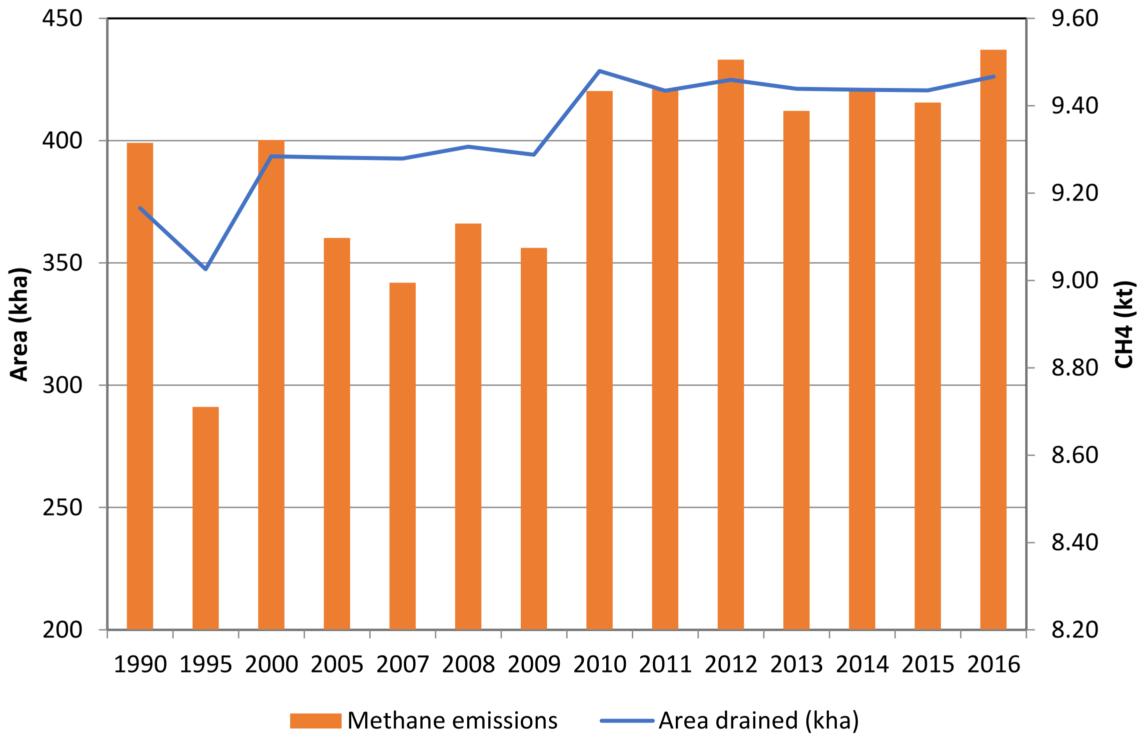


Figure 6.28 Estimate of area drained and CH_4 emission estimates in grasslands.

6.5.3 Land converted to Grassland

In the period 1990-2016, a limited area of Forest land 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 21 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 therefore included in the grassland fire area. Therefore, the incidence of grassland fires increases to 51.9 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 has not been collated at a national level.

Therefore, the incidence of fires on grasslands is assumed to be as a result of land management. As a consequence, all fires on grassland are classified as controlled fire. Figure 6. shows the estimated area of grassland burned.

The emissions associated with fires are estimated based on the 2006 IPCC guidelines Vol 4 Chapter 6, Section 6.2.4 2.

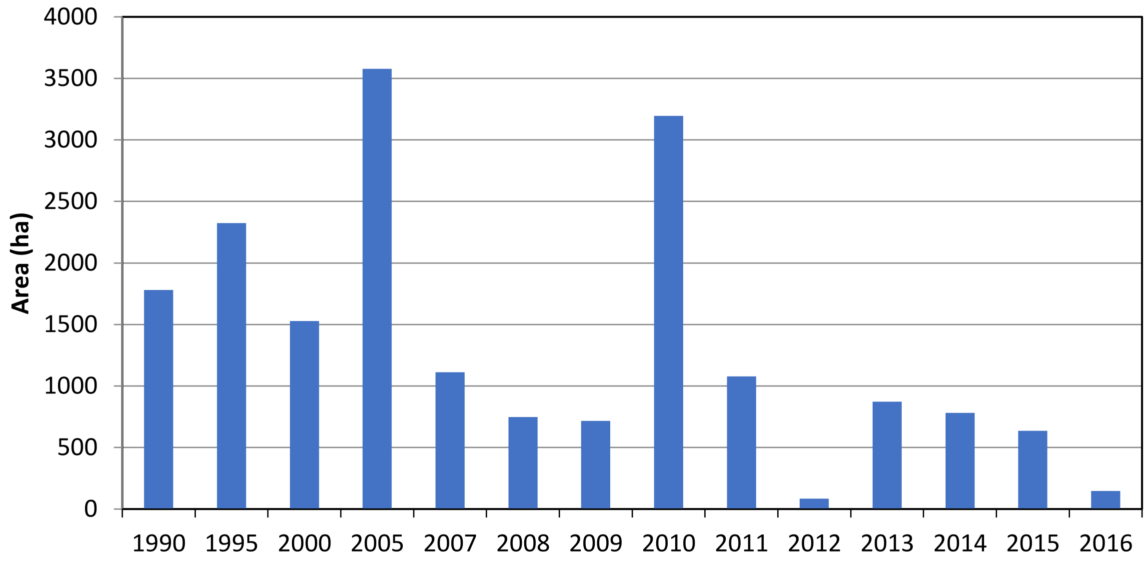


Figure 6.29 The estimated area of grassland subjected to controlled burning from 1990-2016

Emissions of CH_4 and N_2O are calculated using eq 2.27 from Chapter 2 Vol 4 of the 2006 IPCC Guidelines, and shown below. The approach requires the area of grassland burnt to be stratified between mineral soils, drained organic soils and undrained organic soils, and provide appropriate default values for each of the parameters.

$$L_{fire} = A \cdot M_B \cdot C_f \cdot G_{ef} \cdot 10^{-3} \qquad \text{eq 6.5.4}$$

Where L_{fire} = amount of greenhouse gas emissions from fire, in tonnes of gas (CH_4, N_2O),

A = area burnt, ha,

M_B = mass of fuel available for combustion, tonnes ha-1. This includes biomass, litter and dom. For Tier 1 Litter and DOM are assumed zero for croplands remaining croplands.

Cf = combustion factor, dimensionless,

The default values for grassland for M_B are from Table 2.4 in the Ch 2 Vol 4 2006 IPCC Guidelines, and Table 2.7 in the 2013 Wetlands Supplement. See Table 6.34Table 6. C_f is assumed equal to 1.0, that is all available fuel is burned.

G_{ef} = is the emission factor, g kg^{-1} dry matter burnt. The default values for grassland are CH_4=2.3 g kg^{-1} dm_{burnt}, N_20 =0.21 g kg^{-1} dm_{burnt}.

Table 6.34 Default parameters for use in Eq 6.5.4

	Mineral Soil	Drained Organic soil	Undrained Organic soil
$M_B \cdot C_F$ (t ha^{-1})	4.1	336	66
G_{ef} CO_2 (g kg^{-1} dm_{burnt})	1613	362	362
G_{ef} CH_4 (g kg^{-1} dm_{burnt})	2.3	9	9
G_{ef} N_2O (g kg^{-1} dm_{burnt})	0.21	0.21	0.21

In the Tier 1 methodology, there are no long term losses of biomass carbon due to fires on grassland, and emissions are estimated for CH_4 and N_2O only, see Figure 6.30.

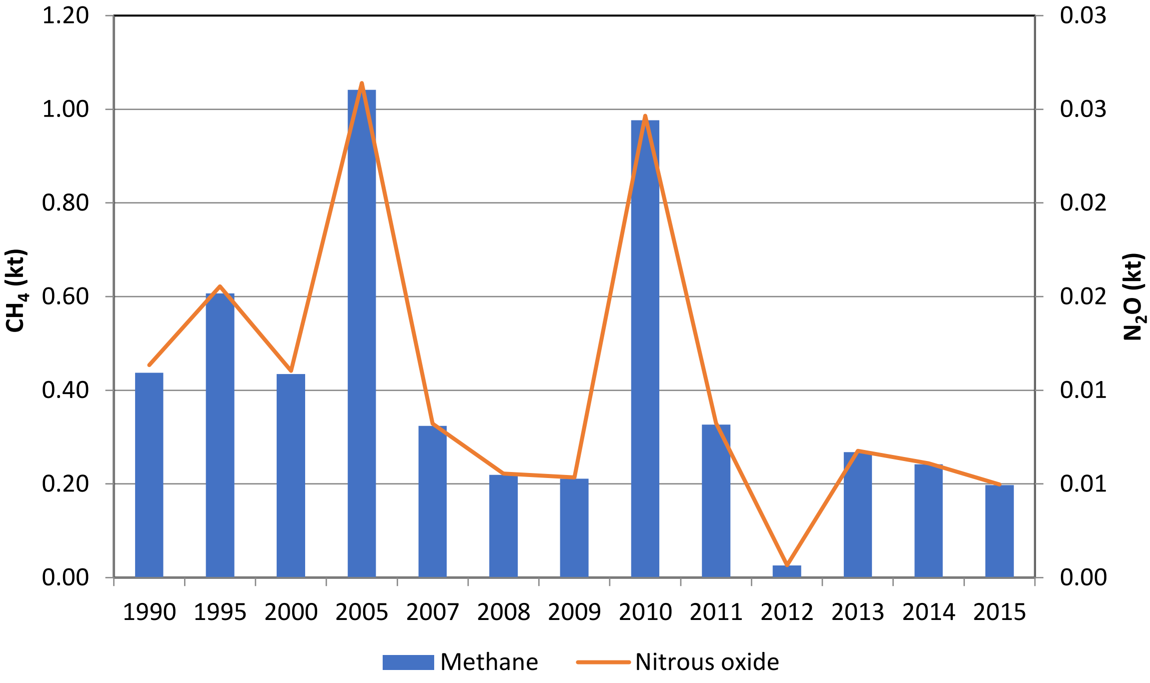


Figure 6.30 Estimated CH_4 and N_2O emissions from wildfires on Grassland

6.5.5 Uncertainties and time-series 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 1000ha to transition between improved and unimproved grassland, and 10 per cent of grasslands are on drained organic soils, then 100ha 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

There are no QA/QC or verification procedures specific to the Grassland category.

6.5.7 Grassland -specific recalculations and impact on emission trend

Recalculations to emissions and removals in the Grassland category in this submission are due to revised assessment of land area statistics and management practices. This has lead to a revised assessment of the area of organic soils under grassland which require drainage. A revised table of probability of fires based on NASA FIRMS data was produced for this submission leading to a revision in the estimates associated with biomass burning. Additionally, transcription errors were identified in the previous submission in relation to the calculation of CH_4 and N_2O emissions from biomass burning. The net effect of these recalculations is an 8.1 per cent on average increase in emissions across the timeseries.

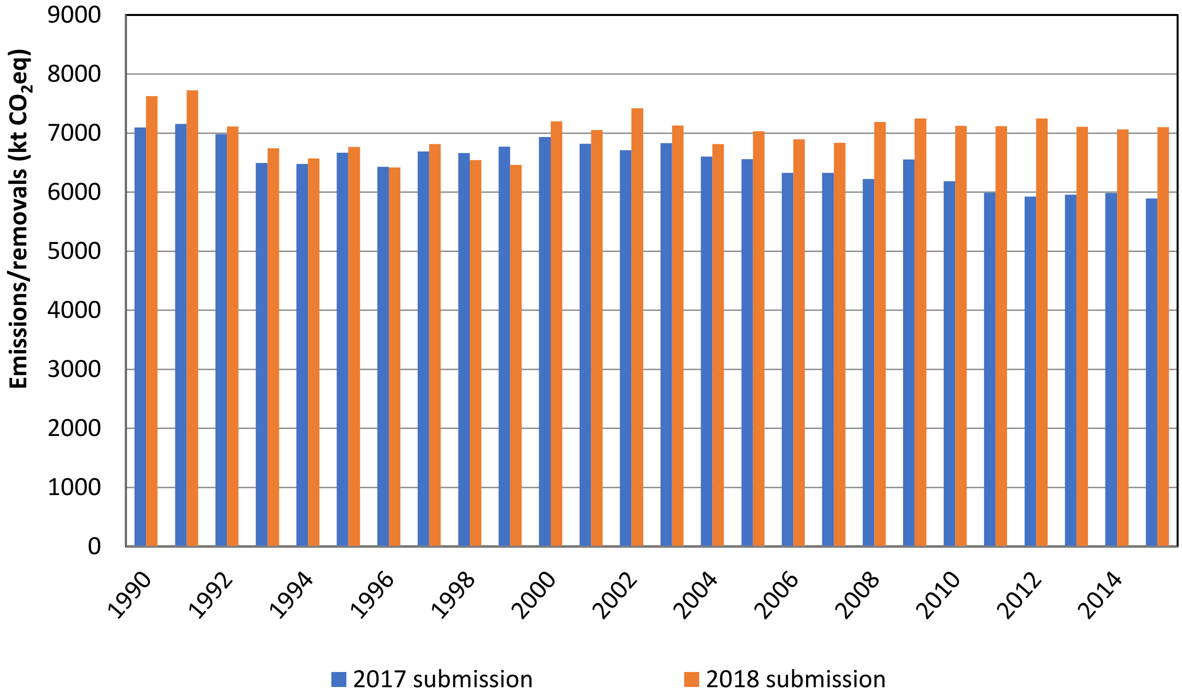


Figure 6.31 Grassland recalculations between the 2016 and 2017 submissions for the period 1990-2015

6.5.8 Grassland Category-specific planned improvements

A major project on Irish soils, the Irish Soils Information System, has recently published its data and produced a new, complete map of soils in Ireland. It is proposed to revise the attribution of soil type and soil carbon, and land use, based on this new, comprehensive dataset. It is hoped this will lead to the adoption of Tier 2 country specific value for reference soil carbon stock and management factors.

The 2015 submission was the first step towards incorporation of the Land Parcel Information System into the reporting methodologies which was continued in this submission. Further steps will include analysis of history of permanent grasslands, in particular assessing changes in condition of grassland no longer reported within the LPIS.

The EPA is funding research into the remote sensing technologies and analytical techniques for the quantification of non-forest wood biomass in the landscape. In the context of grassland, this refers to primarily hedgerows. Hedgerows are an important feature of the Irish landscape. They are a 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. The aim of the research is to explore cost effective measurement and monitoring systems to quantify the impact of such policy incentives on biomass and carbon.

The emission and management factors associated with the drainage of organic and wet soils in Ireland will be assessed, based on the findings of country specific research.

6.6 Wetlands (4.D)

6.6.1 Wetland Areas

The term Wetlands as applied to Ireland refer to natural 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. 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)[10]. In general, traditional methods of peat extraction cumulated 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 where allowed to fall into disrepair, and gradually rewetting of the abandon extraction site occurred. Therefore, it is reasonable to assume all non-commerical 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. The 2018 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 the managed from peat extraction, 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^{-1}. It is also assumed soil carbon loss from these rewetted lands has ceased.

6.6.3 Exploited Peatland Areas

The commercial exploitation of peatlands is dominated by Bord na Mona (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

10 http://www.heartland.ie/articles/brief-history-peat-industry-ireland

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 grasslands or 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. 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, Bord na Mona held a small area of un-drained wetlands in reserve. However, these lands have been transferred to the National Parks and Wildlife Service 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 Bord na Mona 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. The extraction of peat for use for residential heating is estimated from the quantity of residential sod peat presented in the national energy balance and a bulk density estimate of 0.25 t/m^3 for peat 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 and this the 2018 submission include an analysis of GHG emissions and removals associated with peat extraction and use of peat in Horticultural products. BnM is also the dominantly player in 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 non-BnM commercial enterprises. This estimate is based on estimates of market share 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 previous submissions, it was assumed that the restoration of biomass occurred in the year of conversion. However, discussions with experts suggested a more appropriate transition period of 5 years for biomass re-establishment, and is support by findings from restoration peatlands sites managed by Bord na Mona (Wilson et al., 2012).

The vegetation is removed from an area of the peatland reserve that is drained to come under production annually and the restoration area is taken as the annual increase in cutaway wetland. The vegetation is typically heather-dominated bog or heathland cover for which a biomass carbon content of 3 t C/ha 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 6.19 in Section 6.3.6 provides the area of forest land converted to wetlands for the years 1990-2016. The immediate oxidation of biomass, litter and dead wood for years prior to 2006 were derived using the mean IEF for 2006 to 2010 (see section 6.3.3). Similar to re-establishment on cutaway peatland, it is assumed that natural vegetation cover will gradually recover over a period of five years at the rate of 0.6 t C $ha^{-1}yr^{-1}$ up to an equilibrium of 3 t C ha^{-1}.

DOM and Litter emissions and removals

DOM and Litter are indistinguishable from the 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 the appropriate Tier 1 carbon emission factor is 2.8 t C/ha, 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 carbon loss through dissolved carbon entering the drainage system. This is based on the assumption of flows of carbon through extensive drainage systems. The Tier 1 methodology assigns an emission factor of carbon loss per hectare drained.

6.6.5 Emissions of Non-CO_2 Gases

6.6.5.1 N_2O emissions due to drainage of peatland for peat extraction

The Tier 1 methodology for estimation of N_2O 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 6.5.3, for Ireland, and nutrient poor soils.

$$N_2O - N_{os} = F_{OS,G,temp,NP} \cdot EF_{2,G,Temp,NP} \qquad \text{eq 6.5.3}$$

Where N_2O-N = N_2O emissions, as N, for drained organic soils,

F_{os}= Area of drained organic soils,

EF_2= is the emission factor for N_2O 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_2 of 0.3 kg N_2O-N ha^{-1} yr^{-1} 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_4 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_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:

$$CH_{4\_organic} = \left(A_{T,NP,O} \cdot \left((1 - Frac_{ditch}) \cdot EF_{CH_{4_{land}}} + Frac_{ditch} \cdot EF_{CH_4\_ditch}\right)\right) \quad \text{eq 6.5.5}$$

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

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

EF_{CH4_land} = emission factor for methane emissions from nutrient poor soils serviced by drainage ditches in temperate zone. The default value for EF_{CH4_land} is 6.1 kg CH_4 ha^{-1} yr^{-1} from table 2.3 of the 2013 Wetlands Supplement for shallow drained soils, which is typical drainage for Ireland.

EF_{CH4_ditch} = emission factor for methane emissions from ditches in temperate zone, draining nutrient poor soils. The default value for EF_{CH4_land} is 542 kg CH_4 ha^{-1} 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.

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. The dominant producer 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 energy. This approach is continued in the 2018 submission.

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

BnM provide the details on the area of peatland which are in drained for extraction, which includes areas used for horticultural products. Therefore, the direct emissions associated with BnM lands are already included in the analysis above.

The activities of private commercial industry also supplying domestic and international markets are not included in the above analysis. It is estimated that non-BnM enterprises comprise 20 per cent of the export market, based the difference between recent BnM sales of horticultural products and total national sales.

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 BnM. 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.

Figure 6. shows the time series for off site carbon loss based on this analysis.

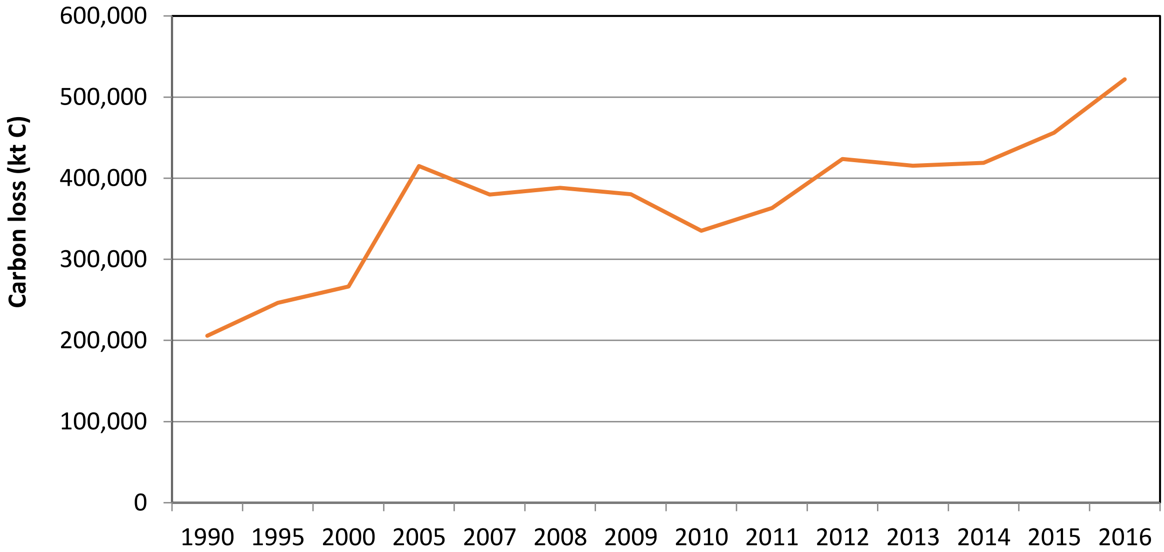


Figure 6.32 Off-Site emissions from Horticultural Peat products

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 approximately 62 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 may 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 31.1 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 6.33).

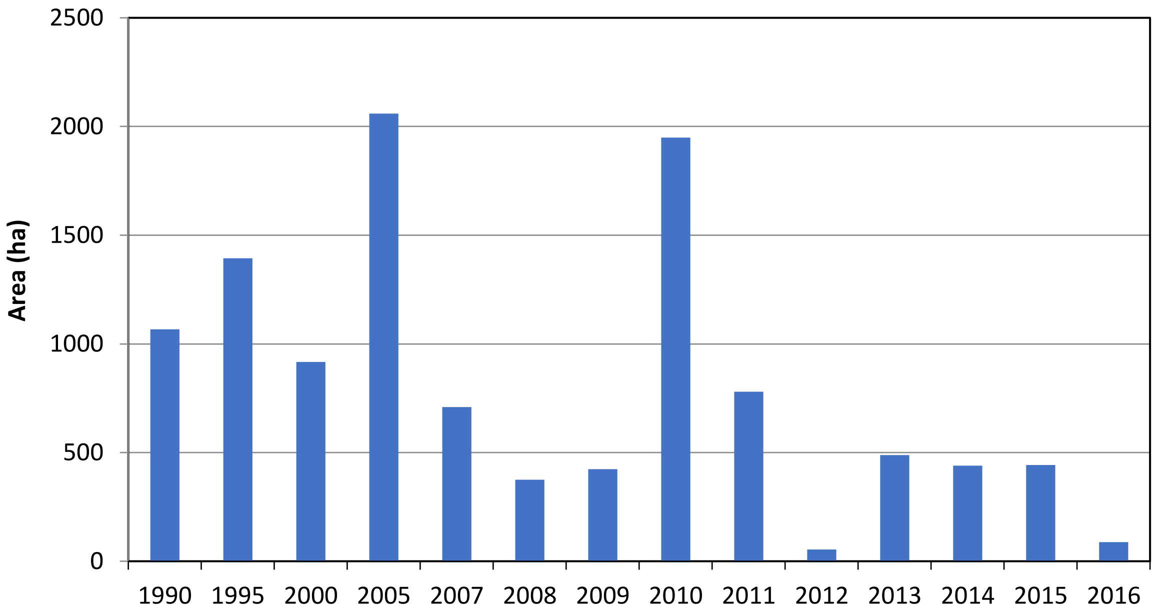


Figure 6.33 Estimate of area of wetland subject to wildfire

The emissions associated with fires are estimated based on the 2006 IPCC guidelines and relevant sections of the 2013 Wetlands Supplement to the 2006 IPCC guidelines.

Emissions of CO_2, CH_4 and N_2O are calculated using eq 2.27 from Chapter 2 Vol 4 of the 2006 IPCC Guidelines, and are shown in Figure 6.34 respectively. The approach requires the area of burnt and provides appropriate default values for each of the parameters.

$$L_{fire} = A \cdot M_B \cdot C_f \cdot G_{ef} \cdot 10^{-3} \qquad \text{eq 6.4.4}$$

Where L_{fire} = amount of greenhouse gas emissions from fire, in tonnes of gas (CH_4, N_2O),

A = area burnt, ha,

M_B = mass of fuel available for combustion, tonnes ha^{-1}. This includes biomass, litter and dom. For Tier 1 Litter and DOM are assumed zero for croplands remaining croplands.

Cf = combustion factor, dimensionless,

The default value for $M_B .C_f$ is 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 gkg^{-1} dm_{burnt} ;CH_4= 9.0 g kg^{-1} $dm_{burnt;}$ N_2O =0.21 g kg^{-1} dm_{burnt}.

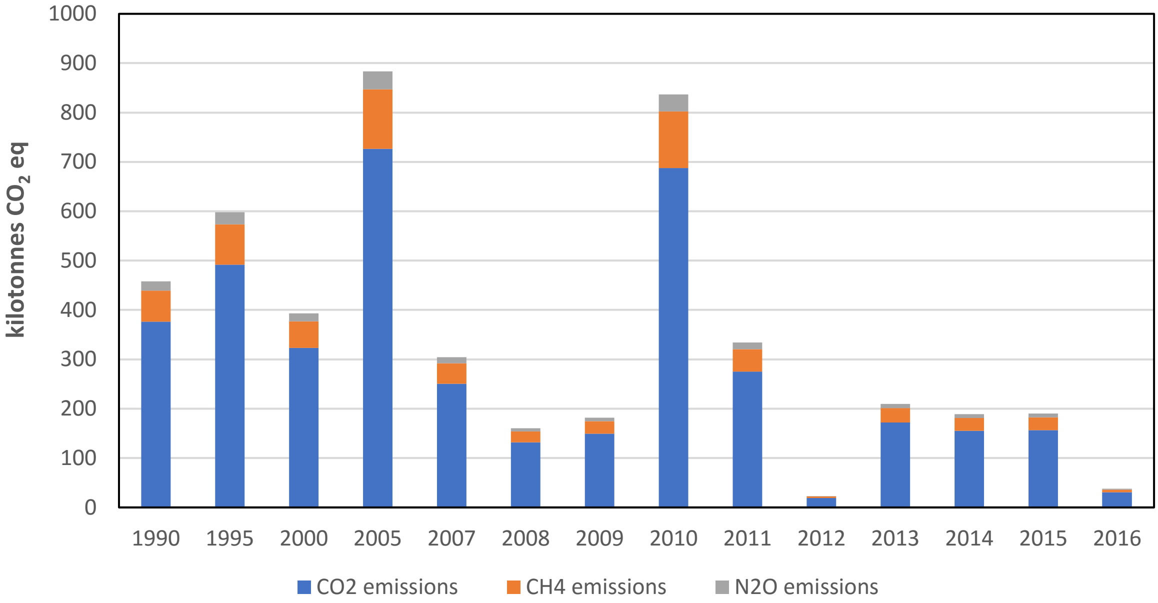


Figure 6.34 Estimated emission (kt CO_2 eq) due to peatland fires

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. Uncertainty analysis reveals 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. 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 Wetland recalculations and impact on emission trend

The main recalculation with the Wetland land use category is the revision of areas associated with the extraction and use of peat for horticultural use. This has had a significant impact on the absolute emissions of carbon to the atmosphere. Revisions to the area of burnt area (as discussed for the *Cropland* and *Grassland* categories) and associated emissions and removals of greenhouse gases (CO_2, N_2O and CH_4) due to biomass burning have had a limited impact on the overall emissions trends. Figure 6. Figure 6.35 shows a comparison between the 2017 and 2018 submissions of estimated total emissions associated with wetlands

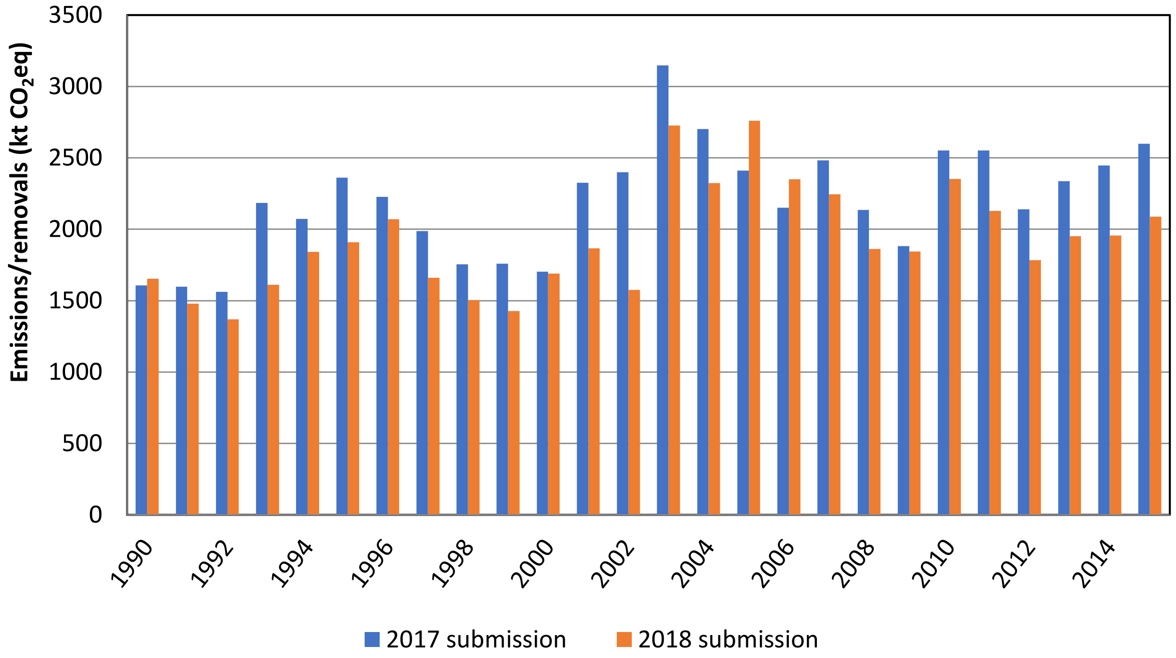


Figure 6.35 Comparison between 2017 and 2018 submissions of estimated total emissions associated with wetlands

6.6.10 Wetland planned improvements

A number of studies are on-going which are investigating improved activity data collation with respect to area and condition of wetlands, including the impact of current drainage systems on raised and blanket bogs, continued domestic removal of peat for use in residential heat generation, and a national assessment on the condition and on-going impact of human interventions on all wetlands. The findings of these studies will be incorporated into the inventory assessment as appropriate.

A study has been funded to verify the default emission factor for carbon losses from the use of horticultural peat, or to establish a country specific emission factor if appropriate.

6.7 Settlements (Category 4.E)

6.7.1 Areas of Settlements

The area of settlements in 1990 base year is estimated from the urban categories within 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 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, beach, etc. The time series for Settlement land use is shown in

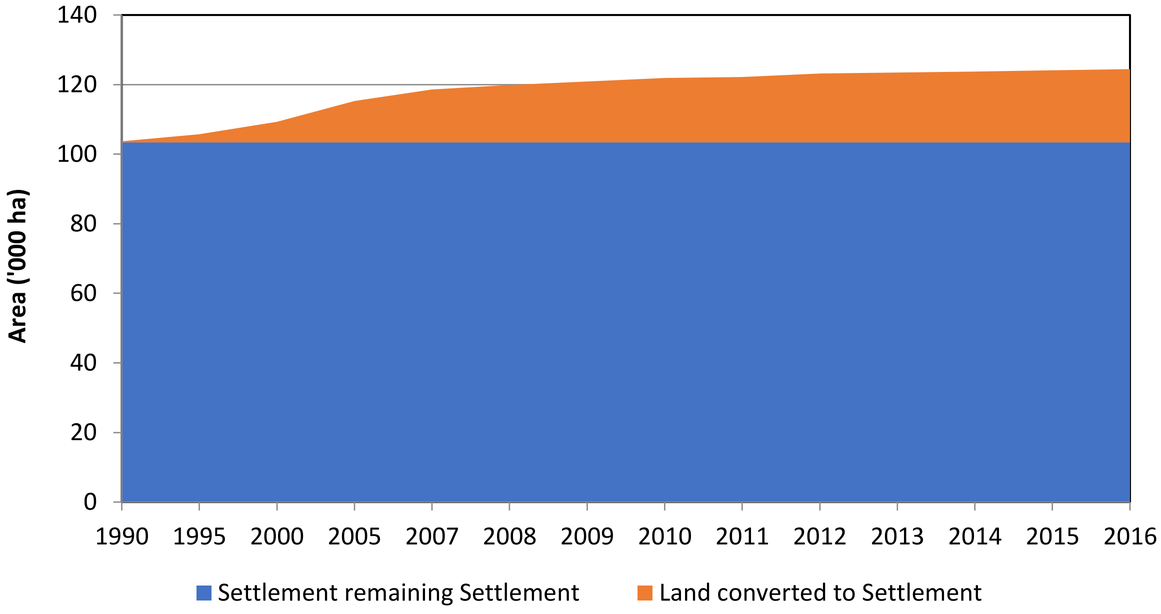


Figure 6.36.

It is assumed Settlement remaining Settlement is constant since 1990. All new settlement activity is categorised as “in transition”.

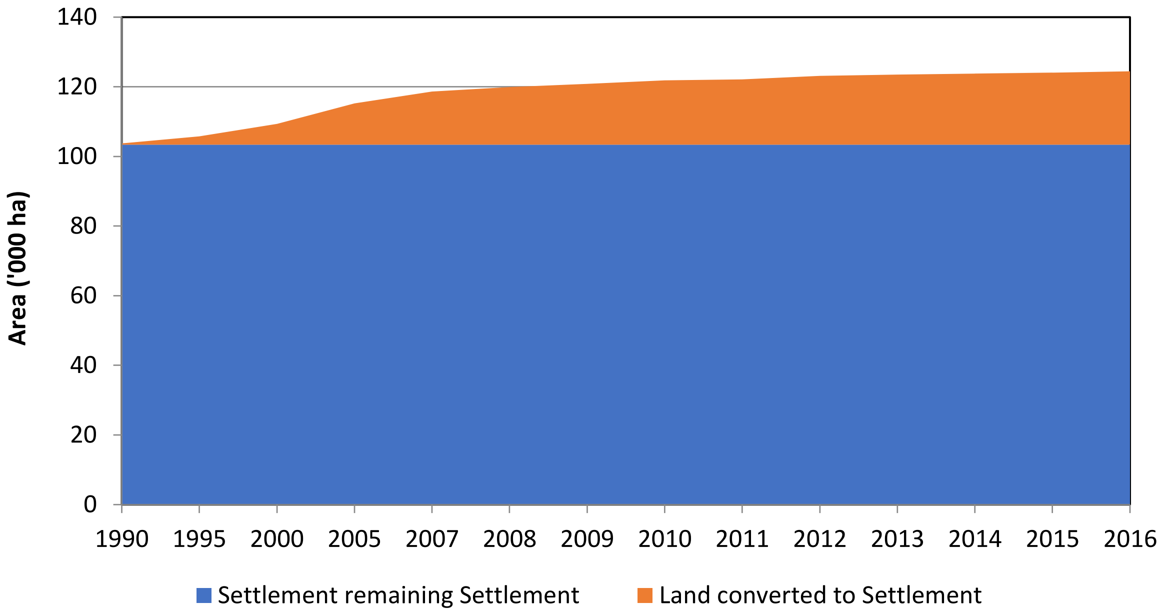


Figure 6.36 Estimated Area of Settlements 1990 to 2016

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.

Table 6.19 includes the area of forest land converted to settlements for the years 1990-2016. 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 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 does not occur.

6.7.2.3 Direct N2O emissions from soils due to Fertiliser application

Artificial Fertiliser:

N_2O emissions associated with use of artificial fertilisers on Settlement soils is included in emission estimates for 3.D Agriculture Soils, which includes all sales of N-fertiliser in the state.

Organic Fertiliser:

Nitrous oxide emissions associated with use of organic fertilisers on Settlement soils is estimated based on statistics on the home composting of organic/food waste. Other organic fertiliser which is available for sale at most gardening supply outlets is not included, as it has not been possible to identify a source of robust data on the volume of sales to generate a complete time series of this type of organic fertiliser use within Settlement.

A national report "*Market Report on Irish Organic Compost Production and Use*" [11] in 2012 suggested provides a nitrogen content of between 7.5 kg $t^{-1,}$ for home composted organic waste which is used to estimate N_2O emissions from organic N fertilizers.

6.7.2.4 Biomass Burning on Settlement

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 in error, and the fires detected are likely to have occurred on adjacent Grassland. Therefore there are no emissions associated with Settlement Biomass Burning, 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 without authorisation.

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 earlier.

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 Agricultural, Forestry or Wetland statistics.

Reporting of potential change in soil carbon during conversion to settlement is based on a review of approaches taken by other reporting parties. The revised 2006 IPCC guidelines also provide some

11 http://www.rx3.ie/MDGUploadedFiles/file/rx3publications/rx3%20Organics%20Market%20Report%20300%20dpi.pdf

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 emission trend

Figure 6.37 shows a comparison between 2016 and 2017 submissions of estimated total emissions associated with Settlements. The difference is driven by a transcription error in the previous submission whereby emissions from mineral grassland soils converted to settlements were not reported in the 2017 submission. Minor revisions to the area of land converted to settlements are also a lesser contributory factor. The net effect of these recalculations is a approx. on average 160 per cent increase in emissions for each year of the timeseries 1990-2015.

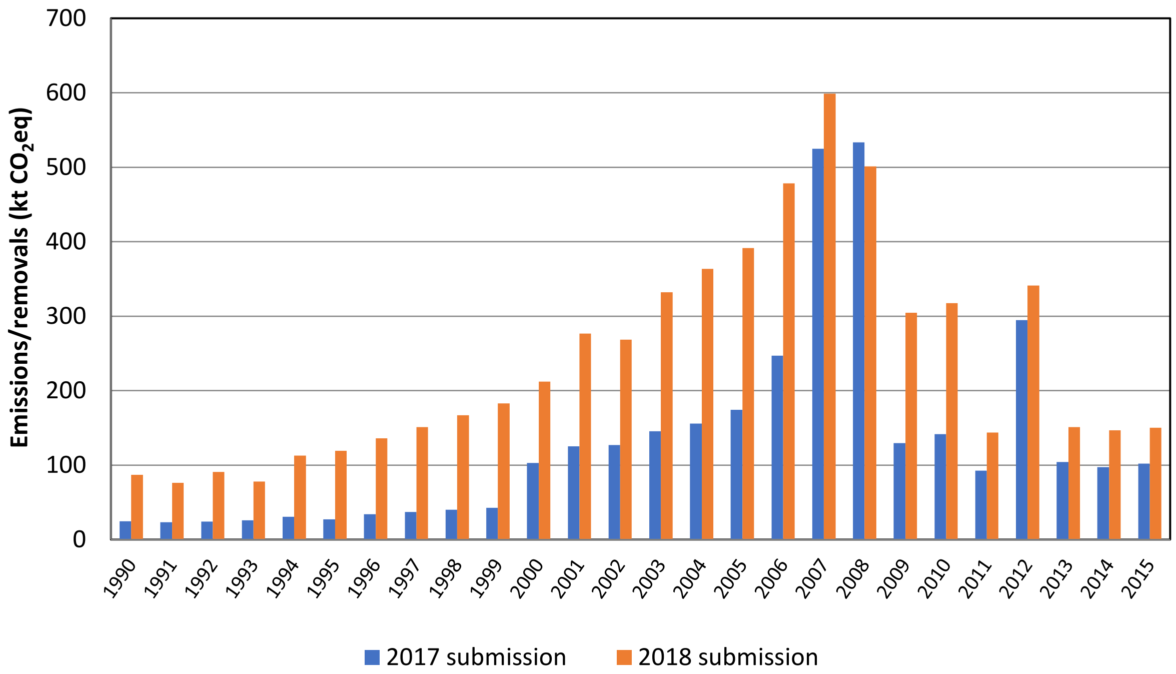


Figure 6.37 Comparison between 2017 and 2018 submissions of estimated total emissions associated with Settlements

6.8 Other Land (Category 4.F)

6.8.1 Areas of Other Land

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 6.19Table 6.9 shows the transition of forest land to other land, which are not classified as crop, grassland, settlements or wetlands for the years 1990-2016. These forest conversions are small areas being converted to quarries or the footprints of telecommunication masts. More recently, these areas also include forest conversions into windfarms, but these are only the areas for roads and turbine platforms. Areas in the turbulence zone are generally clearfelled and replanted.

The immediate oxidation of biomass, litter and dead wood for years prior to 2006 were derived using the mean IEF for 2006 to 2009 (see section 6.3.3). It is assumed that these deforested lands revert to a natural grassland state, and recover an above ground biomass of the order of 6 t C ha^{-1} in the year of conversion.

6.8.3 Biomass Burning on Other Land

See section 6.4.9 for a detailed discussion of the analysis of areas of biomass burning. Only a very small proportion of burnt areas have been identified as occurring on Other Land by this remote sensing approach. This finding includes a very high uncertainty. Given the assumption that Other Land would have low level of biomass available for burning, it is assumed that the GIS analysis which assigned detected fires to Other Land is in error, 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

An error was detected in emissions of N_20 from mineralisation of SOC in forest land converted to other land in the previous submission. All previously submitted values were out by a factor of 100 due to incorrect transfer of data into the CRF tables (4(III)).

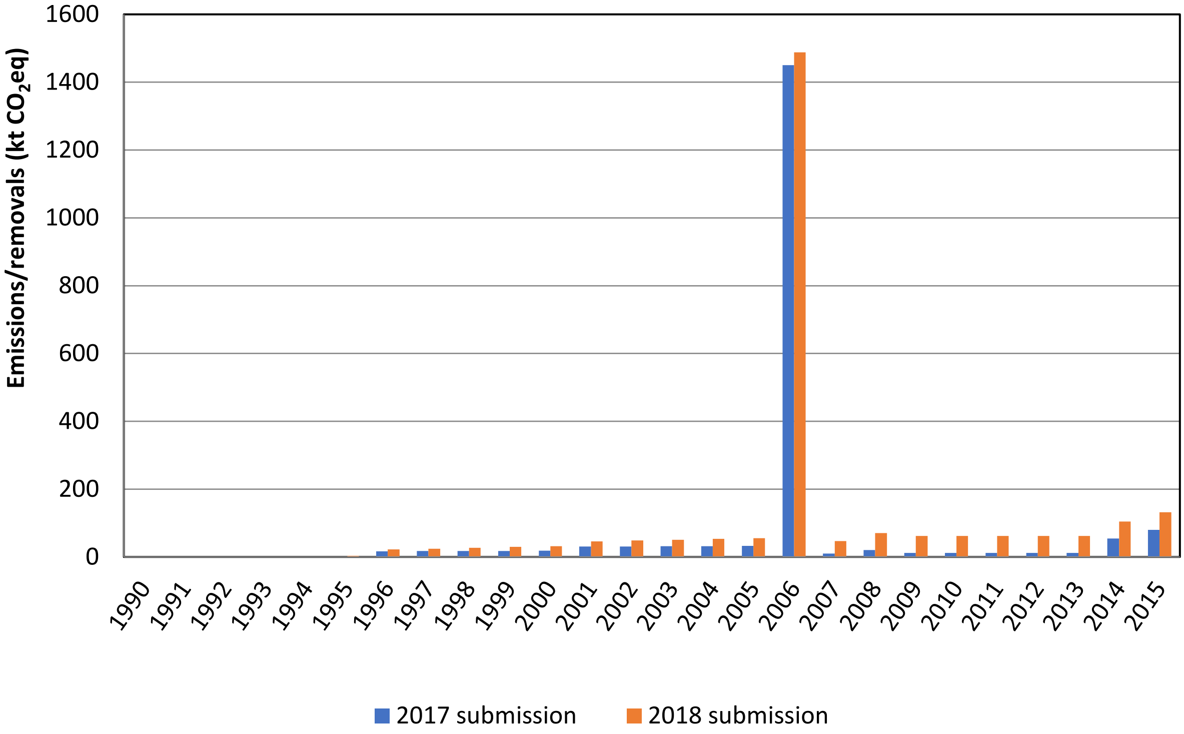


Figure 6.38 Comparison between 2017 and 2018 submissions of estimated total emissions associated with Other Land

6.9 Summary of uncertainty in non-Forest 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 6.35Table 6.. 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.

Table 6.35 Summary of Uncertainty analysis

	IPCC Source Category	Gas	Activity Data (AD) Uncert.	Emission Factor (EF) Uncert.	Reference Activity Data	Reference Emission Factor
	Category/ Sub-category		**%**	**%**		
4.A	Forest land	CO_2	51.0	114.0	See Sections 6.3.4.7 and 6.3.5.7	Country Specific value cf Chapter 6.3
4.B.1	Cropland Remaining Cropland	CO_2	7.2	69.1	Teagasc Soil and Sub-soil Map 2009, Trend analysis of LPIS and CSO UAA areas	Default value from IPCC GPG
4.B.2	Cropland In Transition	CO_2	7.2	69.1	Teagasc Soil and Sub-soil Map 2008, Trend analysis of LPIS and CSO UAA areas	Default value from IPCC GPG
4.C.1	Grassland remaining Grassland	CO_2	12.2	30.2	Teagasc Soil and Sub-soil Map 2008, Trend analysis of LPIS and CSO UAA areas	Default value from IPCC GPG

	IPCC Source Category	Gas	Activity Data (AD) Uncert.	Emission Factor (EF) Uncert.	Reference Activity Data	Reference Emission Factor
4.C.2	Grassland in Transition	CO_2	666.7	401.8	Teagasc Soil and Sub-soil Map 2008, Trend analysis of LPIS and CSO UAA areas	Default value from IPCC GPG
4.D.1	Wetlands remaining wetlands	CO_2	6.1	26.7	CORINE, BnM, SEAI, Expert opinion	Default value from IPCC GPG
4.D.2	Land Converted to Wetland	CO_2	2.5	50.0	Deforestation data, Chapter 6.3	Country Specific value cf Chapter 6.3
4.E.1	Settlement remaining Settlement	CO_2	40.4	75.0	Expert assessment of Dept of Environment Construction figures and National Road Authority infrastructure activity, CORINE	Default value from IPCC GPG
4.E.2	Settlement in Transition	CO_2	40.4	92.5	Expert assessment of Dept of Environment Construction figures and National Road Authority infrastructure activity, CORINE	Default value from IPCC GPG
4.F.1	Other Land remaining Other Land	CO_2	30.9	90.0	Uncertainty in Other Land Area based on combined uncertainty of land use change in other land use categories	Default value from IPCC GPG
4.F.2	Lands converted to Other Land	CO_2	136.8	75.0	Uncertainty in Other Land Area based on combined uncertainty of land use change in other land use categories	Default value from IPCC GPG
4.A	Forest Land	CH_4	30.0	100.0		
4.B	Cropland	CH_4	100.0	39.1	Uncertainty in area of burning based level of detection by remote sensing, scaled by reported Forest fire	Default value from IPCC GPG
4.C	Grassland	CH_4	96.4	91.2	Uncertainty in area of burning based level of detection by remote sensing, scaled by reported Forest fire	Default value from IPCC GPG
4.D	Wetland	CH_4	86.0	66.5	Uncertainty in area of burning based level of detection by remote sensing, scaled by reported Forest fire	Default value from IPCC GPG
4.E	Settlement	CH_4	0.0	0.0	Uncertainty in area of burning based level of detection by remote sensing, scaled by reported Forest fire	Default value from IPCC GPG
4.F	Other Land	CH_4	0.0	0.0	Uncertainty in area of burning based level of detection by remote sensing, scaled by reported Forest fire	Default value from IPCC GPG
4.A	Forest Land	N_2O	30.0	100.0		Default value from IPCC GPG
4.B	Cropland	N_2O	75.0	100.0	N2O emissions associated with burning only, Activity data same as CH4 emissions for Burning	Default value from IPCC GPG
4.C	Grassland	N_2O	17.4	100.0	Combined uncertainty in carbon loss from drained organic soils under grassland. The uncertainty from the carbon estimate cascades to the Activity Data Uncertainty in this approach	Default value from IPCC GPG
4.D	Wetland	N_2O	56.8	92.7	Combined uncertainty in carbon loss from drained organic soils within Wetlands. The uncertainty from the carbon estimate cascades to the Activity Data Uncertainty in this approach	Default value from IPCC GPG
4.E	Settlement	N_2O	45.2	54.7	Combined uncertainty in carbon loss from drained organic soils within Wetlands. The uncertainty from the carbon estimate cascades to the Activity Data Uncertainty in this approach	Default value from IPCC GPG

6.9.1 Uncertainty in Cropland

The dominant contribution to the 2016 uncertainty is estimate of emissions and removals within the Cropland category is uncertainty in the emission factor for the loss of carbon due to conversion to cropland from other land uses, most notably conversion from temporary grassland, accounting for approximately 90% of the overall uncertainty in this category. However this analysis does not include a number of quantified elements which may prove to be just as significant.

The Tier 1 methodology for croplands remaining cropland assumes zero net emissions of carbon where the land management practices are well established. In general, the cropland land area in Ireland is decreasing (in the order of 10 per cent), with croplands concentrated in well-defined regions. This supports the assumption that the lands on which crops are grown are well established within this farming system, and takes place on the most suitable, productive soils and therefore the assumption of zero emissions is reasonable. However, it is difficult to quantify the uncertainty associated with this assumption.

6.9.2 Uncertainty in Grassland

Grassland has the potential for large uncertainty by virtue of large areal extent, and estimates for drainage of organic soils in this category. The dominant sources for uncertainty in this category are the activity data and emission factors associated with the use of drained organic soils within agriculture.

Grass based agriculture accounts for 90 per cent of the agricultural area in Ireland. The area of permanent grasslands is very stable over time, with known afforestation accounting for a high proportion of the observed decrease in reported grassland area. Reported grassland areas include both utilised agricultural areas and non-utilised grassland. Carbon stock changes are estimated using Tier 1 methodologies and are based on inter-annual changes in the reported areas.

The area of drained organic soils under grassland is based on the proportion of agricultural grassland land cover overlaid on a soil map. There are the usual issues of matching mapping scale and interpretation of land use from land cover. Additional analysis is required to confirm these findings and the uncertainty is high.

Tier 1 methodology for grassland remaining grassland on mineral soils assumes zero net emissions where management practices are well established. There is emerging research which indicates that improved grasslands on mineral soils in Ireland continue to act as a sink of carbon. This appears to be a sustained impact of increased intensity of land management (fertiliser usage and manure management, grazing practice). However additional analysis is required to confirm this result on a national scale and link it to activity data related to management practices. However, the analysis to date is sufficient to demonstrate that Grassland remaining Grassland on mineral soils is “not a source”, but the quantitative uncertainty in this assessment is high (Khalil et al. 2013; Peichl, et al 2011; Kiely et al 2009. Byrne, and Kiely, 2006).

6.9.3 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. Uncertainty analysis reveals these two components which 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 this 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. 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 sod peat used for heating in the residential 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 expert 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.

6.9.4 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 is based on construction statistics, national road infrastructure development and specific deforestation activities identified in previous 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.

Reporting of the potential 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.

6.9.5 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 of the 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.

6.10 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

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), these include.

6.10.2 QC plan for Activity Data

- 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;
- QC checks of reference sources for national activity data by evaluation of documentation with regard to activity data. For example, is data collection or sampling regimes adequate and un-bias? Does the agency have any information on uncertainties?
- Comparisons of input data with independent data sets such as harvest statistics (FAO/Eurostat), land cover data such as CORINE (see Black et al., 2009a);
- Time series consistency checks of activity data;
- Collation and initial completeness checks of activity data required;
- Pre-processing activity data and compiling data bases to be used by CARBWARE.

6.10.3 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 2006-litter turnover).

QC checks on Models**:** Both the FORCARB and CABEWARE 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 historic (1950-2000) Irish forestry data (Hawkins and Black, 2012);
- Calibration of the age class distributions used in the FORCARB model was checked against independently derived information (see Figure 6.3.9, Black et al., 2012);

- Model design specifically considered the activity data characteristics, and their applicability to the greenhouse gas inventory. For example, the key activity data for reporting is the NFI. The CARBWARE model was designed to specifically deal with single tree input data, and not stand-based data, because of NFI limitations (see Annex 3.4.A.5);
- 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.A.5) to the NIR;
- 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.

QA/QC of calculations is facilitated by the software and database management system designed to run the CARBWARE model (see Figure 6.3.8, section 6.3.3.1). This reduces the risk of calculation errors or manual error over the time series. Correct coding and calculation QA/QC was carried out by three independent parties using identical data during development of the software under the COFORD funded CARBWARE project (2007-2011).

6.10.4 Completeness and error checks in 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.

6.10.5 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 6.36 and Table 6.37.

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 (Table 6.1Table 6.13).

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.

6.10.6 Validation of Reported Estimates (Category 4.A.1)

In addition to the DBH growth model uncertainty and model validations shown in Annex 3.4.A.5, IEFs reported in the CRF table 4.A were compared to other countries with similar forest characteristics for using the Locator Tool (Table 6.36Table 6.). It is important to note that changes in methodology due to the introduction of new pools and EFs as part of the 2006 IPCC Guidelines, the 2013 Wetland Supplement and the 2013 KP Supplementary Guidance has resulted in significant differences in IEFs for drained organic soils and N_2O from drainage. These comparisons do not take these changes into account. The same methodologies for LB and DOB are applied in the current submission. Ireland has the lowest reported net LB IEF and second highest DOM IEF, when compared to other countries. This is because of the change in age class distribution and reduction in productivity, but harvests are maintained at the same rates, resulting in negative increment. The change in age class distributions are driven by an increase in clearfell harvest resulting in an increase in the IEF for net losses in category 4A1 from -3.5 to -6.4 from 1990 to 2012 and an increase allocation of harvest residues to the DOM pool.

Table 6.36 Comparison of 2013 inventory year IEFs reported for other countries and those reported by Ireland for forest land remaining forest land (4A1)

Pool	IEF (Mg/ha)			
	Ireland	**EU28**	**UK**	**Range**
LB net	-0.29	0.67	1.04	-0.29 to 6.77
DOM	0.43	-0.001	0.22	-0.23 to 0.51
Organic Soils	-0.22	-0.38	-0.4	-0.71 to 1.86
Fire CO_2	260.64	IE,NO,NA	Mg/kg biomass	8.3 to 260.64
Fire CH_4	1.14	IE,NO,NA	Mg/kg biomass	0.03 to 1.14
Fire N_20	0.01	IE,NO,NA	Mg/kg biomass	<0.001 to 0.3008

Ireland is the second highest IEF for LB gains, higher that the UK but lower than Malta. Ireland has the higher LB losses than any other country. The high LB gains are consistent with experimental validation studies (Black et al., 2009a, See Table 6.37)

Reported IEF from organic soils are within the ranges reported.

The IEFs for wildfires in Ireland is the highest reported value under the convention. It should be stressed that IEFs have been validated against other sources such as eddy covariance, NFI and research information and show good agreement (see Table 6.38). The research also shows that Irish forests have a higher NEP, NPP and GPP when compared to most published values in the literature (see Black et al., 2009a, Luyssaert et al 2007).

The higher biomass gains have been attributed to:

a) The mild oceanic climate in Ireland and the large percentage of high yielding Sitka spruce plantations-planted at high stocking rates (2500 stems per ha).

b) Yield classes experienced in Ireland are much higher than that in the UK. For example YC 28 to 30 m^3/ha/yr can be obtained on some mineral soils, compared to a max of 24 in the British yield class tables.

Models used in the UK are based on the BFC yield tables, we show that the individual tree model used in CARBWARE provide a better estimate than BFC models (see a comparison of FORECARB and CARBWARE in section 6.3.4.1). It should be stressed that the CARBWARE single tree model has been validated against a partial sample of the new NFI (see section 6.4.3.7 Table 6.13). In addition, the growth models were developed using a historic permanent sample data base going back to 1950 (i.e the Coillte PSP, see Annex 3.4.A.5).

6.10.7 Validation of reported estimates (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 6.37Table 6.).

All of the reported IEFs for all pools are within the ranges reported for other countries. Additional validations of the CARBWARE growth and C flow models were carried out by comparisons to eddy covariance data (a micrometeorological measure of stand net carbon balance including all pools) from the COFORD funded CARBiFOR project. The eddy covariance measurements and standard inventory assessments, used as inputs in to the CARBWARE single tree growth and C flow model, were carried out for 2 chronosequences ():

Table 6.37 Comparisons of 2010 inventory year IEFs reported for other countries and those reported by Ireland for land converted forest land (4A2)

Pool	IEF (Mg/ha)			
	Ireland	EU28	UK	Range
LB net	3.12	1.34	0.91	-0.187 to 8.79
DOM	0.7	0.21	0.03	-0.22 to 2.55
Organic Soils	-0.45	-0.65	2.77	-10.8 to 2.8
Fire CO_2	151.8	IE,NO,NA	Mg/kg biomass	0.0009 to 151.8
Fire CH_4	0.66	IE,NO,NA	Mg/kg biomass	0.29 to 0.03
Fire N_20	0.003	IE,NO,NA	Mg/kg biomass	0.008 to <0.001

a) A range of Sitka spruce stands on a mineral surface water gley soil, including 2 thinning cycles;
b) Two Ash sites aged 6 and 12 on brown earth soils.

Eddy covariance provides an estimate of net ecosystem exchange (NEE, positive values represent a net removal) excluding emissions related to immediate oxidation of harvested timber. For comparison to the CARBWARE estimated net biome productivity (i.e. NEE minus harvest losses) are shown in bold in Table 6.38 below.

Table 6.38 Validation of net biome productivity

Species	Yield class	Silviculture	Forest age	Year	E.covariance	± Uncertainty	NEE - harvest	± Uncertainty	Carbware	± Uncertainty	Wlicoxin p-value
					NEE		NBP		NBP		
					(t C ha^{-1} yr^{-1})						
Sitka spruce	24	un-thinned	20	2006	8.81	1.09	**8.81**	1.09	**8.50**	1.09	<0.01
Sitka spruce	24	1st Thin	21	2007	10.33	1.41	**-3.09**	2.67	**-4.20**	3.60	<0.05
Sitka spruce	24	1st Thin	22	2008	6.75	1.19	**6.75**	1.19	**9.80**	0.50	0.12
Sitka spruce	24	2ndThin	23	2009	8.14	1.94	**-3.06**	1.90	**-3.90**	0.59	<0.08
Sitka spruce	24	2ndThin	24	2010	8.18	1.47	**8.18**	1.47	**7.80**	0.16	<0.01
Sitka spruce	24	2ndThin	25	2011	8.54	1.11	**8.54**	1.11	**9.30**	0.72	<0.05
Sitka spruce	24	un-thinned	14	2009	8.52	1.46	**8.52**	1.46	**7.15**	0.36	<0.05
Sitka spruce	24	un-thinned	7	2009	2.21	0.46	**2.21**	0.46	**3.58**	2.54	<0.05
Ash	6	un-thinned	6	2010	1.38	0.29	**1.38**	0.29	**-1.23**	1.97	0.25
Ash	12	un-thinned	10	2010	4.67	0.71	**4.67**	0.71	**2.14**	1.54	0.14

Note: *(NBP. i.e. net C emissions/removals) estimates using CARBWARE against eddy covariance derived estimates across 2 chronosequesnces2010 inventory year IEFs reported for other countries and those reported by Ireland land converted forest land*

This analysis shows that there is good agreement between the CARBWARE and eddy covariance based estimates across different age classes, species and silvicultural treatments, as evident from the signed rank Wilcoxin p-value (p-values <0.05 include no significant difference between the two estimates). It is evident that there are, however, differences in the following cases:

- The NBP for Ash sites are underestimated by CARBWARE, when compared to the eddy covariance approach. This is due to:
    - The previously mentioned under-estimation of DBH increment for the fast growing broadleaf cohort (FGB), where DBH is < 12cm (see Table 6.13);
    - Overestimation of litter and mortality losses in the FGB cohort models. Future improvements to the CARBWARE model are planned once more research from the COFORD research programme;
    - CARBWARE assumes that there is no significant change in mineral soil stock changes following afforestation, but NEE based estimated include emissions/ removals from soils, which in some cases can represent an net removal of C over time, although this is not always significant (see chapter 11, justification for not reporting soil CSC);
    - Eddy covariance based estimates include non-forest vegetation gains and losses, which are not estimated in the CARBWARE model. It is feasible that non-forest biomass in the early stages of forest establishment can represent a net removal of C, but this assumed to be zero at steady state since non-forest vegetation is decomposed after canopy closure.
- In one of the Sitka spruce sites (22 year old stand, Table 6.38), CARBWARE overestimated NBP, when compared to eddy covariance. Research form the CARBiFOR project shows that the lower NBP for this site is due to climatic inter-annual variability, which is not captured by CARBWARE.

The CARBWARE models are being continually validated against NFI data and updated as new research information from the COFORD funded programme becomes available.

Planned improvements include:

- Re-evaluation of CSC in mineral soils and emission factors for organic soils (ForCRep project 2012-2017);
- Development of a remote sensing system for tracking deforestation and land use change from forests to other land (ForCRep project 2012-2017);
- Re-evaluation of FGB cohort model using information from the BetterFOR project (2013-2016);
- Development of a remote sensing system to identify forest areas subjected to wild fires and improvement to currently used biomass combustion and EFs used in national reporting.

6.10.8 Independent External Reviews

An external review of the CARBWARE system was completed in 2007 as part of the design and methodology development research programme, funded by COFORD. There was an independent external review of the Kyoto Protocol elements of the LULUCF inventory in 2017. This review was funded by COFORD, DAFM.

6.11 Improvements in LULUCF

The coverage of sources of emissions and removals by Ireland in the LULUCF sector under the Convention is complete for the years 1990-2016. This submission also contains estimates for 2008-2016 in respect of activities under Article 3.3 and for 2013 and 2016 for Article 3.4 (Forest Management, Cropland Management and Grazing land management) of the Kyoto Protocol (chapter 11), which are fully consistent with Convention reporting for LULUCF. Even though a rather simplified approach has had to be followed for many land-use categories due to the level of information available, the assessment of emissions and removals according to the reporting requirements of Decision 24/CP.19 has identified a number of important CO_2 emission sources, in addition to the well-known carbon sink in forests. The inventory agency is continuing to collaborate with the bodies from which the key land-use and forestry datasets are obtained and has established formal arrangements for the provision of the data within the national system, in the same way as for other sectors. The inventory agency's capacity on GIS continues to be developed, which facilitates the assessment and integration of available datasets. It is intended to apply this capacity in a more detailed treatment of soils for future submissions.

The results of the national forest inventory are now being applied more extensively in the LULUCF inventory and this submission reflects further improvements given by this data source and by supporting research projects on climate change and forestry being undertaken over the period from 2007 to 2016. The CARBWARE development project has improved forest carbon stock change reporting tools and software to make available an integrated system that meets the reporting needs of the Convention and the Kyoto Protocol with respect to forest land. It also draws on data from the completed CARBiFOR II project and other related research projects, to continually refine estimates of carbon stock change for reporting purposes and for projecting carbon sinks into the future. A new research project ForCRep (2012-2017) has been funded by COFORD and the DAFM to specifically address reporting of emissions associated with wild fires and further investigate soil stock changes in mineral following conversions to and from forestry. This research project will also explore the development of methods to deforestation using a wall to wall approach based on new remote sensing products. This will be integrated with other EPA projects, using similar approached for tracking land use transitions in grasslands and crop lands.

There has also been extensive validation and verification of the models used for LULUCF and Kyoto reporting. This is part of an on-going QA/QC procedure. The LULUCF sector now adopts a tier 1 QA/QC system for LULUCF.

On-going work on developing a single forest cover and attribute data set has been progressing in the Forest Service. The most recent data set has been compiled for 2010, apart from a subset of grant and premium data that needs to have species attributes input manually. Annual versions will include data on location, planting year, species area and open space area attributes, for all forest greater than 0.5 ha in area (with the post 1990 afforestation data for areas down to 0.1 ha). The Forest Service will have a system in place for access to and use of the data.

Research is on-going into the extent, and condition, of hedgerows in Ireland, which will be classified as settlement biomass in future submissions. Further research is required in this area. New research has been instigated to determine country specific emission factors associated with agricultural and forestry practices on drained organic soils. The land use conversion to settlements, particularly as regards new construction, remains a coarse estimate. Additional analysis is required to determine the real dynamic rate of conversion between grassland and croplands, and *vice versa*. This analysis will be undertaken in collaboration with the Department of Agriculture, Food and Marine.

Further additional improvements are outlined in individual sector (4.A. to 4.F.) sections of this 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, *wastewater treatment*, *waste incineration*, and *biological treatment of solid waste* are the main activities that give rise to greenhouse gas emissions in the *Waste* sector (Table 7.1).

The largest of these sources is usually *solid waste disposal* on land where CH_4 is the gas concerned. Landfills represent a key emission category in Ireland and the emission estimates of CH_4 are considered to be well quantified in the national inventory.

7.1.1 Emissions Overview

A summary of emissions from these activities are given in Table 7.2.

There is one key category in this sector, which is both a trend and level key category:

- ***5.A Solid Waste Disposal (CH_4)*** at solid waste disposal sites (SWDS) is a significant activity in Ireland. Emissions from this source include both historical unmanaged and currently well managed sites.

Other categories present in this sector include:

- ***5.B.1 Composting*** consisting of household organic waste collected at kerbside and brought to civic amenity/temporary collection sites, as well as organic material composted at households;
- ***5.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;
- ***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;*
- ***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;*

- ***Methane*** emissions originate from *5.A.1 Managed Waste Disposal Sites, 5.A.2 Unmanaged Waste Disposal Sites, 5.B.1 Composting, 5.C.1 Waste Incineration, 5.C.2 Open Burning of Waste,* and *5.D.1 Domestic Wastewater.*

The 2018 submission shows total GHG emissions of 957.72 kt CO_2 equivalent in the Waste sector in 2016, of which *5.A Solid waste disposal* accounts for 80.2 per cent, *5.B Biological treatment of solid waste* 2.1 per cent, *5.C Incineration and open burning of waste* 2.4 per cent and *5.D Wastewater treatment and discharge* 15.4 per cent. The latest estimates show that emissions in the *Waste* sector have decreased by 38.1 per cent from 1990 to 2016 mainly due to a 41.7 per cent decrease in CH_4 emissions from *5.A solid waste disposal*.

7.1.2 Methodology Overview

A summary of the Tier methods consistent with the 2006 IPCC Guidelines is provided in Table 7.1 below, along with a summary of the activities applicable to Ireland.

Ireland's first waste to energy municipal solid waste (MSW) incinerator commenced operation in 2011 and emissions from this new plant have been reported under public electricity and heat production (1.A.1.a) in chapter 3 in accordance with the 2006 IPCC guidelines.

Table 7.1 Level 3 Source Methodology for Waste

5. Waste	**CO_2**	**CH_4**	**N_2O**
A. Solid Waste Disposal*			
1. Managed Waste Disposal Sites	NA	NA,T2	NA
2. Unmanaged Waste Disposal Sites	NA	NA,T2	NA
B. Biological Treatment of Solid Waste			
1. Composting	NA	NA,T1	NA,T1
2. Anaerobic Digestion at Biogas Facilities	NA	NA	NA
C. Incineration and Open Burning of Waste			
1. Waste Incineration	T1	T1	T1
2. Open Burning of Waste	T1	T1	T1
D. Wastewater Treatment and Discharge			
1. Domestic Wastewater	NA	T1,T2	T1
2. Industrial Wastewater	NA	NA	NA
E. Other	NA	NA	NA

*Key Category by level and trend in 2016 (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 1990-2016

IPCC	Category	Gas	Unit	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
5.A.1	Managed Waste Disposal Sites	CH_4	kt CO_2eq	NO	NO	1268.2	1007.0	616.0	463.8	284.8	278.6	381.6	302.8	461.0	648.10	742.2	767.8
5.A.2	Unmanaged Waste Disposal Sites	CH_4	kt CO_2eq	1318.1	1592.8	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
5.B.1	Composting	CH_4	kt CO_2eq	NO	NO	NO	8.0	7.3	9.6	12.3	12.2	13.4	13.1	13.3	11.3	12.0	11.6
5.B.1	Composting	N_2O	kt CO_2eq	NO	NO	NO	5.7	5.2	6.9	8.8	8.8	9.6	9.3	9.5	8.0	8.6	8.3
5.C.1	Waste incineration	CH_4	kt CO_2eq	0.0064	0.0064	0.0003	0.0005	0.0004	0.0003	0.0003	0.0003	0.0002	0.0002	0.0002	0.0002	0.0002	0.0001
5.C.1	Waste incineration	N_2O	kt CO_2eq	0.83	0.83	0.60	1.08	0.83	0.62	0.64	0.54	0.38	0.45	0.43	0.39	0.40	0.22
5.C.1	Waste incineration	CO_2	kt CO_2eq	83.0	83.0	58.7	106.3	82.0	61.3	62.7	53.5	37.0	44.4	42.4	38.5	39.0	22.0
5.C.2	Open burning of waste	CH_4	kt CO_2eq	0.82	1.01	1.57	2.27	0.08	0.07	0.07	0.07	0.48	0.07	0.07	0.07	0.07	0.07
5.C.2	Open burning of waste	N_2O	kt CO_2eq	0.21	0.25	0.39	0.57	0.02	0.02	0.02	0.02	0.12	0.02	0.02	0.02	0.02	0.02
5.C.2	Open burning of waste	CO_2	kt CO_2eq	7.65	9.36	14.60	21.00	0.72	0.64	0.67	0.67	4.46	0.67	0.67	0.67	0.67	0.67
5.D.1	Domestic wastewater	CH_4	kt CO_2eq	61.1	62.7	62.4	49.3	44.2	50.9	51.5	50.3	50.1	50.7	50.5	52.3	52.2	50.4
5.D.1	Domestic wastewater	N_2O	kt CO_2eq	75.1	73.1	82.6	89.4	92.1	93.6	93.8	94.2	92.9	93.1	93.3	93.6	94.1	96.7
	Total Waste		**kt CO_2eq**	**1546.8**	**1823.0**	**1489.1**	**1290.7**	**848.5**	**687.4**	**515.2**	**498.9**	**589.9**	**514.6**	**671.0**	**853.0**	**949.3**	**957.7**

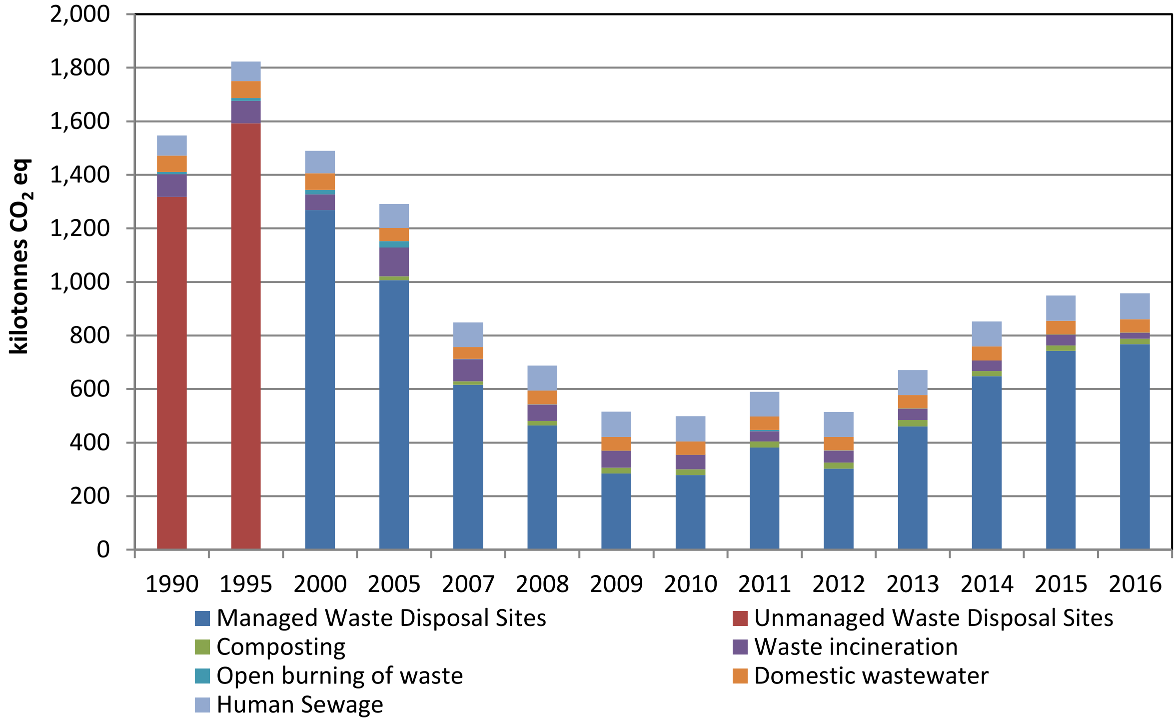


Figure 7.1 Total Emissions from Waste by Sector, 1990-2016

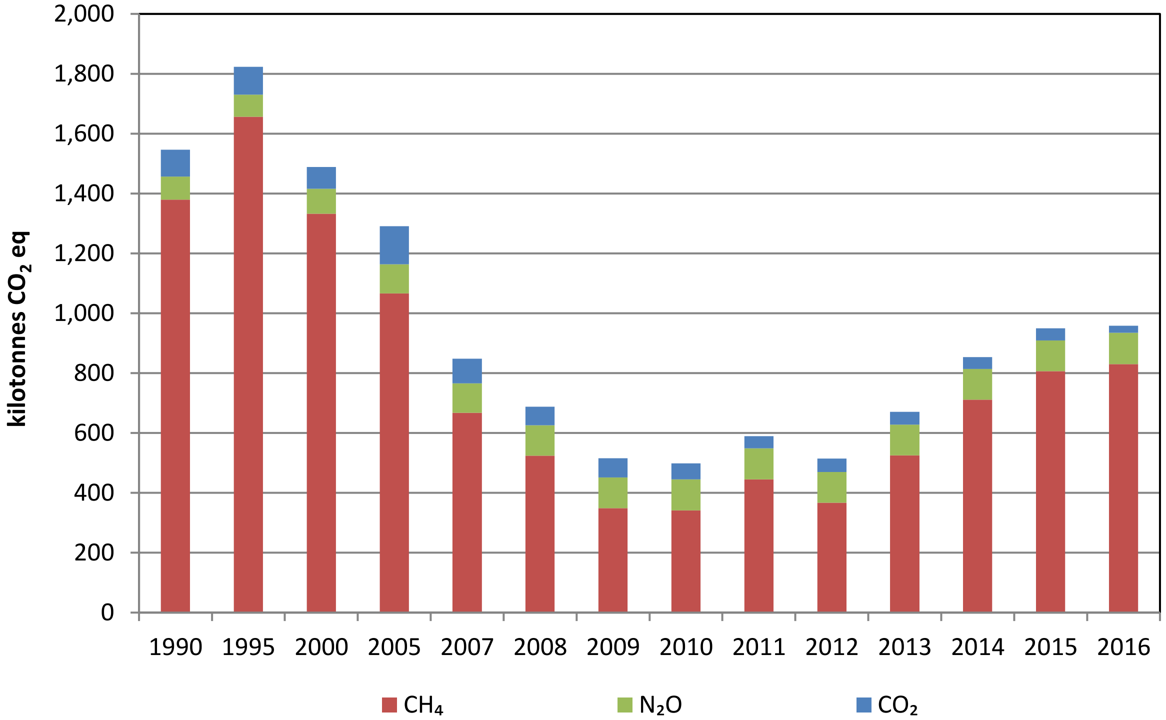


Figure 7.2 Total Emissions from Waste by Gas, 1990-2016

7.2 Emissions from Solid Waste Disposal (5.A)

The IPCC Level 3 emission source categories relevant under *5.A Solid Waste Disposal* in 2016 are *5.A.1 Managed Waste Disposal Sites* and *5.A.2 Unmanaged Waste Disposal Sites*. Total CH_4 emissions from these activities amounted to 767.78 kt CO_2eq in 2016.

7.2.1 Managed Waste Disposal Sites (5.A.1)

7.2.1.1 Category Description

Treatment and disposal of municipal, industrial and other solid waste at solid waste disposal sites (SWDS) produces significant amounts of methane (CH_4). In addition to CH_4, SWDS also produce biogenic carbon dioxide (CO_2) and non-methane volatile organic compounds (NMVOCs) as well as smaller amounts of nitrous oxide (N_2O), nitrogen oxides (NOx) and carbon monoxide (CO). Waste minimisation and recycling/reuse policies (DECLG, 1998, 2002, 2004(a), 2004(b), 2012) have been introduced to reduce the amount of waste generated in Ireland, and increasingly, alternative waste management practices to solid waste disposal on land have been implemented to reduce the environmental impacts of waste management. Also, landfill gas recovery is now commonplace as a measure to reduce CH_4 emissions from SWDS.

7.2.1.2 Methodological Issues

The Tier 2 approach in the 2006 IPCC Guidelines is used for both *Unmanaged* and *Managed Waste Disposal Sites*. The model is a simple first-order decay spreadsheet model that keeps a running total of the amount of degradable organic carbon (DOC) available in a landfill as the basis for calculating the amount of DOC converted to CH_4 and CO_2 annually. Analyses undertaken, as part of the improved methodology introduced in the 2010 submission, shows annual MCF values increasing over time to reflect the change from generally shallow, poorly-managed landfills before 1998 (and therefore pre-landfill licensing) to well controlled and engineered managed landfills in subsequent years. Whilst individual landfill data is collated and analysed for MSW constituent breakdowns and CH_4 recovery statistics, the first order decay model is used at a national level (i.e. assuming all waste in one landfill). Ireland uses the following parameters in the IPCC 2006 model; delay time of 6 months, fraction of methane (F) in landfill gas of 0.5 (default) and an oxidation factor (OX) of 0, Table 3.2 2006 IPCC Guidelines.

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.

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 can be assessed and complied with and that guidance on Municipal Solid Waste –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, assumptions on waste quantities and composition are still required to establish the basic historical information, given the extended time-frame that must be taken into account for a number of the models. 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.

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 utilized. 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 30.1 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 2016. 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 utilized 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. 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 0.67 over this period. MCFs for the time series are available in Table 3.5.B of Annex 3.5.

Information on the number of flares in use, together with data relating to flare capacity, run time and performance is used to estimate the volume of landfill gas flared at each site. The inventory agency undertakes an annual survey of landfill gas recovery at landfill sites. The first such survey was undertaken in 2008 covering the period 1996 (year in which landfill gas recovery begun in Ireland) to 2007. Annual surveys have been undertaken since then. The tonnage of CH_4 flared and or utilised in engines for electricity production is calculated from the landfill gas volume extracted by accounting for methane concentration, gas temperature (assumed to be ambient air temperature) and suction pressure (provided in survey returns) and by using methane destruction efficiencies of 50 per cent for open flares and 98 per cent for enclosed flares and utilization 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 2016 found that there were 57 flares on 50 SWDS with 15 methane utilisation plants housing a total of 33 engines. The overall results of CH_4 production, utilisation and flaring are presented in Table 7.3.

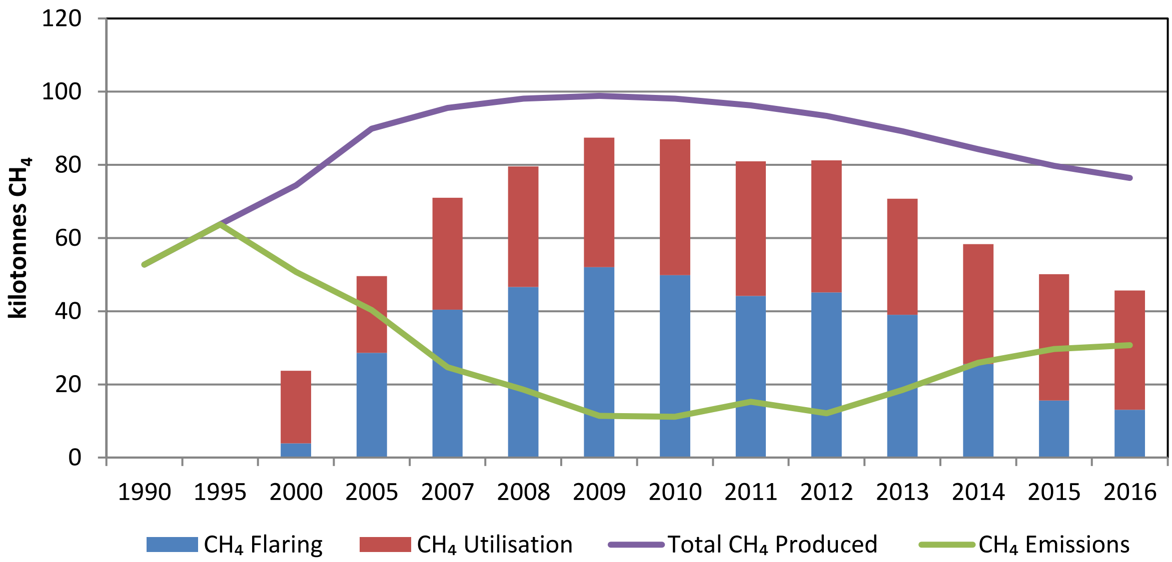


Figure 7.3 Methane Emissions from Solid Waste Disposal 1990-2016

Table 7.3. Methane Emissions from Solid Waste Disposal 1990-2016

	Methane Generation (tonnes)	Methane Flaring (tonnes)	Methane Utilisation (tonnes)	Methane Recovery (tonnes)	Percent Methane Recovery	Methane Emissions (tonnes)	Methane Emissions (kt CO_2eq)
1990	52,723.00	-	-	-	-	52,723.00	52.72
1995	63,710.36	-	-	-	-	63,710.36	63.71
2000	74,400.15	3,855.11	19,818.49	23,673.60	32%	50,726.55	50.73
2005	89,865.44	28,638.38	20,947.12	49,585.50	55%	40,279.94	40.28
2007	95,593.69	40,395.90	30,558.07	70,953.98	74%	24,639.71	24.64
2008	98,102.10	46,639.68	32,908.74	79,548.42	81%	18,553.68	18.55
2009	98,846.53	52,050.80	35,403.54	87,454.33	88%	11,392.20	11.39
2010	98,123.39	49,886.65	37,090.88	86,977.53	89%	11,145.86	11.15
2011	96,212.33	44,205.15	36,744.73	80,949.88	84%	15,262.45	15.26
2012	93,335.39	45,121.03	36,102.70	81,223.72	87%	12,111.66	12.11
2013	89,169.69	38,988.32	31,742.57	70,730.89	79%	18,438.80	18.44
2014	84,277.04	25,538.51	32,814.48	58,352.99	69%	25,924.04	25.92
2015	79,755.03	15,619.44	34,449.45	50,068.89	63%	29,686.13	29.69
2016	76,375.49	13,023.73	32,640.41	45,664.14	60%	30,711.35	30.71

Table 7.3 and Figure 7.3 present the results for methane emissions from *5.A Solid Waste Disposal*. These estimates of CH_4 generation obtained using the model in the IPCC 2006 Guidelines are considered more robust than estimates developed previous to the 2010 submission. The estimates show a steady increase in CH_4 production over the period 1990-2009, reflecting Ireland's strong dependence on solid waste disposal to landfills over that period. Subsequently individual landfill specific and national BMW targets (EPA, 2009) along with increased recycling rates have led to a reduction in CH_4 generation. The utilisation of CH_4 remained generally constant up to 2006 since becoming established in 1996. The quantity of CH_4 utilised subsequently almost doubled in the period to 2012 with the installation of engines at a number of the newer larger landfills and expansion at other sites. The quantity of CH_4 flared increased sharply from 2003 to 2012 (with interannual variability in later years). This reflects the proliferation of the use of enclosed flares as a means of odour and landfill gas control at landfills throughout the country, all of which operate under EPA waste licence and stringent environmental controls. Reductions in the quantities of landfill gas recovered in recent years are the combined result of reductions in the quantities of CH_4 generated and landfill gas management issues. Methane recovery through flaring and utilisation peaked in 2009.

Table 7.4 Information related to Managed Waste Disposal (5.A.1)

IPCC category	Category Description	Method used	CH_4 Emission Factor	Emission Factor Reference
5.A.1	Managed Waste Disposal	T2	First Order Decay (FOD) model	2006 IPCC Guidelines

7.2.1.3 Uncertainties and Time-series Consistency

The methodologies used in the derivation of emissions estimates from the waste sector are consistent over the time-series. In the case of category 5.A, this consistency applies to all three components that determine the ultimate emissions, i.e. CH_4 generation, CH_4 flared and CH_4 utilised.

Despite continuous improvements in national data, the overall uncertainty associated with estimating CH_4 emissions from source category 5.A is high at 49.0 per cent. This uncertainty is primarily due to the length of the historical period that must be taken into account. Uncertainty estimates for the source category are calculated using equations 3.1 and 3.2, Volume 1 of the IPCC Good Practice Guidance. Uncertainties of 20 per cent are assumed in relation to the quantity of MSW, its composition and DOC contents, giving a combined uncertainty of 34.6 per cent for activity data The emission factor uncertainty is also 34.6 per cent, when 20 per cent is taken as the uncertainty for the fraction of DOC dissimilated, MCF and decay rate constant. This gives an uncertainty of 49.0 per cent for CH_4 generation which is combined with uncertainties of 30 per cent and 10 per cent for CH_4 flaring and utilisation, respectively to give an uncertainty of 40.1 per cent for emissions. The Tier 1 uncertainty analysis is presented in Annex 2 of this report.

7.2.1.4 Category-specific QA/QC and verification

The inventory agency intends to continue its annual surveys of landfill operators to determine landfill gas flaring and utilisation statistics. All survey returns with respect to landfill gas flaring and utilisation that was undertaken as part of this submission were reviewed by a member of the inventory team and clarifications were sought directly from landfill operators. This data is collated with other units involved in reporting within the EPA such as annual environmental reports and E-PRTR and this collaboration ensures an element of consistency in environmental reporting in this area.

7.2.1.5 Category-specific Recalculations

This year recalculations show a 0.1 per cent increase in emissions in 2015 due to a revision of flaring data.

7.2.1.6 Category-specific Planned Improvements

The inventory agency intends to reconsider the uncertainty estimates for this category in the next submission. The inventory agency also 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_4 Emission Factor	Emission Factor Reference
5.A.2	Unmanaged Waste Disposal	T2	First Order Decay (FOD) model	2006 IPCC Guidelines

7.2.2.3 Uncertainties and Time-series Consistency

The uncertainties applicable to *Unmanaged Waste Disposal Sites* are provided in Annex 2. The emission time series for 1990-2016 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) is the only source of emissions in this category. Total CH_4 and N_2O emissions from these activities amounted to 19.87 kt CO_2eq in 2016.

7.3.1 Composting (5.B.1)

7.3.1.1 Category Description

Composting is an aerobic process and a large fraction of the degradable organic carbon (DOC) in the waste material is converted into carbon dioxide (CO_2). CH_4 is formed in anaerobic sections of the compost, but it is oxidised to a large extent in the aerobic sections of the compost. The estimated CH_4 released into the atmosphere ranges from less than 1 percent to a few per cent of the initial carbon content in the material (Beck-Friis, 2001; Detzel et al., 2003; Arnold, 2005).

Composting can also produce emissions of N_2O. The range of the estimated emissions varies from less than 0.5 percent to 5 percent of the initial nitrogen content of the material (Petersen et al., 1998; Hellebrand 1998; Vesterinen, 1996; Beck-Friis, 2001; Detzel et al., 2003). Poorly working composts are likely to produce more of both CH_4 and N_2O (e.g., Vesterinen, 1996).

Composting is composed of household organic waste collected at kerbside and brought to civic amenity/temporary collection sites, as well as organic material composted at households.

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 wet waste basis) is obtained each year disaggregated into two categories: organics composted (household organic waste collected at kerbside and brought to civic amenity/temporary collection sites), and household compost material input (material composted at households). Activity data has been obtained from 2001 onwards, before which emission estimates are reported as Not Occurring.

Equation 4.1;

$$CH_4\ Emissions = \sum(M_i * E_{i,CH4}) * 10^3 - R$$

Where:

CH_4 Emissions = total CH_4 emissions in inventory year, kt CH_4

M_i = mass of organic waste treated by biological treatment type *i*, kt

$E_{i,CH4}$ = EF for treatment (composting) *i*, g CH_4/kg waste treated

R = total amount of CH_4 recovered in inventory year, kt CH_4

Equation 4.2;

$$N_2\,O\ Emissions = \sum(M_i * E_{i,N2O}) * 10^3$$

Where,

$E_{i,N,o}$ = EF for treatment (composting) *i*, g N_2O/kg waste treated.

Emission estimates are made for CH_4 and N_2O in line with the 2006 IPCC guidelines. The EFs used are presented in Table 7.6 below.

Table 7.6 Information related to Composting (5.B.1)

IPCC category	Category Description	Method used	CH_4 Emission Factor	N_2O Emission Factor	Emission Factor Reference
5.B.1	Composting	T1	4g CH4/kg	0.24g N2O/kg	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 2001–2016 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

A revised composting activity data for 2015 were incorporated into the inventory resulting in a 7.1 per cent increase in emissions from this sub-category.

7.3.1.6 Category-specific Planned Improvements

There are no planned improvements for this category.

7.3.2 Anaerobic Digestion at Biogas Facilities (5.B.2)

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

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 22.95 kt CO_2eq in 2016.

7.4.1 Waste Incineration (5.C.1)

7.4.1.1 Category Description

Waste incineration is defined as the combustion of solid and liquid waste in controlled incineration facilities. Modern refuse combustors have tall stacks and specially designed combustion chambers, which provide high combustion temperatures, long residence times, and efficient waste agitation while introducing air for more complete combustion. Types of waste incinerated include municipal solid waste (MSW), industrial waste, hazardous waste, clinical waste and sewage sludge. The practice of MSW incineration is currently more common in developed countries, while it is common for both developed and developing countries to incinerate clinical waste.

Emissions from waste incineration without energy recovery are reported in the Waste Sector, while emissions from incineration with energy recovery are reported in the Energy Sector, both with a distinction between fossil and biogenic carbon dioxide (CO_2) emissions.

The category of *Waste Incineration* in Ireland encompasses emissions from **clinical waste** incineration and **hazardous waste** (solvent waste) incineration from industry. The incineration of clinical waste was discontinued after 1997. Ireland's first waste to energy MSW incinerator commenced operation in 2011 and emissions from this new plant 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_2 emissions in inventory year, kt/yr

SW_i = total amount of solid waste of type *i* (wet weight) incinerated or open-burned, kt/yr

dm_i = dry matter content in the waste (wet weight) incinerated or open-burned, (fraction)

CF_i = fraction of carbon in the dry matter (total carbon content), (fraction)

FCF_i = fraction of fossil carbon in the total carbon, (fraction)

OF_i = oxidation factor, (fraction)

44/12 = conversion factor from C to CO_2

i = type of waste incinerated/open-burned specified as follows:

ISW: industrial solid waste, SS: sewage sludge, HW: hazardous waste, CW: clinical waste, others (that must be specified).

Parameters values are taken from the 2006 IPCC guidelines and are presented in Table 7.7 below. Methane (CH_4) and nitrous oxide (N_2O) emission factors are taken from Tables 5.3, 5.4 and 5.6 of the 2006 IPCC guidelines. Additional information on emissions, EFs and parameters used is available in Table 3.5.C of Annex 3.5.

Table 7.7 Information related to Waste Incineration (5.C.1)

IPCC category	Category Description	Method used	Gas	Emission Factors	Emission Factor Reference
5.C.1	Clinical Waste	T1	CH_4	60 kg/kt waste (wet)	2006 IPCC Guidelines Table 5.3
			N_2O	20 g/t waste (wet)	2006 IPCC Guidelines Table 5.4
			CO_2	40% fossil carbon (as % of total carbon) 60% C content of waste (dry) 100% oxidation factor	2006 IPCC Guidelines Table 5.2 2006 IPCC Guidelines Table 5.2 2006 IPCC Guidelines Table 5.2
5.C.1	Solvent (liquid/ vapour) waste	T1	CH_4	0.56 g/t (wet)	2006 IPCC Guidelines section 5.4.2
			N_2O	100 g/t waste (wet)	2006 IPCC Guidelines Table 5.6
			CO_2	100% fossil carbon (as % of total carbon) 80% C content of waste 100% oxidation factor	2006 IPCC Guidelines Table 5.2 2006 IPCC Guidelines Table 5.2 2006 IPCC Guidelines Table 5.2

There are currently only a small number of facilities based in the pharmaceutical and chemical sectors that operate incinerators or thermal oxidisers for the treatment of **hazardous waste**, mainly for solvent or liquid/vapour destruction. The facilities that operate these units report emissions to the atmosphere to the EPA as part of IPPC licensing requirements. Estimates of the quantity of hazardous waste incinerated at the relevant facilities are determined from returns to the National Waste Database (Carey et al, 1996; Crowe et al, 2000; Meaney et al, 2003; Collins et al, 2004a; Collins et al, 2004b; Collins et al, 2005; Le Bolloch et al, 2006; Le Bolloch et al, 2007; Le Bolloch et al, 2008; McCoole et al, 2009; McCoole et al, 2010; McCoole et al, 2011; McCoole et al, 2012 ;McCoole et al, 2013 and McCoole et al, pers comm).

Emissions from solvent waste incineration are estimated using the tier 1 method and equation 5.3 from the 2006 IPCC guidelines. Additional information on emissions, EFs and parameters used is available in Table 3.5.D of Annex 3.5.

Equation 5.3;

$$CO_2Emissions = \sum_i (AL_i * CL_i * OF_i) * 44/12$$

Where:

CO_2 Emissions = CO_2 emissions in inventory year, kt/yr

AL_i = amount of incinerated fossil liquid waste type *i*, kt

CL_i = carbon content of fossil liquid waste type *i*, (fraction)

OF_i = oxidation factor for fossil liquid waste type *i*, (fraction)

44/12 = conversion factor from C to CO_2

7.4.1.3 Uncertainties and Time-series Consistency

The uncertainties applicable to *Waste Incineration* are provided in Annex 2.

7.4.1.4 Category-specific QA/QC and verification

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

7.4.1.5 Category-specific Recalculations

There is no category-specific recalculation this year for *5.C.1.*

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 the open burning of household waste.

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 waste are not available in Ireland and estimates are made based on data for uncollected household waste. The emission factors used to estimate emissions from open burning of waste are presented in Table 7.8.

Table 7.8 Information related to Open Burning of Waste (5.C.2)

Method used	Gas	Material	Emission Factors	Emission Factor Reference
T1,T2	CH_4		6.5 kg/t waste (wet)	2006 IPCC Guidelines section 5.4.2
			58% oxidation factor	2006 IPCC Guidelines Table 5.2
	N_2O		150 g/t waste (dry)	2006 IPCC Guidelines Table 5.6
			58% oxidation factor	2006 IPCC Guidelines Table 5.2
	CO_2	Plastics	100% fossil carbon (as % of total carbon)	2006 IPCC Guidelines Table 2.4
			75% C content of Waste	2006 IPCC Guidelines Table 2.4
		Textiles	20% fossil carbon (as % of total carbon)	2006 IPCC Guidelines Table 2.4
			50% C Content of Waste	2006 IPCC Guidelines Table 2.4

7.4.2.3 Uncertainties and Time-series Consistency

The uncertainties applicable to *Open Burning of Waste* are provided in Annex 2.

7.4.2.4 Category-specific QA/QC and verification

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

7.4.2.5 Category-specific Recalculations

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

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 2016 are *5.D.1 Domestic Wastewater* (CH_4) and (N_2O). Total CH_4 and N_2O emissions from these activities amounted to 147.12 kt CO_2eq in 2016.

7.5.1 Domestic Wastewater (5.D.1)

7.5.1.1 Category Description

Wastewater can be a source of methane (CH_4) when treated or disposed anaerobically. It can also be a source of nitrous oxide (N_2O) emissions. Carbon dioxide (CO_2) emissions from wastewater are not considered in the 2006 IPCC guidelines because these are of biogenic origin and should not be included in national total emissions. Domestic wastewater is defined as wastewater from household water use. Domestic wastewater is either treated in centralized treatment plants or in septic tanks. Centralised wastewater treatment plants also treat commercial and industrial wastewater and for that reason emissions from *Industrial Wastewater (5.D.2)* are included in *Domestic Wastewater (5.D.1).*

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*.

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).

Sludge is produced in all of the primary, secondary and tertiary stages of wastewater treatment. The anaerobic stabilisation of sludge makes it safe for disposal and is a source of CH_4 in Ireland. The amount of wastewater sludge produced in Ireland is available from biennial reports on urban wastewater treatment.

The sludge arising from the secondary treatment of over half of the population equivalent served by urban wastewater treatment plants is anaerobically digested. The CH_4 produced at these plants is used for electricity and heat generation since 2003. Since 2003, there are between 6 to 9 urban wastewater treatment plants with biogas recovery for heat only or CHP. 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 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_4 emissions from SWDS and is accounted for in *5.A Solid Waste Disposal*. The sludge applied to agricultural land contributes to N_2O emissions from soils and is included in emission estimates for *3.D.1 Direct Emissions to Soil*. The total emissions of CH_4 from wastewater are estimated using equation 6.1 from the 2006 IPCC guidelines.

Equation 6.1;

$$CH_4\ Emissions = \left[\sum \left(U_i * T_{i,j} * EF_j\right)\right] (TOW - S) - R$$

Where:

CH_4 Emissions = CH_4 emissions in inventory year, kg CH_4/yr
TOW = total organics in wastewater in inventory year, kg BOD/yr
S = organic component removed as sludge in inventory year, kg BOD/yr
U_i = fraction of population in income group *i* in inventory year
$T_{i,j}$ = degree of utilisation of treatment/discharge pathway or system, *j*, for each income group fraction *i* in inventory year
$_i$ = income group: rural, urban high income and urban low income
$_j$ = each treatment/discharge pathway or system
EF_j = emission factor, kg CH_4 / kg BOD
R = amount of CH_4 recovered in inventory year, kg CH_4/yr

The total organics in wastewater (TOW) in Ireland is estimated based on population equivalent data from urban waste discharge reports (equation 6.3 from the 2006 IPCC guidelines) and is disaggregated by the degree of utilisation of treatment/discharge pathway or system ($T_{i,j}$) as follows;

1. Organically degradable material in wastewater at treatment plant with biogas facility (kg BOD y^{-1})
2. Organically degradable material in wastewater at treatment plant without biogas facility (kg BOD y^{-1})
3. Organically degradable material in wastewater in septic tanks (kg BOD y^{-1})

Equation 6.3;

$$TOW = P * BOD * 0.001 * I * 365$$

Where:

TOW = total organics in wastewater in inventory year (for 365 days), kg BOD/yr

P = country population in inventory year, (person)

BOD = country-specific per capita BOD in inventory year, g/person/day, 60 g (Europe)

I = correction factor for additional industrial BOD discharged into sewers (for collected the default is 1.25, for uncollected the default is 1.00.); and a conversion factor of 0.001 to convert kg BOD from grams BOD was applied in the equation.

On-site domestic septic tanks consist of an underground tank (over 1 metre deep) and a percolation area for the treatment of the 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. Thus, the low prevailing temperatures in septic tanks means that the CH_4 correction factor (MCF) has been revised down from the 2006 IPCC guidelines default value, from 0.5 to 0.083. The CH_4 emission factor for septic tanks is estimated based on equation 6.2 from the 2006 IPCC guidelines and an EF of 0.05 kg CH_4/kg BOD.

Equation 6.2;

$$EF_j = B_o * MCF_j$$

Where:

EF_j = emission factor for treatment/discharge pathway or system *j*, kg CH_4/kg BOD (Table 7.9)

B_o = maximum CH_4 producing capacity, kg CH_4/kg BOD (0.6 kg CH_4/kg BOD)

MCF_j = methane correction factor (fraction), (0.5*2/12 = 0.083)

The CH_4 emission factor for urban wastewater treatment plants without biogas recovery is also estimated using equation 6.2 from the 2006 IPCC guidelines and an EF of 0.018 kg CH_4/kg BOD; based on a MCF of 0.03 (assumed some anaerobic) and a B_o 0.6 kg CH_4/kg BOD.

Table 7.9 Information related to Domestic Wastewater (5.D.1)

IPCC category	Category Description	Method used	Gas	Emission Factor	Emission Factor Reference
5.D.1	Septic tank	T1,T2	CH_4	0.05 kg CH_4/kg BOD	2006 IPCC Guidelines Table 6.2, Modified for Ireland's cold climate
5.D.1	Urban wastewater treatment plant (without biogas facility)	T1,T2	CH_4	0.018 kg CH_4/kg BOD	2006 IPCC Guidelines Table 6.2, Monaghan et al. 2009
5.D.1	Sewage	T1	N_2O	3.2 g N_2O/person	2006 IPCC Guidelines Table 6.11

Wastewater treatment plants with heat or CHP account for on average over 45 percent of the BOD loading in Ireland since 2003. Emissions resulting from the biogas use/recovery are reported in the Energy sector under CRF category 1.A.4.a Commercial/institutional.

Human consumption of food results in the production of sewage, which is processed in septic tanks or in wastewater treatment facilities. This treated waste is disposed of directly onto land, into the soil through percolation areas or discharged to a water body. N_2O can be produced during these processes through nitrification and denitrification. N_2O emissions are estimated using equation 6.7 and 6.8 of the 2006 IPCC guidelines. Parameter values and emission estimates of N_2O are provided in Table 7.10.

Equation 6.7;

$$N_2O\ Emissions = N_{EFFLUENT} * EF_{EFFLUENT} * 44/28$$

Where:

N_2O emissions = N_2O emissions in inventory year, kg N_2O/yr

$N_{EFFLUENT}$ = nitrogen in the effluent discharged to aquatic environments, kg N/yr

$EF_{EFFLUENT}$ = emission factor (0.005 kg N_2O-N/kg N) for discharge to wastewater (Table 6.11),

The factor 44/28 is the conversion of kg N_2O-N into kg N_2O.

$N_{EFFLUENT}$ is estimated from equation 6.8.

Equation 6.8;

$$NE_{FFLUENT} = P \cdot Protein \cdot F_{NPR} \cdot F_{NON-CON} \cdot F_{IND-COM} - N_{SLUDGE}$$

Where:

$N_{EFFLUENT}$ = total annual amount of nitrogen in the wastewater effluent, kg N/yr

P = human population

Protein = annual per capita protein consumption, kg/person/yr

F_{NPR} = fraction of nitrogen in protein, default = 0.16, kg N/kg protein

$F_{NON-CON}$ = factor for non-consumed protein added to the wastewater, 1.1 (Table 6.11)

$F_{IND-COM}$ = factor for industrial and commercial co-discharged protein into the sewer system, 1.25 (Table 6.11)

N_{SLUDGE} = nitrogen removed with sludge (default = zero), kg N/yr

Table 7.10 Estimates of N_2O emissions from human sewage 1990-2016

Year	Pop	Days	Per capita protein consumption	N fraction in protein	Effluent EF kg N_2O-N/kg-N	Non-consumed protein	Industrial co-discharge	N_2O *
	(million)		(g/day)	(IPCC default)	(IPCC default)	(IPCC default)	(IPCC default)	(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
2007	4.376	365	112.0	0.16	0.005	1.1	1.25	0.309
2008	4.485	365	111.0	0.16	0.005	1.1	1.25	0.314
2009	4.533	365	110.0	0.16	0.005	1.1	1.25	0.315
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

*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

Methane emissions from biogas facilities were recalculated due to new activity data for the years 2013 to 2015. Emissions were reduced from 0.7 to 2.5 per cent for *5.D.1* for the period 2013 to 2015. In addition, a recalculation due to a change of non-consumed protein factor (1.1 instead of 1.4) in the calculation of N_2O emission was applied on the basis that sink wastes are not disposed to waste water in Ireland. This recalculation resulted in a 21.4 per cent reduction in emissions throughout the time series. In 2015, the overall recalculation was a decrease in emissions of 2.6 per cent. See table 7.11.

7.5.1.6 Category-specific Planned Improvements

There are no planned improvements for this category.

7.5.2 Industrial Wastewater (5.D.2)

Emissions from *Industrial Wastewater (5.D.2)* are included in *Domestic Wastewater (5.D.1).* This category is reported as Included Elsewhere (IE). On site wastewater treatment at industrial facilities are aerobic systems, therefore no CH_4 emissions occur from these sites.

7.6 Emissions from Other Waste Sources (5.E)

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

Table 7.11(a) Previous and current emission estimates in the Waste Sector (1990-2015)

2017 Submission		Units	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
5.A.1	Managed Waste Disposal Sites	kt CO_2e	NO	NO	1,268.2	1,007.0	1,049.3	616.0	463.8	284.8	278.6	381.6	302.8	461.0	648.1	741.4
5.A.2	Unmanaged Waste Disposal Sites	kt CO_2e	1,318.1	1,592.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.B.1	Treatment of solid waste- composting	kt CO_2e	NO	NO	NO	13.8	13.7	12.5	16.4	21.1	21.0	22.9	22.4	22.7	19.3	19.3
5.C.1	Waste Incineration-Biogenic	kt CO_2e	0.02	0.02	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5.C.1	Waste Incineration-Fossil	kt CO_2e	83.8	83.8	59.3	107.4	103.8	82.9	61.9	63.3	54.0	37.4	44.8	42.8	38.9	39.4
5.C.2	Open Burning of Waste-Biogenic	kt CO_2e	0.6	0.7	1.1	1.6	1.7	0.1	0.0	0.1	0.1	0.3	0.1	0.1	0.1	0.1
5.C.2	Open Burning of Waste-Fossil	kt CO_2e	8.1	9.9	15.4	22.2	22.8	0.8	0.7	0.7	0.7	4.7	0.7	0.7	0.7	0.7
5.D.1	Domestic Wastewater	kt CO_2e	61.1	62.7	62.4	49.3	44.4	44.2	50.9	51.5	50.3	50.1	50.7	50.9	52.6	53.5
5.D.1	Domestic Wastewater	kt CO_2e	95.6	93.1	105.2	113.8	115.5	117.3	119.1	119.3	119.9	118.2	118.5	118.7	119.1	119.8
5.D.2	Industrial Wastewater	kt CO_2e	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
Total Waste		**kt CO_2e**	**1,567.3**	**1,843.0**	**1,511.6**	**1,315.1**	**1,351.1**	**873.6**	**712.9**	**540.8**	**524.6**	**615.2**	**540.0**	**696.8**	**878.8**	**974.2**
2018 Submission		**Units**														
5.A.1	Managed Waste Disposal Sites	kt CO_2e	NO	NO	1,268.2	1,007.0	1,049.3	616.0	463.8	284.8	278.6	381.6	302.8	461.0	648.1	742.2
5.A.2	Unmanaged Waste Disposal Sites	kt CO_2e	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_2e	NO	NO	NO	13.8	13.7	12.5	16.4	21.1	21.0	22.9	22.4	22.7	19.3	20.7
5.C.1	Waste Incineration-Biogenic	kt CO_2e	0.02	0.02	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5.C.1	Waste Incineration-Fossil	kt CO_2e	83.8	83.8	59.3	107.4	103.8	82.9	61.9	63.3	54.0	37.4	44.8	42.8	38.9	39.4
5.C.2	Open Burning of Waste-Biogenic	kt CO_2e	0.6	0.7	1.1	1.6	1.7	0.1	0.0	0.1	0.1	0.3	0.1	0.1	0.1	0.1
5.C.2	Open Burning of Waste-Fossil	kt CO_2e	8.1	9.9	15.4	22.2	22.8	0.8	0.7	0.7	0.7	4.7	0.7	0.7	0.7	0.7
5.D.1	Domestic Wastewater	kt CO_2e	61.1	62.7	62.4	49.3	44.4	44.2	50.9	51.5	50.3	50.1	50.7	50.5	52.3	52.2
5.D.1	Domestic Wastewater	kt CO_2e	75.1	73.1	82.6	89.4	90.7	92.1	93.6	93.8	94.2	92.9	93.1	93.3	93.6	94.1
5.D.2	Industrial Wastewater	kt CO_2e	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
Total Waste		**kt CO_2e**	**1,546.8**	**1,823.0**	**1,489.1**	**1,290.7**	**1,326.4**	**848.5**	**687.4**	**515.2**	**498.9**	**589.9**	**514.6**	**671.0**	**853.0**	**949.3**

Table 7.11(b) Absolute and relative recalculations in the Waste Sector (1990-2015)

Absolute change		Units	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
5.A.1	Managed Waste Disposal Sites	kt CO_2e	-	-	-	0.00	-	0.00	-	-	-	-	-	-0.00	-	0.74
5.A.2	Unmanaged Waste Disposal Sites	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.B.1	Treatment of solid waste- composting	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	1.36
5.C.1	Waste Incineration-Biogenic	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.C.1	Waste Incineration-Fossil	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.C.2	Open Burning of Waste-Biogenic	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.C.2	Open Burning of Waste-Fossil	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.D.1	Domestic Wastewater	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-0.37	-0.31	-1.35
5.D.1	Domestic Wastewater	kt CO_2e	-20.49	-19.94	-22.54	-24.38	-24.74	-25.13	-25.53	-25.57	-25.69	-25.34	-25.39	-25.44	-25.53	-25.67
5.D.2	Industrial Wastewater	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Waste		**kt CO_2e**	**-20.49**	**-19.94**	**-22.54**	**-24.38**	**-24.74**	**-25.13**	**-25.53**	**-25.57**	**-25.69**	**-25.34**	**-25.39**	**-25.81**	**-25.83**	**-24.91**
Relative change		**Units**														
5.A.1	Managed Waste Disposal Sites	kt CO_2e	-	-	-	0.0%	-	0.0%	-	-	-	-	-	-0.0%	-	0.1%
5.A.2	Unmanaged Waste Disposal Sites	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.B.1	Treatment of solid waste- composting	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	7.1%
5.C.1	Waste Incineration-Biogenic	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.C.1	Waste Incineration-Fossil	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.C.2	Open Burning of Waste-Biogenic	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.C.2	Open Burning of Waste-Fossil	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.D.1	Domestic Wastewater	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-0.7%	-0.6%	-2.5%
5.D.1	Domestic Wastewater	kt CO_2e	-21.4%	-21.4%	-21.4%	-21.4%	-21.4%	-21.4%	-21.4%	-21.4%	-21.4%	-21.4%	-21.4%	-21.4%	-21.4%	-21.4%
5.D.2	Industrial Wastewater	kt CO_2e	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Waste		**kt CO_2e**	**-1.3%**	**-1.1%**	**-1.5%**	**-1.9%**	**-1.8%**	**-2.9%**	**-3.6%**	**-4.7%**	**-4.9%**	**-4.1%**	**-4.7%**	**-3.7%**	**-2.9%**	**-2.6%**

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.

9 Indirect CO_2 and N_2O Emissions

9.1 Description of Sources of Indirect Emissions in GHG Inventory

Parties may report indirect emissions of CO_2 from the atmospheric oxidation of CH_4, CO and NMVOCs, and indirect emissions of N_2O from sources other than agriculture and LULUCF under this cross-sectoral category.The use of solvents manufactured using fossil fuels as feedstocks can lead to evaporative emissions of various non-methane volatile organic compounds (NMVOC), which are subsequently further oxidised in the atmosphere.

The IPCC source sector 2.D.3, *Solvent and Other Produce Use*, is important in relation to the emissions of NMVOC. NMVOC are indirect greenhouse gases which result from the use of solvents and various other volatile compounds and are therefore reported as CO_2 equivalent emissions included in national totals. Ireland reports the indirect CO_2 emissions from NMVOC in the IPPU sector 2.D.3, 2.G.4 and 2.H.2 and not in CRF Table 6.

The levels of solvent use and the emissions from solvents have changed substantially in response to product replacement and reformulation and emission controls being implemented under Integrated Pollution Prevention Control (IPPC), the Solvents Directive (CEC, 1999) and the Industrial Emissions Directive (CEP, 2010).

Indirect CO_2 emissions from NMVOC accounted for 0.13 per cent (72.64 kt of CO_2 equivalent) and 0.14 per cent (87.76 kt of CO_2 equivalent) of total national emissions in 1990 and 2016, respectively. See Figure 9.1 below. The national total for Ireland includes indirect CO_2 emissions from 2.D.3, 2.G.4 and 2.H.2 categories and is fully consistent with the national total emissions reported 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.D3.i Other solvent use* including glass wool enduction, fat, edible and non-edible oil extraction, application of glues and adhesives, preservation of wood, underseal treatment and conservation of vehicles and vehicles dewaxing

Also included for the first time are emissions from sector 2.G and 2.H including;

- *2.G.4 Other product use*; Use of tobacco

- *2.H.2 Food and beverages industry,* including bread, beer, spirits, meat, fish etc. frying/curing, coffee roasting and feedstock.

The emission estimates have negligible effect on national total emissions.

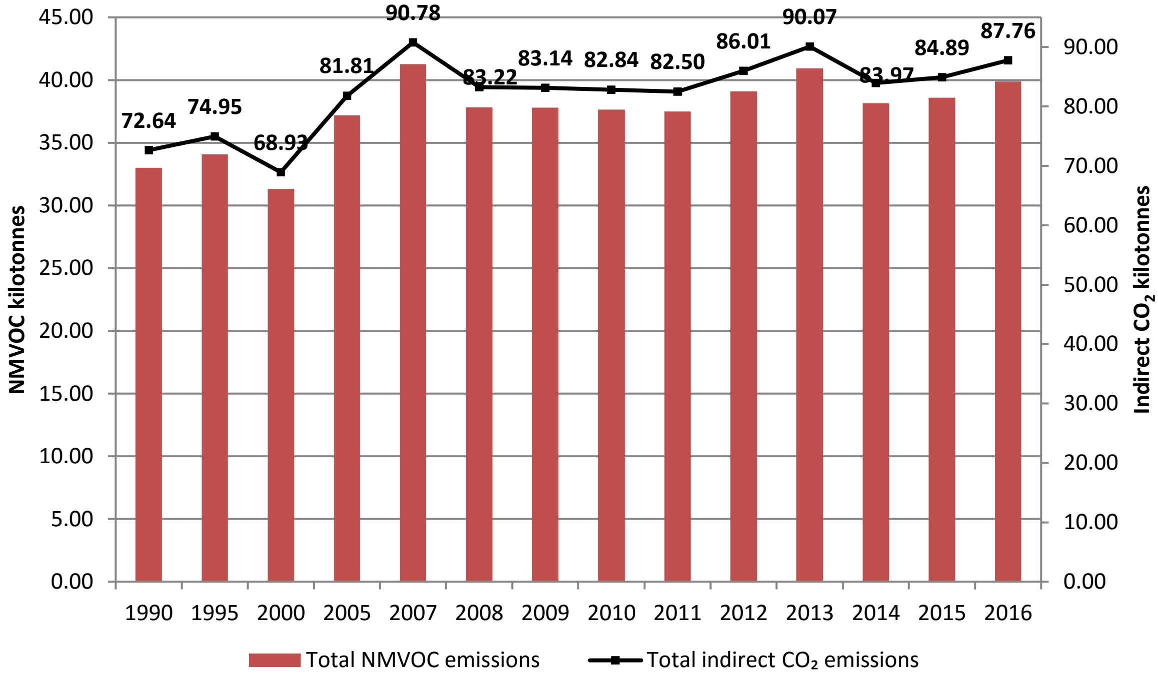


Figure 9.1 Total Indirect CO_2 emissions 1990-2016

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_2 emissions that result from the oxidation of the carbon in NMVOC emissions. This approach is consistent with the overall sectoral approach adopted for estimating CO_2 from the combustion of fuels (Section 3.2), where the CO_2 emissions are based on the full carbon content of the fuel even though some of the carbon is usually emitted as NMVOC or CO. CO_2 emission estimates are derived from NMVOCs by assuming that 60 per cent of the mass of NMVOCs is converted to CO_2.

The activity data used for computing estimates of CO_2 emissions in *Solvent and Other Product Use* are the mass emissions of NMVOC determined for the relevant source categories. The Irish data used for this purpose are the NMVOC emissions compiled according to the EEA/EMEP Guidebook 2016 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) and the recent economic recession.

A detailed description of the methodology behind the NMVOC emissions from this sector can be found in Ireland's Informative Inventory Report 2018 (EPA, 2018).

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 a number of sub sectors within *2.D.3.d Paint applications*, 2.D.3.e *Degreasing*, 2.D.3.f *Dry cleaning*, 2.D.3.g *Chemical products*, *2.G.4 Other Product Manufacture and Use* (reporting disaggregated using CEIP Mapping table categories removed from 2.G.4 and reported in 2.D.3.i) *and 2.H.2 Food and beverages industry.* On average the effect of these recalculations is a 5.96 per cent increase in emissions across the time series. Recalculations focused on updating activity data, emission factors and in some cases methodologies and the inclusion of additional categories following a review of the completeness of reporting of NMVOC emissions sources as outlined in Ireland's Informative Inventory Report 2018 (EPA, 2018).

9.6 Category-specific Planned Improvements

There are no planned improvements for this category.

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

The foregoing chapters describe recalculations and improvements for the individual Level 1 source sectors of the inventory undertaken for the 2018 submission and they present 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 the major changes and where they are described in the 2018 NIR. 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 2018 submission CRF tables. The original and revised numerical values of the emissions estimates for the years 1990-2015, 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 1990-2015 included in the 2018 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 0.04 per cent on average and 464.77 kt CO_2 eq in total in the 1990-2015 trend. The reasons for change between submissions were revised fuel consumption data in the latest energy balance.

Fuel use in Ireland’s new natural gas refinery was included in this submission for the first time, for 2015 and 2016. Source category *1.A.1.c* was recalculated to include minor fuels other than milled peat using data from EU ETS. In addition, revised fuel consumption in the national energy balance for fuels and years in *1.A.2* were also included: Gas oil (2015), biomass (2015), non-renewables wastes (2012-2015) and natural gas (2007-2015).

Road transport in *1.A.3*, was recalculated due to using a new model, COPERT 4 to COPERT 5 software, which impacted the emission factors for CH_4 and N_20 for all years from for 1990-2015.

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 1990-2015 time series is outlined below in Figure 10.1.

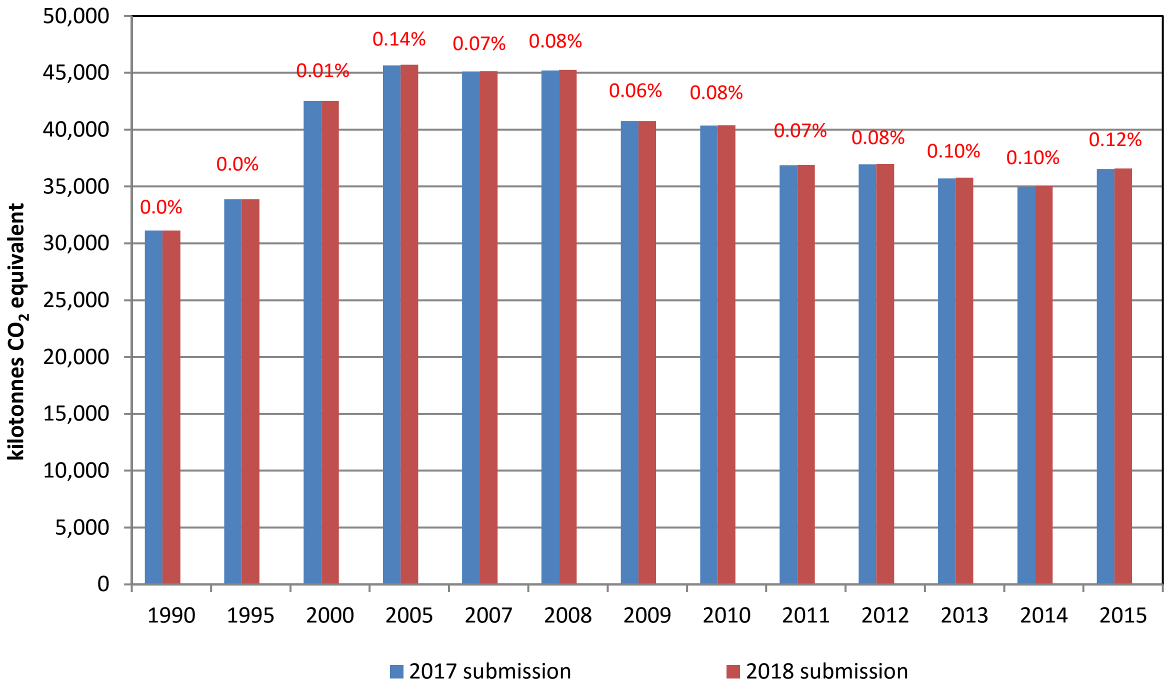


Figure 10.1 Impact of Recalculations in Energy between annual Submissions 1990-2015

10.2.2 Recalculations in Industrial Processes and Product Use

The overall impact of recalculations in the IPPU sector resulted in a 0.36 per cent increase on average and 281.91 kt CO_2 eq. in total in the 1990-2015 trend. 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 correction to, *2.D.2 Paraffin Wax use* and *2.D.3.d Coating applications,* a reallocation of cross sectoral indirect emissions from *2.G.4* to *2.D.3i,* a correction to *2.G.4 Other Product use: Preservation of Wood,* a change to Euro classes of LDV and HDV used in the calculation of *2.D.3 Urea used as a Catalyst* and updated activity data for *2.H.2 Food and Beverages Industry: Spirit Production.*

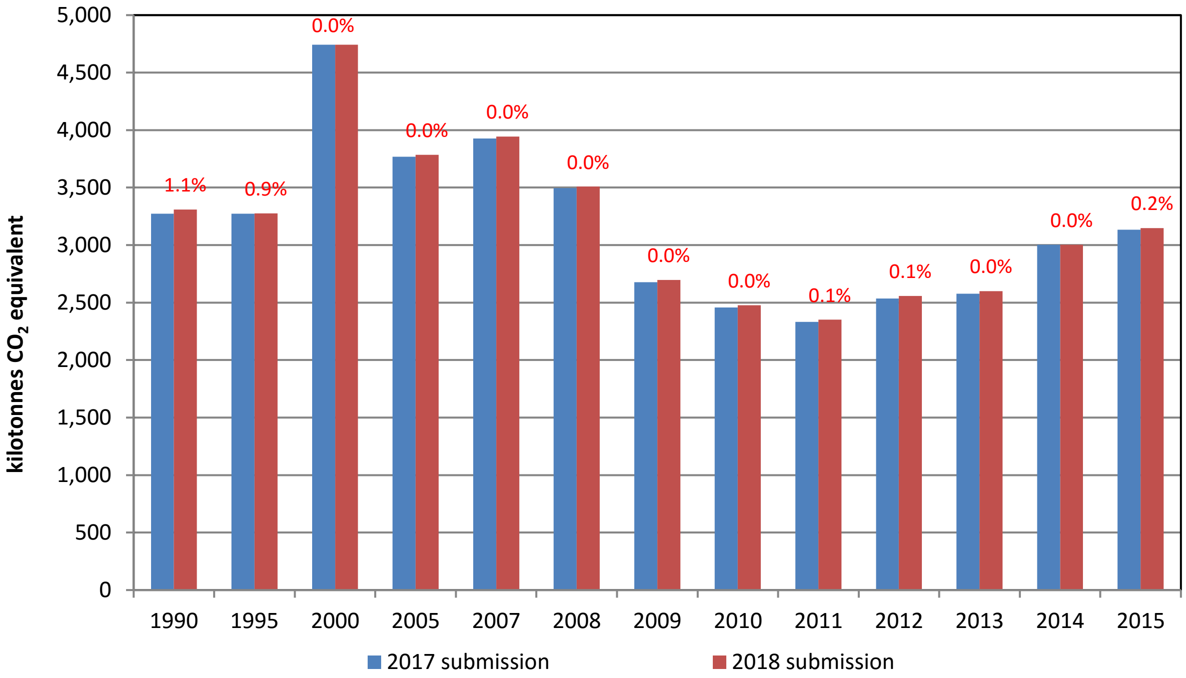


Figure 10.2 Impact of Recalculations in IPPU between annual Submissions 1990-2015

10.2.3 Recalculations in Agriculture

The overall impact of recalculations in the Agriculture sector resulted in an decrease of 2.85 per cent on average and 14,639.21 kt CO_2 eq. in total in the 1990-2015 trend. The main reasons for the change between the two submissions were; an increase in the synthetic fertiliser N_2O emission factor from 1% loss (default in 2006 IPCC Guidelines) to 1.24% loss on average and decrease in urine and dung by grazing cattle on soils N_20 emission factor from a 2% loss (default in 2006 IPCC Guidelines) to 0.86% loss on average, these changes were the result of recent research carried out in Ireland. New country specific nitrogen excretion rates for other cattle (non-dairy cattle) were also used in the 2018 submission. Improvements were made to the CH_4 emissions from manure management for swine and sheep which increased emissions. These changes resulted in a recalculation of emissions for *3.B and 3D for all years*. The impact of the recalculations in the Agriculture sector between annual Submissions in the 1990-2015 time series is outlined below in Figure 10.3.

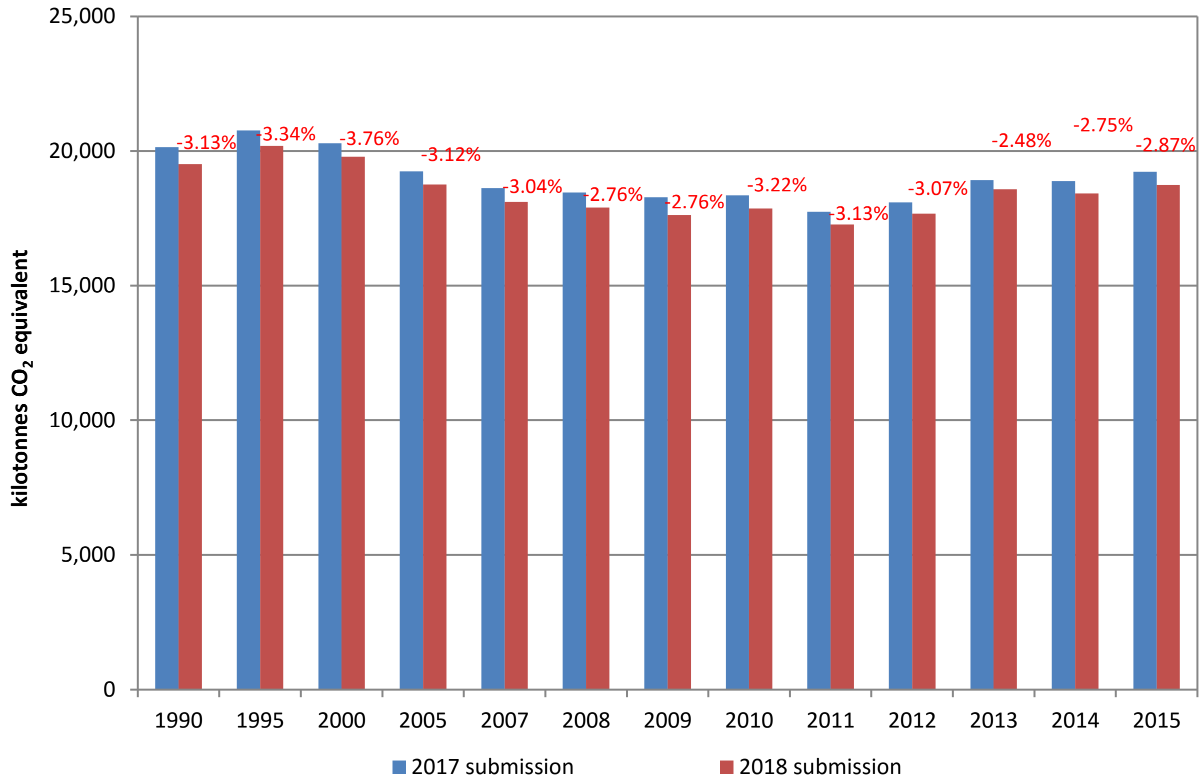


Figure 10.3 Impact of Recalculations in Agriculture between annual Submissions 1990-2015

10.2.4 Recalculations in LULUCF

10.2.4.1 Forest lands (4.A)

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

10.2.4.2 Cropland (4.B)

There have been significant changes made within the Cropland category. These relate to the refinement of LPIS data into the analysis of areas of crop and temporary grassland. In addition a revised table of probability of fires was produced for this submission leading to a revision in the estimates associated with biomass burning. This has led to recalculation of emissions and removals for all years in the reporting period. The net effect of these recalculation is a 77 percent reduction in emissions/increase in removals 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. In addition a revised table of probability of fires was produced for this submission leading to a revision in the estimates associated with biomass burning. This has led to recalculation of emissions and removals for all years in the reporting period. The net effect of these recalculations is an 8.1 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 revision of areas associated with the extraction and use of peat for horticultural use. This has had a significant impact on the absolute emissions of carbon to the atmosphere. Revisions to the area of burnt area (as discussed for the

Cropland and *Grassland* categories) and associated emissions and removals of greenhouse gases (CO_2, N_2O and CH_4) due to biomass burning have had a limited impact on the overall emissions trends.

10.2.4.5 Settlement (4.E)

The largest contributor to the recalculation in this category is the identification and correction of a transcription error whereby the emissions associated with mineral grassland soils converted to settlements was not reported in the previous submission. There were also minor revisions due to the refinement of the assessment of lands converted to settlement based on national statistics. The net effect of these recalculations is a approx. on average 160 per cent increase in emissions for each year of the time series 1990-2015.

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. In addition an error was detected in emissions of N_20 from mineralisation of SOC in forest land converted to other land in the previous submission. All previously submitted values were out by a factor of 100 due to incorrect transfer of data into the CRF tables (4(III)).

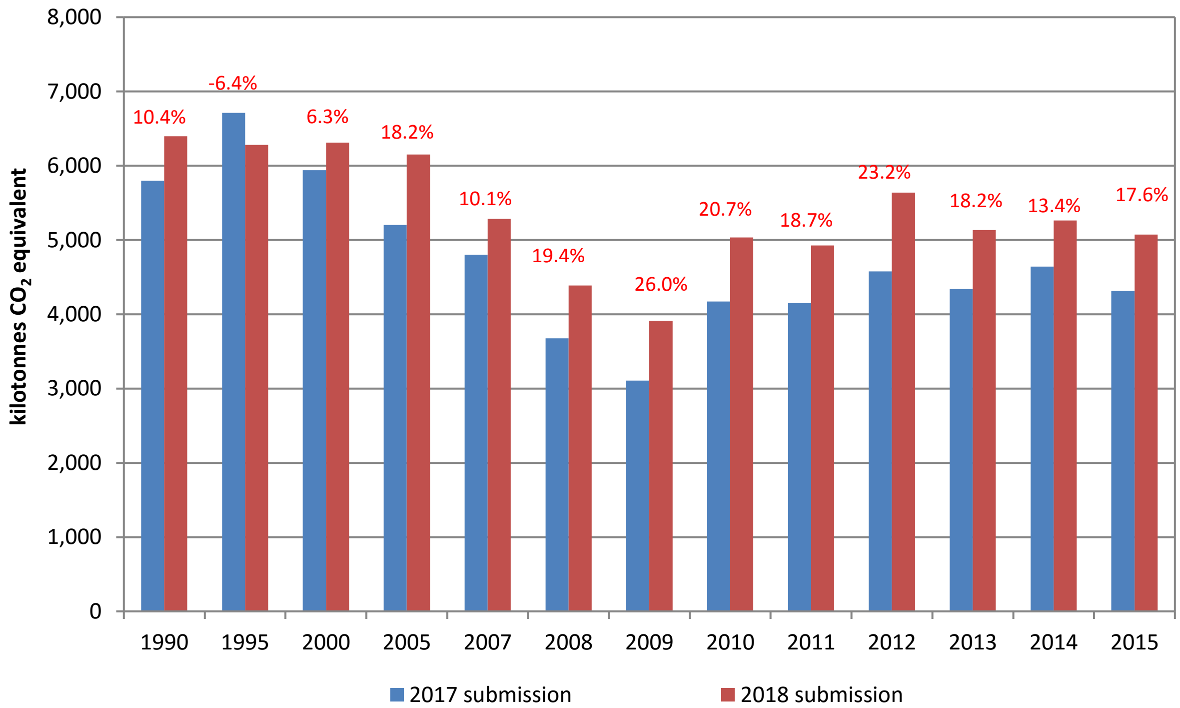


Figure 10.4 Impact of Recalculations in LULUCF between annual Submissions 1990-2015

The net effect of the recalculations and additional information on recalculations is provided in chapter 6 and 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 2.22 per cent decrease on average and 602.46 kt CO_2 eq. in total in the 1990-2015 trend. Additional information on recalculations is presented in CRF Table 8s3 for the relevant years.

The reason for the change between the two submissions is primarily due to revision of the N_2O fraction of non-consumed protein from 1.4 to 1.1 as recommended in the ESD review under the MMR 525/2013, as Ireland does not allow waste disposal via sinks. This change resulted in a recalculation for all years for Wastewater treatment and discharge *(5.D).*

The other minor changes included a revision of activity data in the period 2013-2015 in *5.A.1*, *5.B.1* and *5.D.1*. The impact of the recalculations in the Waste sector between annual Submissions in the 1990-2015 time series is outlined below in Figure 10.5.

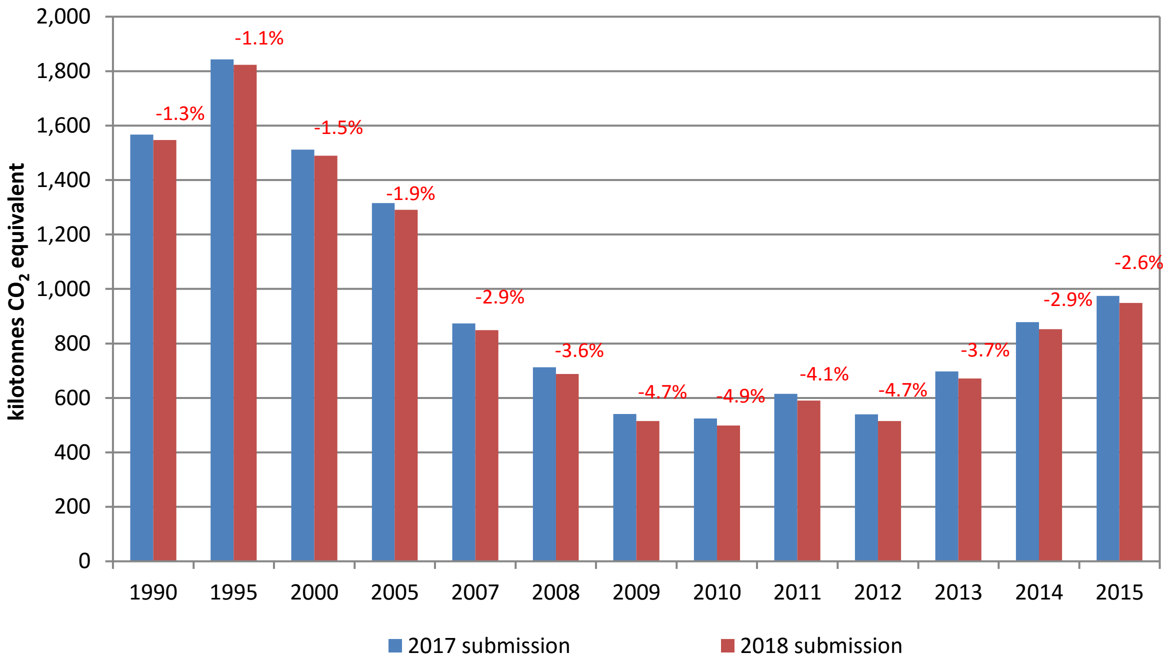


Figure 10.5 Impact of Recalculations in Waste between annual Submissions 1990-2015

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 1990-2015 according to greenhouse gas and the IPCC sectors, respectively. The overall effect on the total emissions (including indirect CO_2, excluding LULUCF) shows decreases in estimates by 1.53 per cent (and 860.98 kt CO_2 eq.) in 1990 and by 1.35 per cent (and 807.67 kt CO_2 eq.) in 2015. There is no significant impact on the trend in total emissions (Chapter Two). Emissions decreased in all 26 years of the timeseries (1990-2015). On average emissions reduced by 1.15 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 1990-2015 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 really 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 1990-2015 included in the 2018 submission are outlined below (Tables 10.1 to 10.3 and Figure 10.6).

Table 10.1. Changes in Methodological Descriptions compared to 2017 NIR

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	DESCRIPTION OF METHODS	RECALCULATIONS	REFERENCE
	Categories where the 2018 NIR includes major changes in methodological descriptions compared to the 2017 NIR	Sub-categories where changes are reflected in recalculations of previous year estimates	Reference to sub-category, gas, pages in the NIR, Annex
Total (Net Emissions)			
1. Energy			
A. Fuel Combustion (Sectoral Approach)			
1. Energy Industries		✓	Revised fuel consumption data for natural gas in refineries and production of peat briquettes from milled peat in *1.A.1.c f*or 2005-2015. Chapter 3, Section 3.2.4.3.5
2. Manufacturing Ind & Construction		✓	Revised fuel consumption in the national energy balance for fuels and years: Gas oil (2015), biomass (2015), non-renewable wastes (2012-2015) and natural gas (2005-2015) result in recalculations for the years 2005-2015. Chapter 3, Section 3.2.5.5
3. Transport		✓	Updated methodology using new road transport model COPERT 5. Minor recalculations for all years from 1990-2015 for CH4 and N2O. Chapter 3, Section 3.2.6.2.5
4. Other Sectors			
5. Other			
B. Fugitive Emissions from Fuels			
1. Solid Fuels			
2. Oil and Natural Gas			
C. CO_2 Transport and Storage			
2. Industrial Processes and Product Use			
A. Mineral Industry			
B. Chemical Industry			
C. Metal Industry			
D. Non-Energy Products from Fuels and Solvent Use		✓	Updates to the national energy balance in 2.D.1 Chapter 4, Section 4.5.1.5. Revision of AD for candle wax section 4.5.2.5, Dissaggregation of indirect emissions between 2.D.3, 2.G.4 and 2.H.2 Section 4.5.3.5
E. Electronics Industry			
F. Product Uses as Substitutes for Ozone Depleting Substances			
G. Other Product Manufacture and Use		✓	Dissaggregation of indirect emissions between 2.D.3, 2.G.4 these emissions are now reported under 2.G.4 in 2018 submission. Chapter 4 Section 4.8.4
H. Other		✓	Dissaggregation of indirect emissions between 2.D.3 and 2.H.2 these emissions are now reported under 2.H.2 in 2018 submission. Chapter 4, Section 4.9
3. Agriculture			
A. Enteric Fermentation		✓	Updated EF in 3.A Chapter 5 Secion 5.2.1 Updated AD for goats in 3.A.2-3.A.4, Chapter 5 Section 5.2.1
B. Manure Management		✓	Revised housing days for Sheep and Horses. Revised N excretion rates for non Dairy Cattle. Chapter 5 Section 5.3.2
C. Rice Cultivation			
D. Agricultural Soils		✓	New country specific emission factors for N2O from inroganic N fertilsers and urine and dung deposited by grazing animals (cattle only), 3.D.1.1 and 3.D.1.3. Revised area of Organic soils in 3.D.1.6. Chapter 5 Section 5.5.1 & 5.5.2
E. Prescribed Burning of Savannas			

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	DESCRIPTION OF METHODS	RECALCULATIONS	REFERENCE
	Categories where the 2018 NIR includes major changes in methodological descriptions compared to the 2017 NIR	Sub-categories where changes are reflected in recalculations of previous year estimates	Reference to sub-category, gas, pages in the NIR, Annex
F. Field Burning of Agricultural Residues			
G. Liming			
H. Urea Application			
I. Other			
4. Land Use, Land-Use Change and Forestry			
A. Forest Land			
B. Cropland		✓	Revised assessment of crop and temporary grassland areas
C. Grassland		✓	Revised assessment of grassland areas and grassland management regimes
D. Wetlands		✓	Revised assessment of wetland areas and management regimes
E. Settlements		✓	Revised assessment of lands covnverted to settlements
F. Other Land			
G. Harvested Wood Products			
H. Other			
5. Waste			
A. Solid Waste Disposal		✓	Revision of flaring data for 2013-2015 in 5.A.1 Chapter 7 section 7.2.1
B. Biological Treatment of Solid Waste			
C. Incineration and Open Burning of Waste			
D. Wastewater Treatment and Discharge		✓	Revised N2O emissions due to change in non-consumed protein Fnon-com from 1.4 to 1.1 Chapter 7 Section 7.5.1, Revised AD in biogas facilities2013-2015, Section 7.5.1
E. Other			
6. Other			
Memo Items:			

Table 10.2. Recalculations by Gas 1990-2015

(a) Emissions by Gas 1990 –2015 reported in 2017 Submission (kt CO_2 eq)

GAS	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015
CO_2 emissions without net CO_2 from LULUCF	32,840.7	35,793.2	45,192.9	48,027.7	47,576.1	47,251.6	42,068.7	41,630.1	37,965.0	38,144.1	37,122.8	36,633.1	38,392.8
CH_4 emissions without CH_4 from LULUCF	14,803.4	14,996.8	14,292.2	13,511.2	12,801.9	12,604.1	12,232.2	11,980.6	11,936.4	12,235.7	12,564.4	12,881.4	13,263.4
N_2O emissions without N_2O from LULUCF	8,423.4	8,698.3	8,635.2	7,422.8	6,993.1	6,990.5	6,901.2	7,069.6	6,649.6	6,747.9	7,112.5	7,049.0	7,079.2
HFCs	1.2	103.2	456.7	678.4	905.9	845.8	915.1	932.0	955.2	948.6	1,070.0	1,152.6	1,076.8
PFCs	0.1	97.6	397.8	216.4	168.1	136.1	83.6	46.6	15.9	9.6	8.3	3.6	20.5
SF_6	33.9	79.1	51.8	96.8	62.9	54.7	39.2	33.1	45.5	37.4	43.5	37.4	44.5
NF_3	NO	4.4	49.2	28.4	37.7	NO	NO	NO	NO	0.8	0.9	1.0	1.0
Total (without LULUCF, with indirect)	**56,102.8**	**59,772.6**	**69,075.7**	**69,981.6**	**68,545.6**	**67,882.8**	**62,240.0**	**61,691.9**	**57,567.4**	**58,124.0**	**57,922.5**	**57,757.9**	**59,878.2**

(b) Recalculated Emissions by Gas 1990 –2015 reported in 2018 Submission (kt CO_2 eq)

GAS	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015
CO_2 emissions without net CO_2 from LULUCF	32,877.9	35,794.4	45,194.0	48,104.6	47,622.9	47,300.1	42,108.5	41,679.5	38,009.3	38,194.8	37,182.8	36,681.6	38,443.6
CH_4 emissions without CH_4 from LULUCF	14,867.8	15,076.9	14,386.8	13,601.9	12,882.6	12,675.6	12,299.3	12,048.9	12,012.2	12,309.5	12,640.7	12,943.4	13,323.0
N_2O emissions without N_2O from LULUCF	7,709.3	8,029.1	8,018.5	6,816.3	6,375.9	6,328.8	6,155.5	6,492.4	6,068.3	6,235.7	6,668.5	6,508.4	6,517.8
HFCs	1.2	103.2	456.7	678.3	905.8	845.8	915.1	932.0	955.2	948.6	1,070.0	1,140.9	1,076.1
PFCs	0.1	97.6	397.8	216.4	168.1	136.1	83.6	46.6	15.9	9.6	8.3	3.6	20.5
SF_6	33.9	79.1	51.8	96.8	62.9	54.7	39.2	33.1	45.5	37.4	43.5	37.4	44.5
NF_3	NO	4.4	49.2	28.4	37.7	NO	NO	NO	NO	0.8	0.9	1.0	1.0
Total (without LULUCF, with indirect)	**55,490.3**	**59,184.7**	**68,554.7**	**69,542.7**	**68,056.0**	**67,341.2**	**61,601.2**	**61,232.5**	**57,106.3**	**57,736.3**	**57,614.9**	**57,316.3**	**59,426.5**

(c) Percentage Change in Emissions by Gas 1990-2015

GAS	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015
CO_2 emissions without net CO_2 from LULUCF	0.11%	0.00%	0.00%	0.16%	0.10%	0.10%	0.09%	0.12%	0.12%	0.13%	0.16%	0.13%	0.13%
CH_4 emissions without CH_4 from LULUCF	0.43%	0.53%	0.66%	0.67%	0.63%	0.57%	0.55%	0.57%	0.64%	0.60%	0.61%	0.48%	0.45%
N_2O emissions without N_2O from LULUCF	-8.48%	-7.69%	-7.14%	-8.17%	-8.82%	-9.46%	-10.81%	-8.16%	-8.74%	-7.59%	-6.24%	-7.67%	-7.93%
HFCs	0.00%	0.00%	0.00%	-0.01%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	-1.01%	-0.06%
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%
SF_6	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%
NF_3	NO	0.00%	0.00%	0.00%	0.00%	NO	NO	NO	NO	0.00%	0.00%	0.00%	0.00%
Total (without LULUCF, with indirect)	**-1.09%**	**-0.98%**	**-0.75%**	**-0.63%**	**-0.71%**	**-0.80%**	**-1.03%**	**-0.74%**	**-0.80%**	**-0.67%**	**-0.53%**	**-0.76%**	**-0.75%**

(d) Actual Change in Emissions by Gas 1990-2015 (kt CO_2 eq)

GAS	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015
CO_2 emissions without net CO_2 from LULUCF	37.24	1.19	1.08	76.88	46.89	48.50	39.79	49.46	44.35	50.64	60.01	48.57	50.81
CH_4 emissions without CH_4 from LULUCF	64.38	80.16	94.62	90.72	80.71	71.53	67.14	68.36	75.84	73.74	76.35	62.00	59.57
N_2O emissions without N_2O from LULUCF	-714.10	-669.20	-616.68	-606.47	-617.13	-661.63	-745.70	-577.19	-581.35	-512.15	-443.97	-540.55	-561.41
HFCs	0.00	0.00	0.00	-0.08	-0.06	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-11.62	-0.69
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
SF_6	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
NF_3	NO	0.00	0.00	0.00	0.00	NO	NO	NO	NO	0.00	0.00	0.00	0.00
Total (without LULUCF, with indirect)	**-612.48**	**-587.85**	**-520.98**	**-438.95**	**-489.60**	**-541.61**	**-638.78**	**-459.38**	**-461.16**	**-387.77**	**-307.62**	**-441.60**	**-451.72**

Table 10.3 Recalculations by IPCC Sector 1990-2015

(a) Emissions by IPCC Sector 1990 –2015 reported in 2017 Submission (kt CO_2 eq)

SOURCE AND SINK CATEGORIES	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015
1. Energy	31,118.5	33,893.1	42,526.1	45,648.8	45,115.2	45,209.9	40,742.4	40,359.6	36,871.7	36,953.6	35,725.0	34,994.7	36,541.6
2. Industrial Processes and Product Use	3,272.2	3,273.6	4,742.8	3,769.0	3,927.4	3,495.4	2,678.2	2,458.5	2,332.4	2,535.6	2,576.7	3,001.9	3,135.3
5. LULUCF	5,796.9	6,709.6	5,938.6	5,203.2	4,799.9	3,674.6	3,107.1	4,170.0	4,148.3	4,575.1	4,340.8	4,640.6	4,313.6
5. Waste	1,567.3	1,843.0	1,511.6	1,315.1	873.6	712.9	540.8	524.6	615.2	540.0	696.8	878.8	974.2
6. Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Total (excl. LULUCF, with indirect)	**56,102.8**	**59,772.6**	**69,075.7**	**69,981.6**	**68,545.6**	**67,882.8**	**62,240.0**	**61,691.9**	**57,567.4**	**58,124.0**	**57,922.5**	**57,757.9**	**59,878.2**

(b) Recalculated Emissions by IPCC Sector 1990 –2015 reported in 2018 Submission (kt CO_2 eq)

SOURCE AND SINK CATEGORIES	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015
1. Energy	31,119.7	33,896.2	42,529.2	45,713.9	45,147.5	45,246.7	40,765.1	40,392.1	36,897.8	36,982.9	35,761.9	35,030.1	36,584.1
2. Industrial Processes and Product Use	3,309.4	3,274.8	4,743.8	3,784.4	3,944.9	3,508.5	2,696.5	2,476.3	2,351.3	2,557.6	2,600.2	3,003.2	3,149.2
3. Agriculture	19,514.4	20,190.6	19,792.6	18,753.7	18,115.1	17,898.6	17,624.4	17,865.3	17,267.2	17,681.2	18,581.7	18,430.1	18,743.9
5. Waste	1,546.8	1,823.0	1,489.1	1,290.7	848.5	687.4	515.2	498.9	589.9	514.6	671.0	853.0	949.3
6. Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Total (excl. LULUCF, with indirect)	**55,490.3**	**59,184.7**	**68,554.7**	**69,542.7**	**68,056.0**	**67,341.2**	**61,601.2**	**61,232.5**	**57,106.3**	**57,736.3**	**57,614.9**	**57,316.3**	**59,426.5**

(c) Percentage Change in Emissions by Sector 1990-2015

SOURCE AND SINK CATEGORIES	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015
1. Energy	0.00%	0.01%	0.01%	0.14%	0.07%	0.08%	0.06%	0.08%	0.07%	0.08%	0.10%	0.10%	0.12%
2. Industrial Processes and Product Use	1.14%	0.04%	0.02%	0.41%	0.45%	0.38%	0.68%	0.72%	0.81%	0.87%	0.91%	0.04%	0.44%
3. Agriculture	-3.13%	-2.76%	-2.48%	-2.57%	-2.76%	-3.07%	-3.58%	-2.64%	-2.71%	-2.29%	-1.81%	-2.40%	-2.51%
5. Waste	-1.31%	-1.08%	-1.49%	-1.85%	-2.88%	-3.58%	-4.73%	-4.90%	-4.12%	-4.70%	-3.70%	-2.94%	-2.56%
6. Other	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total (excl. LULUCF, with indirect)	**-1.09%**	**-0.98%**	**-0.75%**	**-0.63%**	**-0.71%**	**-0.80%**	**-1.03%**	**-0.74%**	**-0.80%**	**-0.67%**	**-0.53%**	**-0.76%**	**-0.75%**

(c) Actual Change in Emissions by Sector 1990-2015

SOURCE AND SINK CATEGORIES	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015
1. Energy	1.2	3.1	3.1	65.1	32.3	36.8	22.7	32.5	26.1	29.3	37.0	35.4	42.5
2. Industrial Processes and Product Use	37.2	1.2	1.1	15.4	17.5	13.1	18.3	17.8	19.0	22.0	23.4	1.3	13.9
3. Agriculture	-630.5	-572.2	-502.6	-495.1	-514.3	-566.0	-654.2	-484.0	-480.9	-413.7	-342.2	-452.4	-483.2
5. Waste	-20.5	-19.9	-22.5	-24.4	-25.1	-25.5	-25.6	-25.7	-25.3	-25.4	-25.8	-25.8	-24.9
6. Other	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total (excl. LULUCF, with indirect)	**-612.48**	**-587.85**	**-520.98**	**-438.95**	**-489.60**	**-541.61**	**-638.78**	**-459.38**	**-461.16**	**-387.77**	**-307.62**	**-441.60**	**-451.72**

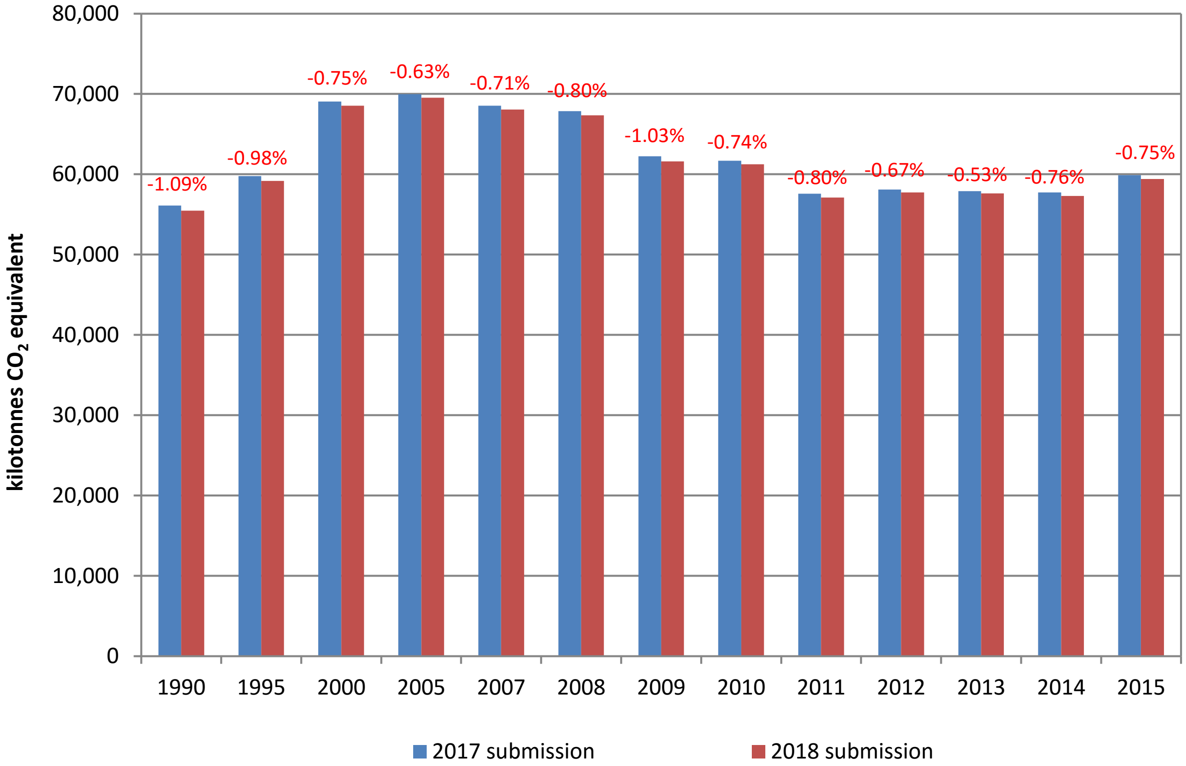


Figure 10.6 Total Impact of Recalculations between annual Submissions 1990-2015

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 2013 centralised reviews of Ireland's inventory have also been addressed where feasible in the present submission.

This submission is the fourth 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 issues raised in the 2011 to 2013 annual inventory review reports and Ireland's response to those issues through the 2014, 2015, 2016, 2017 and the current submission. It may be stated therefore that the inventory material being submitted in 2018 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

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 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 under Wetland Drainage and Rewetting, or Revegetation under Article 3.4. 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_2 in 2016 on 317.48 kha of lands subject to afforestation/ reforestation since 1990 is estimated at 3,860.98 kt CO_2eq while there were net emissions of 205.89 kt CO_2eq on a deforested area of 17.63 kha (Table 11.2 and 11.4). The overall forest sink for Article 3.3 forest increased from 2,335.13 kt CO_2eq in 2008 to 3,655.10 kt CO_2eq in 2016, primarily due to an increase in the area under afforestation and a decrease in emissions associated with deforestation.

Reported removals in 2016 on 449.08 kha of land under forest management is estimated to be 600.06 kt CO_2eq, most of which are associated with long term storage of C in harvested wood products.

Reported net-net removals in 2016, relative to the 1990 base year, on 675.00 kha of land under cropland management is estimated to be 114.72 kt CO_2eq. 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 4,344.90 kha of land in 2016 under grazing land management is estimated to be 562.92 kt CO_2eq. This is mainly due to apparent changes in the patterns of utilisation of improved grassland and rough grazing.

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 CARBWARE national model that is applied specifically 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 CARBWARE model has been developed and reported (see Chapter 6).

The inventory for Article 3.4 CM and GM activities are prepared by a member of the national inventory team. 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 6.5.1 in section 6.3.2.6 of Chapter 6.

Table 11.1 Reported Activities and Pools (CRF Table NIR 1)

Activity	CHANGE IN CARBON POOL REPORTED[1]							GREENHOUSE GAS SOURCES REPORTED[2]							
	Above-ground biomass	Below-ground biomass	Litter	Dead wood	Soil		HWP[4]	Fertilization[5]	Drained, rewetted and other soils[6]		Nitrogen mineralization in mineral soils[8]	Indirect N_2O emissions from managed soil[5]	Biomass burning[9]		
					Mineral	Organic[3]		N_2O	CH4[7]	N_2O	N_2O	N_2O	CO_2[10]	CH_4	N_2O
Article 3.3 activities															
Afforestation and reforestation	R	R	R	R	NO	R	R	IE	R	R	NO	IE	R	R	R
Deforestation	R	R	R	R	R	R	IO	IE	R	R	R	IE	NO	NO	NO
Article 3.4 activities															
Forest management	R	R	R	R	NA	R	R	IE	R	R	NO	IE	R	R	R
Cropland management	R	IE	NO	NO	R	NO			NO		IE		NO	R	R
Grazing land management	R	IE	NO	NO	R	R			R		IE		NO	R	R
Revegetation	NA	NA	NA	NA	NA	NA		NA	NA	NA	NA	NA	NA	NA	NA
Wetland drainage and rewetting	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_2O 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 fro AR and FM, CO_2 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 2016

	ARTICLE 3.3 ACTIVITIES		ARTICLE 3.4 ACTIVITIES						
	Afforestation and reforestation	Deforestation	Forest management[5]	Cropland management (if elected)	Grazing land management (if elected)	Revegetation (if elected)	Wetland drainage and rewetting (if elected)	Other[6]	Total area at the end of the previous inventory year[7]
	(kha)								
Article 3.3 activities									
Afforestation and reforestation	310.98	0.16							311.13
Deforestation		17.42							17.42
Article 3.4 activities									
Forest management		0.05	449.08						449.14
Cropland management[3] (if elected)	0.19		NO	675.00	NA	NA	NA		675.19
Grazing land management[3] (if elected)	2.70		NO	NO	4344.90	NO	NO		4347.60
Revegetation[3] (if elected)	NA		NA	NA	NA	NA	NA		NA
Wetland drainage and rewetting[3] (if elected)	NA		NA	NA	NA	NA	NA		NA
Other[4]	3.61	NO	NO	NO	NO	NA	NA	1307.69	1311.30
Total area at the end of the current inventory year	317.48	17.63	449.08	675.00	4344.90	NO,NA	NO,NA	1307.69	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[4]
		Associated category in UNFCCC inventory[1] is key (indicate which category)	Category contribution is greater than the smallest category considered key in the UNFCCC inventory[2] (including LULUCF)	Other[3]	
Specify key categories according to the national level of disaggregation used[1]					
B.3 Grazing Land Management	CO_2	4.C.1 Grassland remaining grassland	Yes	NA	Level
A.1 Afforestation/Reforestation	CO_2	4.A.2 Land converted to forest land	Yes	NA	Level
B.1 Forest Management	CO_2	4.A.1 Forest land remaining forest land	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.1.KP CM			B.1.KP GM		
	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
1990							-411.73	NA	NA	-16.38	0.0017	$4.5x10^{-5}$	7047.82	9.75	0.01
2013	-3824.43	1.04	0.29	61.89	0.23	0.41	-571.48	2.05	0.28	-31.03	NO	NO	6499.09	9.66	0.01
2014	-3816.28	1.05	0.29	93.37	0.23	0.41	-390.86	1.99	0.28	-73.6	NO	NO	6463.95	9.68	0.01
2015	-3918.61	1.03	0.30	134.31	0.24	0.42	-661.24	1.89	0.28	-92.0	NO	NO	6496.49	9.60	$4.9x10^{-3}$
2016	-3978.26	1.01	0.31	75.73	0.24	0.42	-728.95	1.79	0.28	-131.24	NO	NO	6492.38	9.57	$1.2x10^{-3}$

11.1.3 Definitions and Application

For the definition of different carbon (C) pools please refer to section 6.1 Chapter 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 Chapter 6). 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.

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 1st of January 1990, or are pre-existing semi-natural forests before 1st 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 11.6).

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 6.4.13, Chapter 6);
- CM includes areas identified as temporary grassland, with a history of cultivation for crops in the period 1990-2016;
- 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 1990-2016 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 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 6.5.8);
- GM excludes areas identified as temporary grassland, with a history of cultivation for crops in the period 1990-2015;
- 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 1st 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. 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 Chapter 6).

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 6.5.1 Chapter 6).

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 6.2.3.2 and 6.2.3.3 in Ch 6). 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.7, annex, paragraph 9. 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 Chapter 6). 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, Chapter 6 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 6.3.2.3, Chapter 6). The primary classification of forest land in the NFI uses approach 2 as defined in Chapter 3, Section 3.3 of the 2006 IPPC 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 3 in the annex to decision 2/CMP.7.

The NFI used information from the IFORIS system (section 6.3.2.2 Chapter 6) to identify forest lands afforested after the 31st 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 section 6.2.2.1 Chapter 6) 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 (Table 11.5) within internal national boundaries.

In years when NFI inventory data is not available (i.e. before the 1st or after the last NFI) afforestation areas are tracked on a spatially explicit basis (IPCC Approach 3, see section 6.3.2.5 Chapter 6) while deforestation areas are identifiable but not spatially explicit (IPCC Approach 2, see section 6.3.2.4 Chapter 6). 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 form forest area. This is consistent with forests converted to other land uses in LULUCF Convention reporting (CRF Tables 4 B, C, D and E).

Table 11.5 Forest category codes used in CRF Tables 4 (KP-I)

Forest_Category_Code	Forest_Category_Description
1	Spruce (Pure). Mainly Sitka and Norway spruce
2	Pine (Pure). Prodominantly Scots and lodgepole pine
3	Larch (Pure)
4	Other conifers (Pure)
5	Fast growing broadleaves (Pure) such as ask, Alder, Sycamore, Birch
6	Slow growing broadleaves (Pure) such as Oak and Beech
7	Conifer mixes
8	Broadleaf mix
9	Conifer/Boradleaf mix
10	Open areas including biodiversity areas, roads within the forest boundary
11	Blown areas subjected to windthrow
12	Scrub, felled or failed areas (planted and unplanted)
13	New afforestation after 2006
14	Natural succession and regenreating land
101 to 115	Harvested areas. E.g 101 are harvested spruce areas
200	Burned areas

Forest stands were considered to be pure if one species represents 80 % or more of the canopy
Note: Categories 12 and 14 do not qualify as afforestation or reforestation under Article 3.3 of the KP, so are reported as NO in the CRF tables. Open areas are planned open areas in afforested areas for extraction roads of biodiversity enhancement. These are, however, assumed to be in steady state and reported as NO.

11.1.5.1.1 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 6.4.4 Chapter 6).

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 Chapter 6). 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 Chapter 6) 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. Additional research is planned to explore planning and urban databases to address this.

11.1.6 Information that demonstrates elected activities are directly human induced and have occurred since 1990

Article 3.3 activities

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 captures 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 after1 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, Chapter 6).

Article 3.4 Forest management

All areas subject to FM activities 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/

2. Private g*rant 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 general 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 plants 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. 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 is 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. There 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, 6.4.1, 6.4.2, 6.4.3, 6.5.1 and 6.5.2, Chapter 6).

11.2.1 Afforestation

See Sections 6.3.2.1 to 6.3.2.3 and 6.3.2.5, Chapter 6. For detailed data on areas over the time series see Tables 6.10, 6.16, 6.17 and 6.18, Chapter 6.

A more detailed description of removals and emissions associated with different forest types in 2016 (defined in table 11.5 above) is shown in table 11.6. Emissions associated with forest soils are presented in Table 6.17 Chapter 6.

11.2.2 Forest management

See sections 6.3.2.1 to 6.3.2.4 Chapter 6. For detailed data on areas over the time series see Tables 6.8, 6.9, 6.10 and 6.11 Chapter 6.

Table 11.6 Detailed areas and CSC for level 3 forest categories under AR activities in 2016

Forest_Cat	ADJ_Area	AG_GAin	AG_Loss	AG_Net	BG_GAin	BG_Loss	BG_Net	Litter_Net	DW_Net
1	131.54	972.03	-476.50	495.53	198.43	-35.74	162.69	138.27	32.67
2	7.05	33.36	-17.55	15.80	9.69	-1.11	8.58	4.91	0.11
3	13.81	42.54	-47.70	-5.16	18.07	-8.10	9.97	10.38	11.65
4	2.86	8.28	-6.21	2.07	6.88	-0.20	6.68	2.43	0.04
5	15.42	15.20	-19.38	-4.18	7.52	-0.20	7.32	-4.25	4.23
6	5.12	2.72	-6.58	-3.87	2.39	-0.08	2.31	0.62	-2.27
7	22.42	129.20	-71.02	58.17	33.86	-5.32	28.54	20.76	8.71
8	3.18	2.33	-9.82	-7.49	1.36	0.00	1.36	2.27	-0.78
9	22.47	96.17	-65.48	30.69	29.42	-3.50	25.91	12.95	3.50
10	41.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.28	0.42	-0.36	0.06	0.12	0.00	0.12	0.18	-0.08
12	NO	NO	NO	NO	NO	NO	NO	NO	NO
13	51.54	29.67	-2.92	26.75	25.29	-0.12	25.17	2.18	0.00
14	NO		NO	NO	NO	NO	NO	NO	NO
200	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	317.48	1331.91	-723.53	608.38	333.03	-54.38	278.65	190.71	57.78

Table 11.7 Detailed areas and CSC for level 3 forest categories under FM activities in 2016

Forest_Cat	ADJ_Area	AG_GAin	AG_Loss	AG_Net	BG_GAin	BG_Loss	BG_Net	Litter_Net	DW_Net
1	132.42	1062.57	-1239.97	-177.40	255.28	-179.57	75.71	154.90	60.72
2	40.10	210.99	-270.07	-59.08	53.90	-58.20	-4.30	9.43	38.49
3	2.40	5.40	-3.82	1.58	1.40	-0.40	1.00	1.83	-6.80
4	1.52	10.40	-33.73	-23.33	4.36	-4.33	0.03	-0.07	6.13
5	9.76	3.45	-122.70	-119.25	0.62	-16.24	-15.62	11.28	-4.41
6	5.76	32.62	-32.22	0.40	9.58	-0.67	8.91	5.62	-10.14
7	36.98	226.73	-112.16	114.57	56.67	-12.30	44.37	1.91	-26.33
8	31.21	35.47	-72.18	-36.72	10.42	-11.02	-0.60	3.39	-19.11
9	55.71	208.50	-209.83	-1.33	54.57	-30.36	24.21	1.92	28.78
10	43.61	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00
11	2.44	34.05	-9.02	25.02	9.34	-0.15	9.18	0.89	-6.72
12	26.94	35.61	-18.89	16.73	18.02	-2.52	15.50	1.73	-6.00
13	25.60	6.41	-0.10	6.31	1.88	0.00	1.88	0.00	0.00
14	34.06	18.65	-22.12	-3.46	6.10	-0.68	5.42	22.85	-6.30
200	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	449.08	1890.84	-2146.80	-255.96	482.13	-315.42	166.71	215.69	48.30

A more detailed description of removals and emissions associated with different forest types in 2016 (defined in table 11.5 above) is shown in table 11.7. Emissions associated with forest soils are presented in Chapter 6 (Table 6.8).

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 in Chapter 6), this definition of deforestation has been applied consistently in developing the 1990 to 2016 area time-series.

The NFI 2012 enabled the detection of all deforestation events including illegal deforestation and failure to replant felled areas within 5 years. The NFI completes an inventory of all forest areas every 5 years on a rotational basis. The 3rd NFI cycle is due to be complete in 2018. ***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 6.3.2.1 to 6.3.2.3 and 6.3.2.4, Chapter 6. For detailed data on areas over the time series see Tables 6.20 and 6.21.

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 category (see CRF 5(KP-I)A.2) into the following (see Table 11.8):

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.

Table 11.8 CSC for forestland converted to other land categories (also see information item in CRF table 4(KP-1)A.2)

		2016					
Deforestation		FL	CL	GL	WL	S	OL
Activity data							
Area subject to the activity	kha	NO	NO	6.93	2.23	4.90	3.57
Area of mineral soils	kha	NO	NO	6.51	0.34	2.01	1.61
Area of organic soils	kha	NO	NO	0.42	1.89	2.89	1.96
Change in carbon stock							
CSC above-ground biomass							
Gains	kt C	NO	NO	0.18	IE	NO	NO
Losses	kt C	NO	NO	-3.86	-0.12	-0.59	-0.64
Net change	kt C	NO	NO	-3.68	-0.12	-0.59	-0.64
CSC below-ground biomass							
Gains	kt C	NO	NO	0.85	IE	NO	NO
Losses	kt C	NO	NO	-0.94	-0.02	-0.17	-0.23
Net change	kt C	NO	NO	-0.09	-0.02	-0.17	-0.23
Net CSC in litter	kt C	NO	NO	-0.38	-0.01	-0.07	-0.09
Net CSC in dead wood	kt C	NO	NO	-2.66	-0.02	-0.13	-0.04
Net CSC in soils							
Mineral soils	kt C	NO	NO	NO	NO	-2.15	-1.61
Organic soils	kt C	NO	NO	-1.63	-1.94	-2.60	-1.77
Net emissions/removals							
CO2	kt	NO	NO	30.98	7.74	20.94	16.06

IE for wetland biomass gains reported under soils as specified in 2013 Wetland supplement for rewetted soils CH_4.
NO for mineral soils, not occurring because soils are demonstrated not to be a source. For emissions from mineral settlement and other land soils see section 6.3.6.1.1 in Ch 6.
NO not occurring
Biomass gains are only reported for grasslands based on 2006 IPCC Table 6.4 Ch 6.

11.2.4 Cropland management

See sections 6.4.1 to 6.4.4 Chapter 6. For detailed data on areas over the time series see Figures 6.18 and 6.21.

11.2.5 Grazing land management

See sections 6.5.1 to 6.5.4 Chapter 6. For detailed data on areas over the time series see Figures 6.32 and 6.33.

11.2.6 Direct and indirect emissions from N fertilisation

Direct and indirect emissions of N_2O from N fertiliser application are included under Agriculture (3.D.a.2).

11.2.7 N_2O and CH_4 from drained and rewetted organic soils

See sections 6.3.4.5, 6.3.5.6 and 6.3.6.12 in Chapter 6. Note that CO_2 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_2O losses from mineralization of soils due C loss associated with land use change

For afforestation activities this does not occur (NO) because we demonstrate that CSC in mineral soils is not a source. This also applies for forest to grassland conversions (see Section 11.3 below).

For deforestation to settlement and other land, CSC in mineral soils are reported and N_2O emission are reported using tier 1 approaches (see 6.3.6.1.1, Chapter 6)

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 6.5.6 in Chapter 6). 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 6.10 Chapter 6), 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 and Figure 6.28 Chapter 6) remote sensor 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 6.43 Chapter 6) remote sensor detection of fires from the NASA FIRMS database.

11.3 Justification for Omitting a Carbon Pool

This section provides detailed information that demonstrates that the mineral soil pools under afforestation, forest management and forest land conversions to grasslands are not a net source of anthropogenic GHG emissions; therefore, the mineral soil pool is not accounted for and as the notation key “NO” is reported. If a pool is not reported and it is demonstrated that it is not a net source then the approach is consistent with requirements under paragraph 2(e) of annex II to decision 2/CMP.8.

It also outlines the justification for omitting Litter and Dead Litter pools from CM and GM activities.

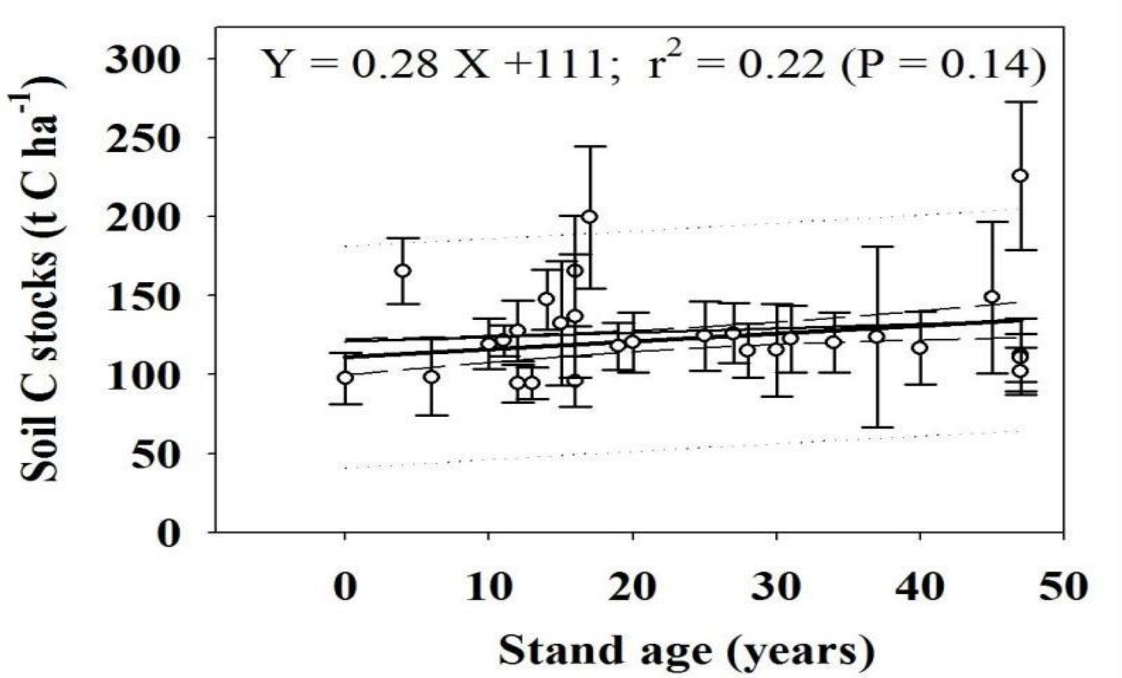
11.3.1 Afforestation: Mineral Soils for grassland, cropland and forest land transitions

Demonstration that soils are not a source is based on numerous research data, which have been subject to rigorous statistical analyses using different approaches. **The working null hypothesis is that mineral soils are a source when lands are converted to forest land, and visa-versa. The null hypothesis can be rejected if statistical tests prove that mineral soils are not a source. Therefore, we demonstrate that mineral soils for cropland and grassland conversion to and from forestry are not a source by rejecting the null hypothesis.**

Changes in mineral soil C pools over time (ΔC_{so}) are not reported because of all current information confirms that it is not a source. These findings are based on three research approaches, but this is re-evaluated every submission year following review of national research. There is also a new project ForCRep (2012-2017) specifically initiated to further develop a method for reporting mineral soils stock changes.

a) A chronosequence approach:

National research information does suggest that mineral soils are a sink for a minimum of 50 years following afforestation (Black et al., 2009b). These authors show that SOC is higher when a 9 year old stand was compared to year 0 (i.e. un-forested grassland in the chronosequence). Other information from 30 different afforested sites, previously located on grasslands, suggest that there is *no significant* change (P>0.1) of mineral soil C stocks over time following afforestation (Black, 2008 see Figure 11.1). If anything, the data suggest an increase in SOC stocks over time, suggesting that afforestation of mineral soils results in a net sink, albeit not significant. Therefore, we opt not to report stock changes for mineral soils because we can **reject the null hypothesis and demonstrate that the pool is not a source**. However, this can only be applied to grassland/forestland conversions, so additional data and analysis is required (see improvement plant section 6.12.1, Chapter 6).



The solid line represents the linear change on C stock over time. The dashed and dotted lines represent the 95% confidence and prediction intervals

Figure 11.1 Variation in mineral soil carbon stocks and estimation of ∆Csoil using the nationally derived data (n = 30).

b) A paired plot approach:

National forest research projects (FORESTSOIL C and CARBiFOR2 projects 2007-2012) designed a soil carbon monitoring system for Ireland using country-specific land use and soil carbon information. The system is based on a stratified NFI sample of the country by soil type and land use. This element of the work concentrated on a paired plot approach to assess soil C stock changes due to afforestation and deforestation activities. The sampling strategy was designed to augment NFI plot measurements, but included additional paired plot samples from adjacent non-forest land uses. The overall concept applies the assumption that changes in soil C stocks, due to transition from one land use to another, is a function of the difference between the forest and non-forest plot soil carbon pools and that both soil pools are in steady state. For this reason, all land use samples were assessed to have not undergone land use transitions in the past 20 to 50 years.

The following assumptions and conditions were applied:

- The analysis only applies to mineral soils. Organic soils stock changes are determined using emission factors. This includes organo-mineral soils, such as peaty-gley soils (see equations 6.3.23 and 6.3.24 in section 6.3.3.1.2(d) in Chapter 6);
- Carbon stock changes in mineral soils for all sample plots were at steady state when sampled;
- The age at steady state (i.e. the mean age of the land use or soil type) is equivalent to the transition time for soil C stocks to reach steady state;
- The land use transitions did not include wetlands or croplands because transitions between forestry and these land uses (and vice versa) were not detected in the random stratified sample grid of 60 out of 1762 NFI sample plots.(section 6.3.2.4 and Annex 3.4.A.2). In addition, there are very few mineral soils in wetlands;
- Settlement and other land soils were not sampled because of technical difficulties in obtaining soil samples. Deforestation and transition to settlements and other land does occur in Ireland but the soils stocks are assumed to be a source and are reported (see section 11.4.1.1). No paired settlement or other land plots were identified in the random stratified sample taken in this study;
- This analysis is primarily concerned with transitions between forestry, scrub, unimproved grassland and improved grassland. Scrub in this case refers to land uses dominated by non-tree species such as gorse or bramble. These in effect are degraded or disused grasslands (unimproved grasslands), previously used for rough grazing;
- Changes in soil C stocks due to land use change is assumed to occur only if the difference between the forest and non-forest pair, within a given soil group is found to be significantly different following statistical analysis.

To quantify the relative importance of the different factors on Ireland's soil C stocks, and to test the null hypothesis for different land use and soil strata, we carried out a hierarchical analysis of variance and multiple regression analysis using the SPSS statistical package.

Table 11.9 Record sample plots taken from mineral soils sites

Soil	Land use	Transition time (years)	Number of plots	Number of soil profiles
Gleys	Forest	30	10	50
	Un-managed grassland	30	4	20
	Managed grassland	30	4	20
	Scrub grassland	30	2	10
Brown earths	Forest	35	10	50
	Un-managed grassland	35	6	30
	Managed grassland	35	4	20
	Scrub grassland			
Brown podsols	Forest	50	10	50
	Un-managed grassland	50	6	30
	Managed grassland	50	4	20
	Scrub grassland	50		
Podsols	Forest	39	10	50
	Un-managed grassland	39	5	25
	Managed grassland	39	4	20
	Scrub grassland	39	1	5
Total			**80**	**400**

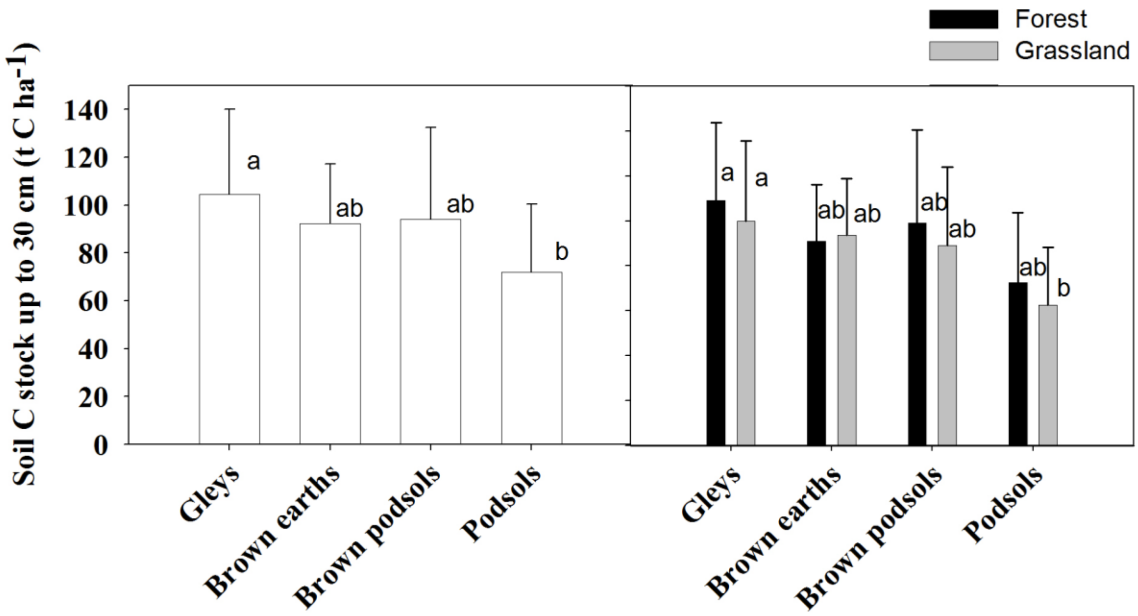
Land uses were first categorized as shown in Table 11.9, and then re-classified either as forest or grassland (Grassland/Forest pair). The forest grassland pair was categorised because there are no significant difference soils stock or changes in the different grassland types.

Table 11.10 Results from the hierarchical analysis of variance on soil C at a depth of 0-30cm

Source	SS	MS	F	P
Between soils	763902	254634	3.49	<0.01
Land use within soils	29663	2963	1.24	0.34
Grassland/Forest within soils	20215	4043	0.81	0.48

Based on the hierarchical analysis of variance on soils C at a depth of 0-30 cm, it was evident that there was a significant difference in soils C stock when soil types were compared. However, there was no difference in the soil C stock when the different land use classes were compared (Table 11.10). Therefore, the null hypothesis is rejected (i.e. the p value for the Land-use source of variance is >0.05). **This confirms that mineral soils are not a source since there is no difference in the soil C stock when forests, unimproved grasslands, improved grasslands and scrublands are compared.**

To further illustrate this point, Figure 11.2 shows that the mean soil C stock was significantly different within soil types for combined data from forests and grasslands (left panel Figure 11.2). Although there were marginal differences between the mean soil C stocks when forest and grassland plots are compared within the soil categories, these were not significantly different (right panel in Figure 11.2).



Histogram bars with different letters are significantly different at P < 0.05

Figure 11.2 Mean soil C reference values for forest and grasslands at steady state across different mineral soil types

Based on these analyses and the chronosequence of soil stock changes (Black et al., 2009) it is evident that there is no significant change in soil C stocks for up to 30 years following transitions between all grassland types and forest land. Therefore **the null hypothesis is rejected and we clearly demonstrate that this pool is not a source for grassland/forest land transitions**. Similar results have been reported by Davis and Condron (2002) and Scott et al (2002) for studies conducted in New Zealand, where many more plots were sampled.

Based on these conclusions and related publications (Wellock et al., 2011) Ireland has elected not to account for mineral soil C stock changes following afforestation and deforestation from and into grassland uses, because we demonstrate that this pool is not a source across different mineral soil types. However, more research is being undertaken to provide activity data and methods for reporting mineral soil c stock changes for all land use transitions (see section 6.12.1, Chapter 6).

c) A new SOC database from the For CRep project:

In 2013, the ForCRep project (2012-2017) compiled a national database using all available SOC survey data sampled from mineral soils representing major land use categories in the Republic of Ireland. The mineral soil database comprises of a total of 227 sample sites obtained from the Soil C project (Wellock et al., 2011), the Irish national soil database of Ireland (NCD, see Xu et al., 2011), the An Foras Taluntas project (Creamer, R., unpublished data), and the CARBiFOR project (Black et al 2009a). For this study it is not yet possible to make comparisons across different soil types because detailed soil profile data is still being processed and collected. However, a preliminary analysis was conducted to test the null hypothesis if mineral soils are a source across all cropland/ grassland and forest land transitions.

Analysis of variance confirmed that the **null hypothesis can be rejected for cropland to forest land conversions**. The SOC in forest mineral soils is significantly higher (37 per cent), when compared to croplands, confirming that these soils are a sink (Figure 11.3). In the **case of forest land conversions to cropland, the null hypothesis can be accepted** since mineral soils could represent a significant loss of SOC (i.e. a source). However, there are no deforestation activities and conversion to cropland in Ireland (see CRF table KP.A.2). This is primarily due to the poorer quality of land under forestry, which is not suitable of cropland production. Cropland conversions to forestry have declined in recent years because previous transitions represented marginal land not ideally suitable for cropland production.

Based on a comparison of mean SOC values for all grasslands and forest land, there was no statistical difference in the mean SOC for these land categories (Figure 11.3). Therefore, **the null hypothesis is rejected and SOC in following grassland/forest land transitions are demonstrated not to be a source**.

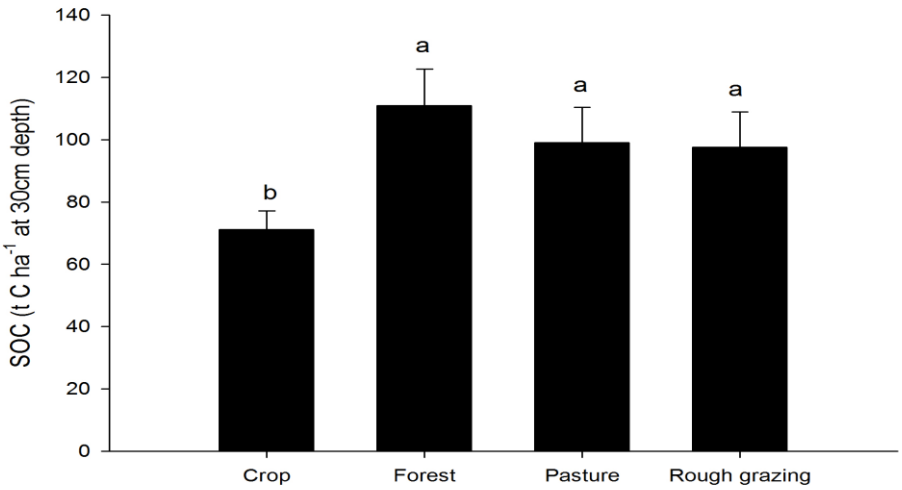


Figure 11.3 Comparison of mean SOC values (histograms) and standard deviations (error bars) across different land use categories. Mean values with different alphabetical characters indicate a significant difference (p<0.05)

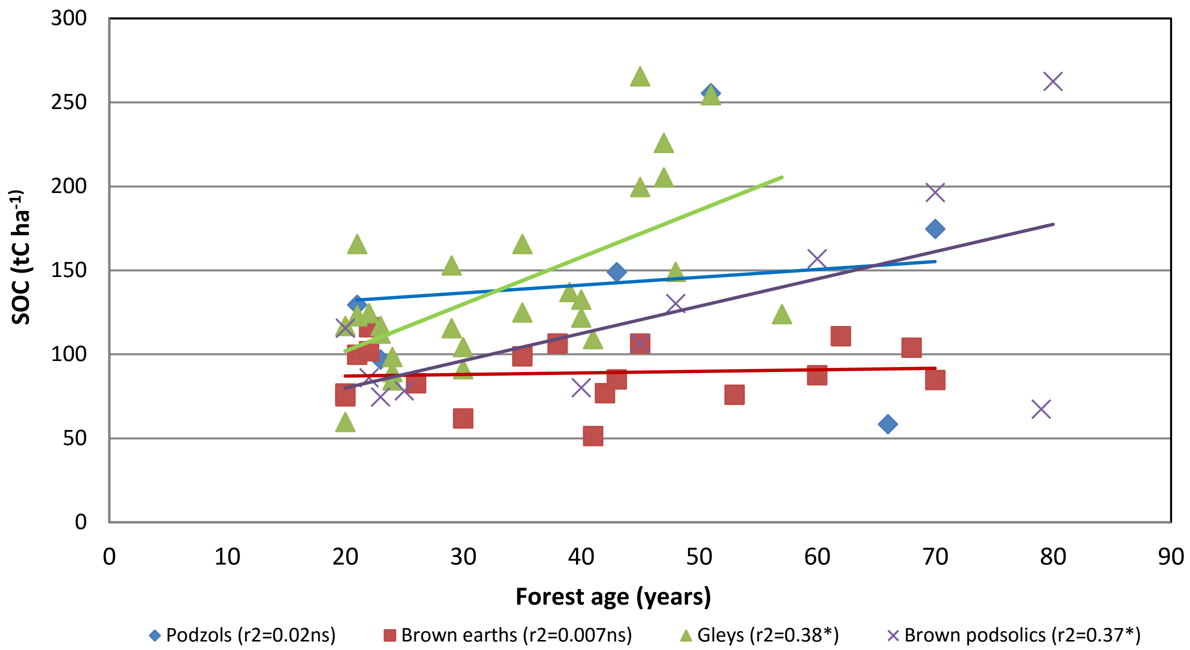
11.3.2 Forest management: Mineral Soils

Mineral soils emissions were assumed to be zero for the Forest Management Reference Level (FMRL), so the same assumption is applied to reporting of CSC in mineral soils under FM in the 2nd commitment period.

Although there was no supporting information for this assumption under the FMRL review under 2/CMP.6, we now provide additional information supporting this assumption based on the new SOC database from the For CRep project.

a) First rotation forests older than 20 years old:

The ForCRep database was used to investigate the SOC stock changes of different mineral soils associated with 1st rotation crops older than 20 years old. Data were stratified into 4 basic soils groups due to significant differences in SOC between soil types. Based on regression analysis it was confirmed that CSC mineral soils in 1st rotation forests older than 20 are not a source (Figure 11.4). In contrast, the results suggest that CSC in gley and brown podsolic soils increase over the first rotation. This result is expected since an increased transfer of deadwood and litter carbon to soils as a result of thinning residues and mortality would result in an accumulation of recalcitrant C in soils (see Liski et al. 2005. Carbon and decomposition model YASSO for forest soils.



*Coefficients of determination (r2) values were significant when p values were > 0.05

Figure 11.4 Regression analysis showing trends in SOC stocks for different soils types as a function of forest age

b) Second rotation crops:

The national forest soil database only contains SOC data for one 2nd rotation site, so there is no reliable national information for 2nd rotation crops. Verifiable information supporting the assumption that 2nd rotation crops are not a source comes from literature reviews from regions with similar forest types and climatic conditions:

1. Soil carbon dynamics in a Sitka spruce (Picea sitchensis (Bong.) Carr.) chronosequence on a peaty gley in Scotland (Zerva et al. 2005) suggests that SOC carbon stocks increased from 140 t C ha^{-1} at the end of the 1st rotation to 249 tC ha^{-1} at 30years in the second rotation, so they are not a net source. This study was conducted in forests similar to those occurring in Ireland.
2. The effect of forest management on SOC varies considerably depending on management regime, species, climate harvest intensity etc. (see Waldchen et al 2013). These authors report that there are no detectable effects of forest management on SOC. This study was based on 190 inventory plots taken from forests in Europe varying in age from 100-200 years old and with different management interventions from coppicing to selective harvest.
3. Many tier 3 modelling approaches (e.g. YASSO see Laiski et al., 2005) show that SOC generally accumulates in successive rotations due to increased inputs of C from harvest residues. In Ireland, there has been an age class shift from mature 1st rotation age forests to 2nd rotation forest (see Figure 6.11 Chapter 6). This has resulted in an increase allocation of harvest residue

to the dead organic matter pool, some of which is emitted due to decomposition. However, some of the recalcitrant C will accumulate in soils. The current hypothesis represented by the literature and the current age class structure of Irish forests under forest management suggest that mineral soils cannot be a net emission of CO_2. A study on organic soils in Ireland, soils which are more likely to result in emissions due to forestry, show that emissions from soils decline after the 1st rotation (Byrne and Farrell, 2005).

It should be noted that the same approach for mineral soils are taken for reporting the FMRL and emissions/removals for FM in the 2nd commitment period. Therefore, this approach does not result in an underestimation of emissions associated with FM activities.

11.3.3 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. It the case of Christmas trees, there is evidence that the market for trees is stable or increasing over time, and as such the biomass associated with this crop is stable or increasing, See 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[12]). 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 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.

11.3.4 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

[12] http://www.teagasc.ie/publications/2013/2865/Environment_Newsletter_September2013.pdf

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 a N deposition, CO_2 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_2 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[13], with an observed increase in temperature of 0.5^{o}C between climate average 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.

[13] Met Eireann, May 2012, Meteorological Note No. 14, A Summary of Climate Averages for Ireland 1981-2010 http://www.met.ie/climate-ireland/SummaryClimAvgs.pdf

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.

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 11.11a and 11.11b). Wildfires have only been recorded in AR lands since 2008 and are assumed not to occur before 2008.

Table 11.11a Total emissions form wild fires and area specific emissions from disturbances for the calibration period for FM

Year	Wildfires (kt CO_2 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 11.11b Total and area specific emissions from disturbances for the calibration period for AR

Year	Wildfires (kt CO_2 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 8 below).

Table 11.12 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_2 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_2 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 2016 were 2.58 kt CO_2eq, which is higher than the background plus margin (70.62 kt CO_2) presented in table 11.12. Therefore, Ireland cannot trigger the election of the natural disturbance provision in 2016 (i.e. trigger test in CRF table 4(KP-1) A1.1 is reported as “NO”).

The reported emissions from wild fires in lands under FM activities are lower than the background and margin presented in table 11.12. Therefore, Ireland cannot trigger the election of the natural disturbance provision in 2016 (i.e. trigger test in CRF table 4(KP-1) A1.1 is reported as “NO”).

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 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_2 equivalent, see table 11.14 below.

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 2013. 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 new version of CARBWARE, "v5" is now used for the basis for CSC changes in biomass, litter and deadwood pools. The FMRL submission (see 2/CMP7) used CARBWARE version 4.5 (Black et al., 2012).
- There have been a range of methodological changes for estimation of CO_2, N_2O and CH_4 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_2O and CH_4 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 polices 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 11.13 below).
    - New historical harvest rates from FM areas before 2009 based on new national forest inventory (NFI) data (highlighted in bold in Table 11.13).

  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.

Table 11.13 A comparison of previous activity data for 1990-2009 used for the FMRL submission and the new data used in the 2016 inventory

	Area (Kha)		**Harvests (M m^3)**	
Year	**FM 2013 inventory**	**FMRL submission**	**FM 2016 (this submission)**	**FMRL submission**

1990	465.26	**481.35**	1.676	**1.787**
1991	465.24	**479.91**	1.767	**1.837**
1992	465.22	**476.96**	2.082	**2.156**
1993	465.20	**479.40**	2.097	**2.003**
1994	465.18	**480.70**	2.283	**2.220**
1995	464.84	**474.14**	2.377	**2.424**
1996	464.51	**463.20**	2.461	**2.520**
1997	464.18	**461.33**	2.313	**2.398**
1998	463.84	**463.32**	2.632	**2.493**
1999	463.51	**466.75**	2.765	**2.842**
2000	462.65	**462.14**	3.002	**2.940**
2001	461.79	**456.02**	2.822	**2.700**
2002	460.94	**450.85**	2.899	**2.911**
2003	460.08	**458.81**	2.986	**2.951**
2004	459.22	**456.45**	2.829	**2.818**
2005	458.37	**454.35**	2.925	**2.775**
2006	456.37	**477.21**	2.947	**2.803**
2007	454.77	**444.52**	2.864	**2.160**
2008	452.77	**446.94**	2.209	**2.056**
2009	451.97	**447.29**	2.682	**2.392**
2010	451.17		3.036	1.833
2011	449.57		2.729	2.061
2012	449.57		2.735	2.314
2013	449.53		2.827	2.390
2014	499.40		2.215	2.104
2015	449.14		2.590	2.402
2016	449.01		2.461	2.558
2017				2.704
2018				2.870
2019				3.026
2020				3.182

The corrected time series (FMRLcorr) was re-estimated using the original assumptions in projected harvest and FM areas (Table 11.13). Projected areas for organic soils and fire assumptions were based on the original FMRL submission.

Table 11.14a: The corrected FRML (FMRLcorr) time series from 2013-2020.

		Year								
	Units	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**Average**
Area	**kHa**	445.58	445.16	444.73	444.3	443.88	443.45	443.02	442.59	
AB_gain		2054.47	1840.33	1909.63	1811.63	1764.49	1722.18	1686.97	1848.86	**1829.82**
AB_loss		-2249.38	-2069.46	-2168.86	-2213.54	-2246.30	-2265.08	-2250.28	-2328.44	**-2223.92**
AB_net		-194.91	-229.13	-259.24	-401.91	-481.81	-542.91	-563.31	-479.58	**-394.10**
Bggain		505.51	461.04	489.13	471.77	467.53	461.60	458.58	498.87	**476.75**
BG_loss	**kt C**	-241.21	-252.70	-249.58	-259.52	-259.28	-275.90	-261.43	-320.11	**-264.97**
BG_net		264.30	208.34	239.55	212.25	208.25	185.70	197.15	178.76	**211.79**
Litter_Net		221.72	233.54	201.09	181.86	175.37	187.86	183.43	279.35	**208.03**
DW_net		25.96	35.27	41.42	55.35	73.38	124.74	88.38	209.81	**81.79**
Soils		-142.08	-141.83	-141.94	-141.86	-132.74	-141.24	-132.49	-132.36	**-138.32**
Total C		**174.99**	**106.19**	**80.88**	**-94.31**	**-157.56**	**-185.85**	**-226.83**	**55.98**	**-30.81**
Total CO2		**-641.65**	**-389.35**	**-296.57**	**345.80**	**577.70**	**681.45**	**831.72**	**-205.28**	**112.98**
Fires		12.00	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	**127.75**
Total excl HWP	**kt CO2 eq**	-501.46	-249.29	-156.63	485.61	717.40	821.02	971.16	-65.96	**252.73**
HWP		-607.43	-531.21	-657.54	-786.90	-850.65	-967.04	-1062.68	-1129.22	**-824.08**
Total incl HWP		-1108.89	-780.50	-814.17	-301.29	-133.26	-146.02	-91.52	-1195.17	**-571.35**

Table 11.14b 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 2013-2016

	FMRLcorr (mean 2013-2020)	FMRL (2/CMP6) submission (mean 2013-2020)	FM Reported (mean 2013-2016)
Biomass (kt C)	-182.31	-2.64	-119.27
Litter	208.03	45.6	225.37
Deadwood	81.79	60.21	44.84
Soils	-138.32	-94.75	-125.94
Sub-total C-CO_2	**112.98**	**-30.87**	**-91.67**
Fires CO_2 eq	12	12	41.87
N_2O and CH_4 drainage CO_2eq	127.75	10.91	128.29
HWP CO_2 eq	**-824.08**	**-134.09**	**-553.96**
Total	**-571.35**	**-142.07**	**-529.69**

Major reasons for the difference between the corrected estimate of FMRL (FMRLcorr) and the original FMRL include:

- The new version of the CARBWARE model (v5) is a dynamic model which provides more accurate estimates of biomass, litter and deadwood CSC over time. The older version 4.5 of the model 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 FRMRLcorr and FMRL values are compared (Table 11.14b)
- There was also changes to the litter pool turnover and decomposition rates in the new version of CARBWARE (Table 11.14b).
- Higher CO_2 and non-CO_2 emissions from soils inn the FMRLcorr due to the new Wetland supplement methodology (Table 11.14b).
- 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 11.14b).

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, Chapter 6). 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 1st 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, (para 2g(i and vii) of annex II of 2/CMP.8

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 Chapter 6).

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 uses for HWP are the default values as indicated in section 6.3.7.1 Chapter 6.

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 of Ch 6.

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 11.15). The emissions are excluded from accounting for the second commitment period by applying a corrected AR fraction (fARcorr) 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.

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 (fFM), land converted to forest (fAR) and deforested (fD) 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 11.15). The input information for the different activities (j) are derived from harvest data shown in Tables 6.24 and 6.25 Chapter 6 and in the CRF table 4(KP-1)C). All harvests for deforested land are assumed to be immediately oxidised by applying a fD corrected ratio of zero (fDcorr, Table 11.15), so CSC in the CRF under HWP are reported as instantaneous oxidation (IO) under in CRF table 4(KP-1)C.

Table 11.15 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 form AR lands for the 1st 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	2.41E-03	IO	1.00
1991	NO	NO	2.28E-03	IO	1.00
1992	NO	NO	1.94E-03	IO	1.00
1993	NO	NO	1.92E-03	IO	1.00
1994	NO	NO	1.77E-03	IO	1.00
1995	NO	NO	0.03	IO	0.97
1996	NO	NO	0.03	IO	0.97
1997	NO	NO	0.03	IO	0.97
1998	NO	NO	0.02	IO	0.98
1999	NO	NO	0.02	IO	0.98
2000	NO	NO	0.06	IO	0.94
2001	NO	NO	0.06	IO	0.94
2002	NO	NO	0.06	IO	0.94
2003	NO	NO	0.06	IO	0.94
2004	NO	NO	0.06	IO	0.94
2005	NO	NO	0.06	IO	0.94
2006	NO	NO	0.32	IO	0.68
2007	0.03	0.03	0.14	IO	0.83
2008	9.71E-03	IO	0.10	IO	0.89
2009	8.69E-02	IO	0.09	IO	0.83
2010	5.34E-02	IO	0.04	IO	0.91
2011	6.19E-02	IO	0.04	IO	0.90
2012	3.90E-02	IO	0.04	IO	0.93
2013	0.06	0.06	4.60E-03	IO	0.93
2014	0.28	0.28	0.01	IO	0.71
2015	0.18	0.18	9.52E-03	IO	0.81
2016	0.21	0.21	5.91E-03	IO	0.78

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_2 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 $\mathbf{f_{IRW}}$ 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 Chapter 6). The $\mathbf{f_{IRW}}$ 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 0.91 by 2016. This decrease is consistent with an increase utilisation of timber for energy purposes in Ireland.

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 Chapter3 Vol 1 of the 2006 IPCC guidelines (see equations 6.3.34 and 6.3.35, Chapter 6).

For detailed characterisation of individual uncertainties refer to sections 6.3.4.9 (FM), 6.3.5.9 (AR), 6.3.6.1.3 (D) and 6.3.7.1 (HWP) Chapter 6. Note that the uncertainty estimates for HWP in AR lands is different due to the exclusion of feedstock for 2008-2012.

Table 11.16 Uncertainty estimates of forest activity estimates.

		Combined uncertainty in year (±%)			
Activity	**CRF table**	**2013**	**2014**	**2015**	**2016**
AR	4(KP-I)A.1	20.28	20.28	20.31	20.71
	4(KP-I)C	24.24	24.24	24.24	24.28
	4(KP-II)2	94.19	93.87	94.06	94.03
	4(KP-II)4	52.2	52.20	52.20	52.20
Total		**20.81**	**21.22**	**20.58**	**21.00**
D	4(KP-I)A.2	120.1	85.97	68.51	108.44
	4(KP-II)2	154.43	153.17	150.14	150.13
	4(KP-II)3	66	66.00	66.00	66.00
Total		**140.13**	**121.41**	**105.29**	**131.92**
FM	4(KP-I)A.1	5687.51	2195.40	329.00	266.04
	4(KP-I)C	24.28	24.24	24.31	24.50
	4(KP-II)2	78.52	78.52	78.52	78.52
	4(KP-II)4	59.36	59.36	59.36	59.36
Total		**126.33**	**209.46**	**105.90**	**181.46**
CM	4(KP-I) B.2	72.15	72.15	72.15	72.15
GM	4(KP-I) B.3	90.83	72.15	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 Autumn 2017. This provides an important element of quality assurance for this 2016 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 element 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 2018 submission are:

Deforestation to settlements: - There was an error in the calculation of emissions of CO_2 from organic soils for forest land converted to settlements for the inventory year 2006 to 2014. The error was corrected, but had a very small effect on the net emission from this subcategory.
Cropland Management: - Refinement of the analysis of the LPIS spatial dataset; Revision of the activity for biomass burning. Further information on these recalculations is presented in section 6.4.11.
Grazing land Management: - Revised assessment of land area statistics and management practices.: Revision of the activity for biomass burning. Further information on these recalculations is presented in section 6.5.7.

12 Information on Accounting of Kyoto Units

12.1 Background Information

Ireland's Standard Electronic Format report for the 2017 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 2017 reported year (second commitment period):

RREG1_IE_2017_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 2017 reporting period (second commitment period):

There were ZERO AAUs in Ireland's domain of the Union Registry at the end of the year 2017.

There was 5,255,000 CERs in the registry at the end of 2017: all of which were held in the entity holding accounts.

There was 74,964 ERUs in the registry at the end of 2017; all of which were held in the entity holding accounts.

There were ZERO t-CERs in the registry at the end of 2017.

There were ZERO RMUs in the registry at the end of 2017.

The registry did not contain any l-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 5,329,964 tonnes CO_2 eq.

Ireland's assigned amount for the second commitment period is 343,519,892 tonnes CO_2eq. as indicated in FCCC/IRR/2016/IRL.

Table 12.1 Information on the SEF tables

Annual Submission Item	Reported for 2017
15/CMP.1 annex I.E paragraph 11: Standard electronic format (SEF)	Ireland's Standard Electronic Format report for the 2017 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 RREG1_IE_2017_2_2.xlsx The contents of the SEF reports (R1) can also be found in Appendix 1 – *SIAR Supplementary Information* of this document. The contents of the report can also be found in annex 6 of this document.

12.3 Discrepancies and notifications

For the 2017 reporting period (second commitment period), there were no discrepant transactions, no CDM notifications, no non-replacements and no invalid units in 2017. Accordingly, no actions were taken or changes made to address discrepancies for the 2017 reporting period (Table 12.2).

Table 12.2 Discrepancies and notifications

Annual Submission Item	Reported for 2017
15/CMP.1 annex I.E paragraph 12: List of discrepant transactions	No discrepant transactions, pursuant of 15/CMP.1 annex I.E paragraph 12, occurred for the 2017 reporting period (second commitment period). The contents of the report R2 can also be found in the Appendix 1 – *SIAR Supplementary Information* of this document. Refer to Separate Electronic Attachments for the 2017 reporting period (second commitment period): RREG2_IE_2017_2_1.xlsx
15/CMP.1 annex I.E paragraph 13 & 14: List of CDM notifications	No CDM notifications were received for the 2017 reporting period (second commitment period), pursuant of 15/CMP.1 annex I.E paragraphs 13 & 14. The contents of the Report R3 can also be found in Appendix 1 – *SIAR Supplementary Information* of this document. Refer to Separate Electronic Attachments for the 2017 reporting period (second commitment period): RREG3_IE_2017_2_1.xlsx

Annual Submission Item	Reported for 2017
15/CMP.1 annex I.E paragraph 15: List of non-replacements	No non-replacements occurred for the 2017 reporting period (second commitment period), pursuant of 15/CMP.1 annex I.E paragraph 15. The contents of the Report R4 can be found in Appendix 1 – *SIAR Supplementary Information* of this document. Refer to Separate Electronic Attachments for the 2017 reporting period (second commitment period): RREG4_IE_2017_2_1.xlsx
15/CMP.1 annex I.E paragraph 16: List of invalid units	No invalid units exist for the 2017 reporting period (second commitment period), as at 31 December 2017, pursuant of 15/CMP.1 annex I.E paragraph 16. The contents of the Report R5 can also be found in Appendix 1 – SIAR Supplementary Information of this document. Refer to Separate Electronic Attachments for the 2017 reporting period (second commitment period): RREG5_IE_2017_2_1.xlsx
15/CMP.1 annex I.E paragraph 17 Actions and changes to address discrepancies	No actions were taken or changes made to address discrepancies for the second commitment period for the 2017 reporting period.

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 2017
15/CMP.1 annex I.E Publicly accessible information	There was no change regarding publicly accessible information during 2017. The following information is publicly accessible and is available via the homepage of Ireland's domain on the Union Registry – https://ets-registry.webgate.ec.europa.eu/euregistry/IE/public/reports/publicReports.xhtml See also the EPA website: http://www.epa.ie/climate/emissionstradingoverview/union%20registry/publicreports 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.
	Account Information (Paragraph 45) In line with the data protection requirements of Regulation (EC) No 45/2001 and Directive 95/46/EC 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. The most up-to-date account information may be accessed via the homepage of Ireland's domain on the Union Registry https://ets-registry.webgate.ec.europa.eu/euregistry/IE/public/reports/publicReports.xhtml See also the EPA website: http://www.epa.ie/climate/emissionstradingoverview/union%20registry/publicreports

Annual Submission Item	Reported for 2017
	JI projects in Ireland (Paragraph 46) 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.
	Holding and transaction information of units (Paragraph 47) Holding and transaction information is provided on a holding type level, due to more detailed information being declared confidential. The detailed information on transactions is considered confidential according to Article 110 of Commission Regulation (EU) No 389/2013: *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.* The most up-to-date account information may be accessed via the homepage of Ireland's domain on the Union Registry https://ets-registry.webgate.ec.europa.eu/euregistry/IE/public/reports/publicReports.xhtml See also the EPA website: http://www.epa.ie/climate/emissionstradingoverview/union%20registry/publicreports
15/CMP.1 annex I.E Publicly accessible information	Paragraph 47c For the 2017 reporting period (second commitment period): Ireland does not host JI projects. Paragraph 47e For the 2017 reporting period (second commitment period): Ireland does not perform LULUCF activities and therefore does not issue RMUs. Paragraph 47g For the 2017 reporting period (second commitment period):

Annual Submission Item	Reported for 2017
	No ERUs, CERs, AAUs and RMUs have been cancelled on the basis of activities under Article 3, paragraphs 3 and 4 to date. Paragraph 47h For the 2017 reporting period (second commitment 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. Paragraph 47j For the 2017 reporting period (second commitment period): No ERUs, CERs, AAUs and RMUs have been retired to date Paragraph 47k Ireland requests to carry over 7,816,073 AAUs; 5,255,000 CERs and 74,964 ERUs from the first to the second commitment period of the Kyoto Protocol. 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. 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. 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: http://unfccc.int/kyoto_protocol/reporting/true-up_period_reports_under_the_kyoto_protocol/items/9049.php
	Entities authorised to hold Kyoto Units (Paragraph 48) In line with the data protection requirements of Regulation (EC) No 45/2001 and Directive 95/46/EC 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. The most up-to-date account information may be accessed via the homepage of Ireland's domain on the Union Registry https://ets-registry.webgate.ec.europa.eu/euregistry/IE/public/reports/publicReports.xhtml

Annual Submission Item	Reported for 2017
	See also the EPA website: http://www.epa.ie/climate/emissionstradingoverview/union%20registry/publicreports

12.5 Calculation of the Commitment Period Reserve

For the 2017 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_2 eq for the second commitment period as outlined in Table 3 of the report, 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 [FCCC/IRR/2016/IRL].

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.

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 were no changes to the national system of Ireland in 2017.

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 2017.

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	The version of the EUCR released after Version 8.0.7 (the production version at the time of the last Chapter 14 submission) introduced minor changes in the structure of the database. These changes were limited and only affected EU ETS functionality. No change was required to the database and application backup plan or to the disaster recovery plan. The database model is provided in **Annex A** - this is provided in electronic form as Appendix 1 *SIAR Supplementary Information* to the NIR. No change to the capacity of the national registry occurred during the reporting period.

Reporting Item	Description
15/CMP.1 annex II.E paragraph 32.(d) Change regarding conformance to technical standards	Changes introduced since Version 8.0.7 of the national registry are listed in **Annex B** – this is provided in electronic form as Appendix 1 *SIAR Supplementary Information* to the NIR. 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 were successfully carried out prior to the relevant major release of the version to Production (see Annex B). No other change in the registry's conformance to the technical standards occurred during the reporting period.
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	No changes regarding security occurred during the reporting period.
15/CMP.1 annex II.E paragraph 32.(g) Change to list of publicly available information	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 – https://ets-registry.webgate.ec.europa.eu/euregistry/IE/public/reports/publicReports.xhtml See also the EPA website: http://www.epa.ie/climate/emissionstradingoverview/union%20registry/publicreports 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.
	Account Information (Paragraph 45)

Reporting Item	Description
	In line with the data protection requirements of Regulation (EC) No 45/2001 and Directive 95/46/EC 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. The most up-to-date account information may be accessed via the homepage of Ireland's domain on the Union Registry – https://ets-registry.webgate.ec.europa.eu/euregistry/IE/public/reports/publicReports.xhtml See also the EPA website: http://www.epa.ie/climate/emissionstradingoverview/union%20registry/publicreports
	JI projects in Ireland (Paragraph 46) 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.
	Holding and transaction information of units (Paragraph 47) Holding and transaction information is provided on a holding type level, due to more detailed information being declared confidential. The detailed information on transactions is considered confidential according to Article 110 of Commission Regulation (EU) No 389/2013: *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.*

Reporting Item	Description
	The most up-to-date information may be accessed via the homepage of Ireland's domain on the Union Registry – https://ets-registry.webgate.ec.europa.eu/euregistry/IE/public/reports/publicReports.xhtml See also the EPA website: http://www.epa.ie/climate/emissionstradingoverview/union%20registry/publicreports
	Paragraph 47c For the 2017 reporting period (second commitment period): Ireland does not host JI projects. Paragraph 47e For the 2017 reporting period (second commitment period): Ireland does not perform LULUCF activities and therefore does not issue RMUs Paragraph 47g For the 2017 reporting period (second commitment period): No ERUs, CERs, AAUs and RMUs have been cancelled on the basis of activities under Article 3, paragraphs 3 and 4 to date. Paragraph 47h For the 2017 reporting period (second commitment 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. Paragraph 47j For the 2017 reporting period (second commitment period): No ERUs, CERs, AAUs and RMUs have been retired to date

Reporting Item	Description
	Paragraph 47k Ireland requests to carry over 7,816,073 AAUs; 5,255,000 CERs and 74,964 ERUs from the first to the second commitment period of the Kyoto Protocol. 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. 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. 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: http://unfccc.int/kyoto_protocol/reporting/true-up_period_reports_under_the_kyoto_protocol/items/9049.php
	Entities authorised to hold Kyoto Units (Paragraph 48) In line with the data protection requirements of Regulation (EC) No 45/2001 and Directive 95/46/EC 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. The most up-to-date account information may be accessed via the homepage of Ireland's domain on the Union Registry – https://ets-registry.webgate.ec.europa.eu/euregistry/IE/public/reports/publicReports.xhtml See also the EPA website: http://www.epa.ie/climate/emissionstradingoverview/union%20registry/publicreports

Reporting Item	Description
15/CMP.1 annex II.E paragraph 32.(h) Change of Internet address	No change of the registry internet address occurred during the reporting period. Ireland's domain of the Union Registry can be found at this link: https://ets-registry.webgate.ec.europa.eu/euregistry/IE/public/reports/publicReports.xhtml
15/CMP.1 annex II.E paragraph 32.(i) Change regarding data integrity measures	No change of data integrity measures occurred during the reporting period.
15/CMP.1 annex II.E paragraph 32.(j) Change regarding test results	Changes introduced since Version 8.0.7 of the national registry are listed in **Annex B** – this is provided in electronic form as Appendix 1 *SIAR Supplementary Information* to the NIR. Both regression testing and tests on the new functionality were successfully carried out prior to release of the version to Production. The site acceptance test was carried out by quality assurance consultants on behalf of and assisted by the European Commission; the report is attached as **Annex B.**
The previous Annual Review Recommendations	No recommendations relevant to registry operations in FCCC/IRR/2016/IRL of 20 July 2017.

15 Minimisation of Adverse Impacts under Article 3, paragraph14

15.1 Introduction

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_2 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_2. 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

Annex 1 Parties	Countries listed in Annex I to the United Nations Framework Convention on Climate Change
Base year	The year or period under the Kyoto Protocol on which quantified emission limitation or reduction commitments in the commitment period are based.
BOD	Biochemical Oxygen Demand
CARBWARE	A forest model to calculate carbon stock change and growth increment for Irish forests
CFCs	Chlorofluorocarbons
CH_4	Methane
CHP	Combined Heat and Power.
CMMS	Cattle Movement and Monitoring System
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CO_2 equivalent	The equivalent mass as CO_2 of other greenhouse gases converted on the basis of their global warming potential (GWP)
COFORD	National Council for Forest Research and Development
Commitment Period	The years 2008 to 2012 (first CP) or 2013 to 2020 (second CP) inclusive for which quantified emission limitation or reduction commitments are established under the Kyoto Protocol
COP	Conference of the Parties
CORINAIR	Co-ordinated Information on the environment in the European Community-AIR. CORINAIR was one of several collaborative exercises initiated under the CORINE programme to harmonise the collection and dissemination of information on the environment in the EU.
CRF	Common Reporting Format
DAF	Department of Agriculture and Food
DAFM	Department of Agriculture, Food and the Marine
DCENR	Department of Communications, Energy and Natural Resources
DEHLG	Department of Environment Heritage and Local Government
DNDC	DeNitrification-DeComposition, is a computer simulation model of carbon and nitrogen biogeochemistry in agri-ecosystems
EMEP	European Monitoring and Evaluation Programme, a co-operative programme for monitoring and evaluation of the long-range transmissions of air pollutants in Europe
Emission	(of a greenhouse gas). The release of greenhouse gases into the atmosphere.
Enteric Fermentation	The digestive process in ruminant animals (e.g cattle and sheep) where bacteria convert the feed to a usable form of energy for the animal, producing CH_4 as a by product
EUROSTAT	Statistical Agency of the European Union
FAO	Food and Agriculture Organisation of the United Nations
FFS	Farm Facilities Survey
FIPS	Forest Inventory and Planning System
Fluorinated Gases	HFCs, PFCs, SF_6 and NF_3

Fossil Fuel	Peat, coal, oil and natural gas and associated derivatives
FTA	Fraction of BOD in sludge that degrades anaerobically
GDP	Gross Domestic Product
Gg	Gigagram (10^9 g) = kilo tonne = 1,000 tonnes
Greenhouse Gas	A gas in the atmosphere that allows solar radiation through to the earth's surface, but traps some of the heat radiated back from the earth's surface
GWP	The cumulative warming over a specified time period, e.g. 100 years, resulting from a unit mass of a greenhouse gas emitted at the beginning of that time period, expressed relative to an absolute GWP of 1 for CO_2
HCFCs	Hydrochlorofluorocarbon
HFCs	Hydrofluorocarbons
HGV	Heavy Goods Vehicle
IEA	International Energy Agency
IEF	Implied Emission Factor
IPC	Integrated Pollution Control
IPCC	Intergovernmental Panel on Climate Change
IUCC	Information Unit on Climate Change
kt	kilo tonne (1,000 tonnes)
Kyoto Protocol	The Protocol to the UNFCCC adopted by Decision 1/CP.3 under which industrialised countries agreed to reduce their combined greenhouse gas emissions in 1990 by at least 5 per cent by the period 2008-2012
LTO	Landing and Take-off cycle
MMS	Manure Management System
Montreal Protocol	Protocol on substances that deplete the ozone layer
Mt	million tonnes or mega tonnes
N_2O	Nitrous Oxide
NBP	Net Biome Productivity
NEE	Net Ecosystem Exchange
NF_3	Nitrogen trifluoride
NIR	National Inventory Report
NMVOC	Non Methane Volatile Organic Compounds
NO_x	Nitrogen Oxides
NRA	National Roads Authority
OSPAR	Oslo and Paris Convention for the Protection of the Marine Environment
PFCs	Perfluorocarbons
SBSTA	Subsidiary Body for Scientific and Technological Advice
SEAI	Sustainable Energy Authority of Ireland
SF_6	Sulphur Hexafluoride
Sink	The reservoir or pool in which sequestered carbon is stored; the process of sequestration
SO_2	Sulphur Dioxide
Teagasc	Irish Agriculture and Food Development Authority
TPER	Total Primary Energy Requirement
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
VOC	Volatile Organic Compounds

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Annex 1

Key Category Analyses

1.A 2016 Key Category Analysis Level Assessment excluding LULUCF

1.B 2016 Key Category Analysis Level Assessment including LULUCF

1.C 2016 Key Category Analysis Trend Assessment excluding LULUCF

1.D 2016 Key Category Analysis Trend Assessment including LULUCF

1.E Information on the level of disaggregation

1.F Description of methodology used for identifying key categories

Table 1.A   2016 Key Category Analysis Level Assessment excluding LULUCF

Ranking	IPCC Sub-Category	Emission Source / Activity	Direct GHG	Value (Kt CO_2 eq)	2016 Level assessment (%)	Cumulative total (%)
1	1.A.3.b	Road Transport - Liquid Fuels	CO2	11623.55	18.89	18.89
2	3.A.1	Enteric Fermentation - Non-Dairy Cattle	CH4	6697.92	10.88	29.77
3	3.D.1	Agricultural Soils - Direct Soil Emissions	N2O	5062.89	8.23	38.00
4	1.A.1	Energy Industries - Gaseous Fuels	CO2	4896.48	7.96	45.95
5	1.A.1	Energy Industries - Solid Fuels	CO2	4281.83	6.96	52.91
6	3.A.1	Enteric Fermentation - Dairy Cattle	CH4	3780.92	6.14	59.05
7	1.A.4.b	Residential - Liquid Fuels	CO2	3008.64	4.89	63.94
8	1.A.1	Energy Industries - Peat Fuel	CO2	2600.14	4.22	68.16
9	1.A.2	Manufacturing Industries & Construction - Gaseous Fuels	CO2	2372.52	3.85	72.02
10	2.A.1	Cement Production	CO2	1793.52	2.91	74.93
11	1.A.2	Manufacturing Industries & Construction - Liquid Fuels	CO2	1556.14	2.53	77.46
12	1.A.4.b	Residential - Gaseous Fuels	CO2	1316.51	2.14	79.60
13	1.A.4.a	Commercial/Institutional - Gaseous Fuels	CO2	1094.85	1.78	81.38
14	2.F.1	Product Uses as Substitutes for ODS -Refrigeration and air-con (incl. MAC)	HFC	1021.89	1.66	83.04
15	1.A.4.b	Residential - Peat Fuel	CO2	842.41	1.37	84.41
16	5.A	Solid Waste Disposal	CH4	767.78	1.25	85.66
17	1.A.4.a	Commercial/Institutional - Liquid Fuels	CO2	756.06	1.23	86.88
18	1.A.4.b	Residential - Solid Fuels	CO2	721.27	1.17	88.06
19	3.A.2	Enteric Fermentation - Sheep	CH4	670.59	1.09	89.15
20	3.B.1.1	Manure Management - Non-Dairy Cattle	CH4	640.79	1.04	90.19
21	1.A.4.c	Agriculture/Fishing - Liquid Fuels	CO2	547.83	0.89	91.08
22	3.D.2	Agricultural Soils - Indirect Soil Emissions	N2O	535.95	0.87	91.95
23	1.A.1	Energy Industries - Liquid Fuels	CO2	503.82	0.82	92.77
24	1.A.2	Manufacturing Industries & Construction - Solid Fuels	CO2	436.33	0.71	93.48
25	3.G.1	Liming - Limestone CaCO3	CO2	425.60	0.69	94.17
26	3.B.1.1	Manure Management - Dairy Cattle	CH4	344.28	0.56	94.73
27	1.A.3.d	Navigation - Liquid Fuels	CO2	263.69	0.43	95.16
28	3.B.1.3	Manure Management - Swine	CH4	260.35	0.42	95.58
29	3.B.2.1	Manure Management - Non-Dairy Cattle	N2O	240.61	0.39	95.97
30	3.B.2.5	Manure Management - Indirect N2O emissions	N2O	211.97	0.34	96.31
31	2.A.2	Lime Production	CO2	173.90	0.28	96.60
32	1.A.2	Manufacturing Industries & Construction - Non-Renewable waste	CO2	161.96	0.26	96.86
33	1.A.3.e	Other Transport - Gaseous Fuels	CO2	139.90	0.23	97.09
34	2.F.4	Product Uses as Substitutes for ODS -Aerosols (incl. MDIs)	HFC	133.61	0.22	97.30
35	1.A.3.b	Road Transport - Liquid Fuels	N2O	114.11	0.19	97.49

Ranking	IPCC Sub-Category	Emission Source / Activity	Direct GHG	Value (Kt CO_2 eq)	2016 Level assessment (%)	Cumulative total (%)
36	1.A.3.c	Rail Transport - Liquid Fuels	CO2	111.93	0.18	97.67
37	3.B.1.4	Manure Management - Other livestock	CH4	97.29	0.16	97.83
38	5.D	Wastewater treatment and discharge	N2O	96.69	0.16	97.99
39	2.D.3	Solvents	CO2	87.76	0.14	98.13
40	1.A.1	Energy Industries - Other Fuels	CO2	86.12	0.14	98.27
41	1.A.1	Energy Industries - Gaseous Fuels	N2O	77.09	0.13	98.39
42	1.A.4.b	Residential - Peat Fuel	CH4	61.82	0.10	98.49
43	3.B.1.2	Manure Management - Sheep	CH4	59.52	0.10	98.59
44	2.E.1	Electronics Industry - Integrated circuit or semiconductor	HFC, PFC, SF6, NF3	57.04	0.09	98.68
45	1.A.4.b	Residential - Solid Fuels	CH4	56.14	0.09	98.78
46	3.A.3	Enteric Fermentation - Swine	CH4	52.21	0.08	98.86
47	1.A.4.c	Agriculture/Fishing - Liquid Fuels	N2O	51.74	0.08	98.94
48	5.D	Wastewater treatment and discharge	CH4	50.43	0.08	99.03
49	3.B.2.1	Manure Management - Dairy Cattle	N2O	48.29	0.08	99.10
50	3.A.4	Enteric Fermentation - Other livestock	CH4	45.63	0.07	99.18
51	1.A.1	Energy Industries - Peat Fuel	N2O	45.18	0.07	99.25
52	2.G.3.a	Other Product Manufacture and Use - Other (Anaesthesia in medical applications)	N2O	42.57	0.07	99.32
53	3.H.	Urea Application	CO2	35.80	0.06	99.38
54	2.F.3	Product Uses as Substitutes for ODS -Fire protection	HFC	32.45	0.05	99.43
55	5.C.1 & 2	Incineration and open burning of waste - Incineration (fossil C)	CO2	22.64	0.04	99.47
56	2.D.2	Paraffin wax use	CO2	21.55	0.04	99.50
57	2.D.1	Lube oil from Transport	CO2	20.56	0.03	99.54
58	1.B.2.b	Fugitive emissions - Natural gas	CH4	20.04	0.03	99.57
59	1.B.1.a	Fugitive Emissions - Coal Mining and Handling	CH4	19.24	0.03	99.60
60	2.G.1	Other Product Manufacture and Use - Electrical equipment	SF6	19.06	0.03	99.63
61	3.B.2.2	Manure Management - Sheep	N2O	14.83	0.02	99.66
62	1.A.3.b	Road Transport - Liquid Fuels	CH4	13.23	0.02	99.68
63	3.B.2.4	Manure Management - Other livestock	N2O	13.12	0.02	99.70
64	1.A.3.c	Rail Transport - Liquid Fuels	N2O	13.01	0.02	99.72
65	3.B.2.3	Manure Management - Swine	N2O	12.25	0.02	99.74
66	5.B.1	Biological treatment of solid waste - Composting	CH4	11.58	0.02	99.76
67	1.A.4.b	Residential - Liquid Fuels	CH4	10.31	0.02	99.78
68	1.A.4.b	Residential - Biomass	CH4	10.13	0.02	99.79
69	1.A.3.a	Domestic Aviation - Liquid Fuels	CO2	9.66	0.02	99.81
70	2.D.3	Urea based catalysts	CO2	9.06	0.01	99.82
71	1.A.1	Energy Industries - Biomass	N2O	8.78	0.01	99.84
72	1.A.2	Manufacturing Industries & Construction - Biomass	N2O	8.57	0.01	99.85

Ranking	IPCC Sub-Category	Emission Source / Activity	Direct GHG	Value (Kt CO_2 eq)	2016 Level assessment (%)	Cumulative total (%)
73	5.B.1	Biological treatment of solid waste - Composting	N2O	8.28	0.01	99.86
74	1.A.4.a	Commercial/Institutional - Biomass	CH4	8.18	0.01	99.88
75	1.A.4.b	Residential - Liquid Fuels	N2O	7.28	0.01	99.89
76	1.A.1	Energy Industries - Solid Fuels	N2O	6.87	0.01	99.90
77	1.A.2	Manufacturing Industries & Construction - Biomass	CH4	5.40	0.01	99.91
78	1.A.2	Manufacturing Industries & Construction - Peat Fuel	CO2	3.48	0.01	99.91
79	1.A.4.b	Residential - Peat Fuel	N2O	3.44	0.01	99.92
80	1.A.4.b	Residential - Solid Fuels	N2O	3.35	0.01	99.93
81	2.G.2	Other Product Manufacture and Use - SF6 and PFCs from other product use	SF6	3.24	0.01	99.93
82	1.A.4.b	Residential - Gaseous Fuels	CH4	2.95	0.00	99.94
83	1.A.2	Manufacturing Industries & Construction - Liquid Fuels	N2O	2.92	0.00	99.94
84	1.A.4.a	Commercial/Institutional - Liquid Fuels	CH4	2.54	0.00	99.94
85	1.A.4.a	Commercial/Institutional - Gaseous Fuels	CH4	2.45	0.00	99.95
86	1.A.1	Energy Industries - Gaseous Fuels	CH4	2.29	0.00	99.95
87	1.A.3.d	Navigation - Liquid Fuels	N2O	2.14	0.00	99.96
88	1.A.2	Manufacturing Industries & Construction - Solid Fuels	N2O	2.06	0.00	99.96
89	1.A.1	Energy Industries - Biomass	CH4	1.85	0.00	99.96
90	1.A.4.a	Commercial/Institutional - Liquid Fuels	N2O	1.80	0.00	99.97
91	1.A.1	Energy Industries - Peat Fuel	CH4	1.65	0.00	99.97
92	1.B.1.a	Fugitive Emissions - Coal Mining and Handling	CO2	1.61	0.00	99.97
93	1.A.4.b	Residential - Biomass	N2O	1.60	0.00	99.97
94	1.A.3.e	Other Transport - Gaseous Fuels	N2O	1.49	0.00	99.98
95	1.A.4.a	Commercial/Institutional - Biomass	N2O	1.30	0.00	99.98
96	1.A.2	Manufacturing Industries & Construction - Liquid Fuels	CH4	1.28	0.00	99.98
97	1.A.2	Manufacturing Industries & Construction - Gaseous Fuels	N2O	1.27	0.00	99.98
98	1.A.1	Energy Industries - Other Fuels	N2O	1.22	0.00	99.98
99	1.A.2	Manufacturing Industries & Construction - Solid Fuels	CH4	1.15	0.00	99.99
100	1.A.2	Manufacturing Industries & Construction - Gaseous Fuels	CH4	1.06	0.00	99.99
101	1.A.4.c	Agriculture/Fishing - Liquid Fuels	CH4	0.93	0.00	99.99
102	1.A.1	Energy Industries - Solid Fuels	CH4	0.81	0.00	99.99
103	2.A.4.a	Other process uses of carbonates - ceramics	CO2	0.78	0.00	99.99
104	1.A.1	Energy Industries - Other Fuels	CH4	0.77	0.00	99.99
105	1.A.4.b	Residential - Gaseous Fuels	N2O	0.70	0.00	99.99
106	1.A.3.d	Navigation - Liquid Fuels	CH4	0.63	0.00	100.00
107	1.A.4.a	Commercial/Institutional - Gaseous Fuels	N2O	0.58	0.00	100.00
108	1.B.2.a	Fugitive Emissions - Oil Refining	CH4	0.38	0.00	100.00
109	1.A.1	Energy Industries - Liquid Fuels	N2O	0.37	0.00	100.00

Ranking	IPCC Sub-Category	Emission Source / Activity	Direct GHG	Value (Kt CO_2 eq)	2016 Level assessment (%)	Cumulative total (%)
110	1.A.3.e	Other Transport - Gaseous Fuels	CH4	0.31	0.00	100.00
111	1.A.2	Manufacturing Industries & Construction - Non-Renewable waste	N2O	0.31	0.00	100.00
112	5.C.1 & 2	Incineration and open burning of waste - Incineration	N2O	0.24	0.00	100.00
113	2.A.4.d	Other process uses of carbonates - limestone	CO2	0.16	0.00	100.00
114	1.A.3.c	Rail Transport - Liquid Fuels	CH4	0.16	0.00	100.00
115	1.A.1	Energy Industries - Liquid Fuels	CH4	0.15	0.00	100.00
116	1.A.2	Manufacturing Industries & Construction - Non-Renewable waste	CH4	0.13	0.00	100.00
117	1.A.3.a	Domestic Aviation - Liquid Fuels	N2O	0.13	0.00	100.00
118	5.C.1 & 2	Incineration and open burning of waste - Incineration	CH4	0.07	0.00	100.00
119	2.A.4.b	Other process uses of carbonates - soda ash	CO2	0.04	0.00	100.00
120	1.A.2	Manufacturing Industries & Construction - Peat Fuel	N2O	0.02	0.00	100.00
121	1.A.3.a	Domestic Aviation - Liquid Fuels	CH4	0.01	0.00	100.00
122	1.A.2	Manufacturing Industries & Construction - Peat Fuel	CH4	0.00	0.00	100.00

Table 1.B 2016 Key Category Analysis Level Assessment including LULUCF

Ranking	IPCC Sub-Category	Emission Source / Activity	Direct GHG	Absolute Value (Kt CO_2 eq)	2016 Level assessment (%)	Cumulative total (%)
1	1.A.3.b	Road Transport - Liquid Fuels	CO2	11,623.55	15.27	15.27
2	4.C	LULUCF - Grassland	CO2	6,889.15	9.05	24.33
3	3.A.1	Enteric Fermentation - Non-Dairy Cattle	CH4	6,697.92	8.80	33.13
4	3.D.1	Agricultural Soils - Direct Soil Emissions	N2O	5,062.89	6.65	39.78
5	1.A.1	Energy Industries - Gaseous Fuels	CO2	4,896.48	6.43	46.21
6	1.A.1	Energy Industries - Solid Fuels	CO2	4,281.83	5.63	51.84
7	3.A.1	Enteric Fermentation - Dairy Cattle	CH4	3,780.92	4.97	56.81
8	4.A.2	LULUCF - Land Converted to Forest Land	CO2	3,692.46	4.85	61.66
9	1.A.4.b	Residential - Liquid Fuels	CO2	3,008.64	3.95	65.61
10	1.A.1	Energy Industries - Peat Fuel	CO2	2,600.14	3.42	69.03
11	1.A.2	Manufacturing Industries & Construction - Gaseous Fuels	CO2	2,372.52	3.12	72.15
12	4.D	LULUCF - Wetlands	CO2	2,061.28	2.71	74.85
13	2.A.1	Cement Production	CO2	1,793.52	2.36	77.21
14	1.A.2	Manufacturing Industries & Construction - Liquid Fuels	CO2	1,556.14	2.04	79.26
15	1.A.4.b	Residential - Gaseous Fuels	CO2	1,316.51	1.73	80.99
16	1.A.4.a	Commercial/Institutional - Gaseous Fuels	CO2	1,094.85	1.44	82.42
17	2.F.1	Product Uses as Substitutes for ODS -Refrigeration and air-con (incl. MAC)	HFC	1,021.89	1.34	83.77
18	1.A.4.b	Residential - Peat Fuel	CO2	842.41	1.11	84.87
19	4.G	LULUCF - Harvested wood products	CO2	799.52	1.05	85.92
20	5.A	Solid Waste Disposal	CH4	767.78	1.01	86.93
21	1.A.4.a	Commercial/Institutional - Liquid Fuels	CO2	756.06	0.99	87.93
22	1.A.4.b	Residential - Solid Fuels	CO2	721.27	0.95	88.87
23	3.A.2	Enteric Fermentation - Sheep	CH4	670.59	0.88	89.76
24	3.B.1.1	Manure Management - Non-Dairy Cattle	CH4	640.79	0.84	90.60
25	1.A.4.c	Agriculture/Fishing - Liquid Fuels	CO2	547.83	0.72	91.32
26	3.D.2	Agricultural Soils - Indirect Soil Emissions	N2O	535.95	0.70	92.02
27	1.A.1	Energy Industries - Liquid Fuels	CO2	503.82	0.66	92.68
28	1.A.2	Manufacturing Industries & Construction - Solid Fuels	CO2	436.33	0.57	93.26
29	3.G.1	Liming - Limestone CaCO3	CO2	425.60	0.56	93.82
30	3.B.1.1	Manure Management - Dairy Cattle	CH4	344.28	0.45	94.27
31	1.A.3.d	Navigation - Liquid Fuels	CO2	263.69	0.35	94.62
32	3.B.1.3	Manure Management - Swine	CH4	260.35	0.34	94.96
33	3.B.2.1	Manure Management - Non-Dairy Cattle	N2O	240.61	0.32	95.27
34	4.C	LULUCF - Grassland	CH4	240.02	0.32	95.59
35	3.B.2.5	Manure Management - Indirect N2O emissions	N2O	211.97	0.28	95.87
36	4.A.1	LULUCF - Forest land Remaining Forest Land	CO2	183.46	0.24	96.11
37	4.A	LULUCF - Forest land	N2O	175.88	0.23	96.34
38	2.A.2	Lime Production	CO2	173.90	0.23	96.57
39	1.A.2	Manufacturing Industries & Construction - Non-Renewable waste	CO2	161.96	0.21	96.78
40	1.A.3.e	Other Transport - Gaseous Fuels	CO2	139.90	0.18	96.96
41	2.F.4	Product Uses as Substitutes for ODS -Aerosols (incl. MDIs)	HFC	133.61	0.18	97.14
42	4.B.1	LULUCF - Cropland Remaining Cropland	CO2	131.93	0.17	97.31
43	1.A.3.b	Road Transport - Liquid Fuels	N2O	114.11	0.15	97.46

Ranking	IPCC Sub-Category	Emission Source / Activity	Direct GHG	Absolute Value (Kt CO_2 eq)	2016 Level assessment (%)	Cumulative total (%)
44	1.A.3.c	Rail Transport - Liquid Fuels	CO2	111.93	0.15	97.61
45	3.B.1.4	Manure Management - Other livestock	CH4	97.29	0.13	97.74
46	5.D	Wastewater treatment and discharge	N2O	96.69	0.13	97.87
47	4.E.2	LULUCF - Land Converted to Settlements	CO2	91.06	0.12	97.99
48	2.D.3	Solvents	CO2	87.76	0.12	98.10
49	1.A.1	Energy Industries - Other Fuels	CO2	86.12	0.11	98.21
50	1.A.1	Energy Industries - Gaseous Fuels	N2O	77.09	0.10	98.31
51	4.E	LULUCF - Settlements	N2O	77.02	0.10	98.42
52	4.A	LULUCF - Forest land	CH4	69.88	0.09	98.51
53	4.D	LULUCF - Wetlands	CH4	64.97	0.09	98.59
54	1.A.4.b	Residential - Peat Fuel	CH4	61.82	0.08	98.67
55	3.B.1.2	Manure Management - Sheep	CH4	59.52	0.08	98.75
56	2.E.1	Electronics Industry - Integrated circuit or semiconductor	HFC, PFC, SF6, NF3	57.04	0.07	98.83
57	1.A.4.b	Residential - Solid Fuels	CH4	56.14	0.07	98.90
58	3.A.3	Enteric Fermentation - Swine	CH4	52.21	0.07	98.97
59	1.A.4.c	Agriculture/Fishing - Liquid Fuels	N2O	51.74	0.07	99.04
60	5.D	Wastewater treatment and discharge	CH4	50.43	0.07	99.10
61	4.F.2	LULUCF - Land Converted to Other Land	N2O	50.29	0.07	99.17
62	3.B.2.1	Manure Management - Dairy Cattle	N2O	48.29	0.06	99.23
63	3.A.4	Enteric Fermentation - Other livestock	CH4	45.63	0.06	99.29
64	1.A.1	Energy Industries - Peat Fuel	N2O	45.18	0.06	99.35
65	2.G.3.a	Other Product Manufacture and Use - Other (Anaesthesia in medical applications)	N2O	42.57	0.06	99.41
66	3.H.	Urea Application	CO2	35.80	0.05	99.46
67	2.F.3	Product Uses as Substitutes for ODS -Fire protection	HFC	32.45	0.04	99.50
68	5.C.1 & 2	Incineration and open burning of waste - Incineration (fossil C)	CO2	22.64	0.03	99.53
69	2.D.2	Paraffin wax use	CO2	21.55	0.03	99.56
70	2.D.1	Lube oil from Transport	CO2	20.56	0.03	99.58
71	1.B.2.b	Fugitive emissions - Natural gas	CH4	20.04	0.03	99.61
72	1.B.1.a	Fugitive Emissions - Coal Mining and Handling	CH4	19.24	0.03	99.64
73	2.G.1	Other Product Manufacture and Use - Electrical equipment	SF6	19.06	0.03	99.66
74	4.F.2	LULUCF - Land Converted to Other Land	CO2	15.21	0.02	99.68
75	3.B.2.2	Manure Management - Sheep	N2O	14.83	0.02	99.70
76	1.A.3.b	Road Transport - Liquid Fuels	CH4	13.23	0.02	99.72
77	3.B.2.4	Manure Management - Other livestock	N2O	13.12	0.02	99.73
78	1.A.3.c	Rail Transport - Liquid Fuels	N2O	13.01	0.02	99.75
79	3.B.2.3	Manure Management - Swine	N2O	12.25	0.02	99.77
80	5.B.1	Biological treatment of solid waste - Composting	CH4	11.58	0.02	99.78
81	4.D	LULUCF - Wetlands	N2O	10.98	0.01	99.80
82	1.A.4.b	Residential - Liquid Fuels	CH4	10.31	0.01	99.81
83	1.A.4.b	Residential - Biomass	CH4	10.13	0.01	99.82
84	1.A.3.a	Domestic Aviation - Liquid Fuels	CO2	9.66	0.01	99.84
85	2.D.3	Urea based catalysts	CO2	9.06	0.01	99.85
86	1.A.1	Energy Industries - Biomass	N2O	8.78	0.01	99.86

Ranking	IPCC Sub-Category	Emission Source / Activity	Direct GHG	Absolute Value (Kt CO_2 eq)	2016 Level assessment (%)	Cumulative total (%)
87	1.A.2	Manufacturing Industries & Construction - Biomass	N2O	8.57	0.01	99.87
88	5.B.1	Biological treatment of solid waste - Composting	N2O	8.28	0.01	99.88
89	1.A.4.a	Commercial/Institutional - Biomass	CH4	8.18	0.01	99.89
90	1.A.4.b	Residential - Liquid Fuels	N2O	7.28	0.01	99.90
91	1.A.1	Energy Industries - Solid Fuels	N2O	6.87	0.01	99.91
92	4.C.1	LULUCF - Grassland Remaining Grassland	N2O	5.77	0.01	99.92
93	1.A.2	Manufacturing Industries & Construction - Biomass	CH4	5.40	0.01	99.93
94	1.A.2	Manufacturing Industries & Construction - Peat Fuel	CO2	3.48	0.00	99.93
95	1.A.4.b	Residential - Peat Fuel	N2O	3.44	0.00	99.94
96	1.A.4.b	Residential - Solid Fuels	N2O	3.35	0.00	99.94
97	2.G.2	Other Product Manufacture and Use - SF6 and PFCs from other product use	SF6	3.24	0.00	99.94
98	1.A.4.b	Residential - Gaseous Fuels	CH4	2.95	0.00	99.95
99	1.A.2	Manufacturing Industries & Construction - Liquid Fuels	N2O	2.92	0.00	99.95
100	1.A.4.a	Commercial/Institutional - Liquid Fuels	CH4	2.54	0.00	99.96
101	1.A.4.a	Commercial/Institutional - Gaseous Fuels	CH4	2.45	0.00	99.96
102	1.A.1	Energy Industries - Gaseous Fuels	CH4	2.29	0.00	99.96
103	1.A.3.d	Navigation - Liquid Fuels	N2O	2.14	0.00	99.96
104	1.A.2	Manufacturing Industries & Construction - Solid Fuels	N2O	2.06	0.00	99.97
105	1.A.1	Energy Industries - Biomass	CH4	1.85	0.00	99.97
106	1.A.4.a	Commercial/Institutional - Liquid Fuels	N2O	1.80	0.00	99.97
107	1.A.1	Energy Industries - Peat Fuel	CH4	1.65	0.00	99.97
108	1.B.1.a	Fugitive Emissions - Coal Mining and Handling	CO2	1.61	0.00	99.98
109	1.A.4.b	Residential - Biomass	N2O	1.60	0.00	99.98
110	1.A.3.e	Other Transport - Gaseous Fuels	N2O	1.49	0.00	99.98
111	1.A.4.a	Commercial/Institutional - Biomass	N2O	1.30	0.00	99.98
112	1.A.2	Manufacturing Industries & Construction - Liquid Fuels	CH4	1.28	0.00	99.98
113	1.A.2	Manufacturing Industries & Construction - Gaseous Fuels	N2O	1.27	0.00	99.99
114	1.A.1	Energy Industries - Other Fuels	N2O	1.22	0.00	99.99
115	1.A.2	Manufacturing Industries & Construction - Solid Fuels	CH4	1.15	0.00	99.99
116	1.A.2	Manufacturing Industries & Construction - Gaseous Fuels	CH4	1.06	0.00	99.99
117	1.A.4.c	Agriculture/Fishing - Liquid Fuels	CH4	0.93	0.00	99.99
118	1.A.1	Energy Industries - Solid Fuels	CH4	0.81	0.00	99.99
119	2.A.4.a	Other process uses of carbonates - ceramics	CO2	0.78	0.00	99.99
120	1.A.1	Energy Industries - Other Fuels	CH4	0.77	0.00	99.99
121	1.A.4.b	Residential - Gaseous Fuels	N2O	0.70	0.00	100.00
122	1.A.3.d	Navigation - Liquid Fuels	CH4	0.63	0.00	100.00
123	1.A.4.a	Commercial/Institutional - Gaseous Fuels	N2O	0.58	0.00	100.00
124	1.B.2.a	Fugitive Emissions - Oil Refining	CH4	0.38	0.00	100.00
125	1.A.1	Energy Industries - Liquid Fuels	N2O	0.37	0.00	100.00
126	1.A.3.e	Other Transport - Gaseous Fuels	CH4	0.31	0.00	100.00
127	1.A.2	Manufacturing Industries & Construction - Non-Renewable waste	N2O	0.31	0.00	100.00
128	5.C.1 & 2	Incineration and open burning of waste - Incineration	N2O	0.24	0.00	100.00
129	2.A.4.d	Other process uses of carbonates - limestone	CO2	0.16	0.00	100.00

Ranking	IPCC Sub-Category	Emission Source / Activity	Direct GHG	Absolute Value (Kt CO_2 eq)	2016 Level assessment (%)	Cumulative total (%)
130	1.A.3.c	Rail Transport - Liquid Fuels	CH4	0.16	0.00	100.00
131	1.A.1	Energy Industries - Liquid Fuels	CH4	0.15	0.00	100.00
132	1.A.2	Manufacturing Industries & Construction - Non-Renewable waste	CH4	0.13	0.00	100.00
133	1.A.3.a	Domestic Aviation - Liquid Fuels	N2O	0.13	0.00	100.00
134	5.C.1 & 2	Incineration and open burning of waste - Incineration	CH4	0.07	0.00	100.00
135	2.A.4.b	Other process uses of carbonates - soda ash	CO2	0.04	0.00	100.00
136	1.A.2	Manufacturing Industries & Construction - Peat Fuel	N2O	0.02	0.00	100.00
137	1.A.3.a	Domestic Aviation - Liquid Fuels	CH4	0.01	0.00	100.00
138	1.A.2	Manufacturing Industries & Construction - Peat Fuel	CH4	0.00	0.00	100.00

Table 1.C 2016 Key Category Analysis Trend Assessment excluding LULUCF

Ranking	IPCC Sub-Category	Emission Source / Activity	Direct GHG	1990 Emissions (Kt CO_2 eq)	2016 Emissions (Kt CO_2 eq)	2016 Level assessment (%)	2016 trend assessment (%)	Cumulative total (%)
1	1.A.3.b	Road Transport - Liquid Fuels	CO2	4690.42	11623.55	18.89	9.41	20.16
2	1.A.1	Energy Industries - Gaseous Fuels	CO2	1880.66	4896.48	7.96	4.12	28.99
3	1.A.4.b	Residential - Peat Fuel	CO2	3123.37	842.41	1.37	3.84	37.22
4	1.A.4.b	Residential - Solid Fuels	CO2	2483.42	721.27	1.17	2.98	43.60
5	1.A.4.b	Residential - Liquid Fuels	CO2	1175.34	3008.64	4.89	2.50	48.96
6	1.A.2	Manufacturing Industries & Construction - Gaseous Fuels	CO2	873.02	2372.52	3.85	2.06	53.36
7	1.A.4.a	Commercial/Institutional - Liquid Fuels	CO2	1870.07	756.06	1.23	1.93	57.50
8	1.A.1	Energy Industries - Solid Fuels	CO2	4844.66	4281.83	6.96	1.60	60.93
9	2.F.1	Product Uses as Substitutes for ODS -Refrigeration and air-con (incl. MAC)	HFC	0.00	1021.89	1.66	1.50	64.14
10	1.A.4.b	Residential - Gaseous Fuels	CO2	269.73	1316.51	2.14	1.49	67.33
11	1.A.1	Energy Industries - Peat Fuel	CO2	3164.78	2600.14	4.22	1.33	70.19
12	1.A.1	Energy Industries - Liquid Fuels	CO2	1254.90	503.82	0.82	1.30	72.98
13	1.A.2	Manufacturing Industries & Construction - Liquid Fuels	CO2	2198.38	1556.14	2.53	1.29	75.75
14	1.A.4.a	Commercial/Institutional - Gaseous Fuels	CO2	223.49	1094.85	1.78	1.24	78.41
15	2.A.1	Cement Production	CO2	884.00	1793.52	2.91	1.19	80.96
16	3.D.1	Agricultural Soils - Direct Soil Emissions	N2O	5296.13	5062.89	8.23	1.19	83.51
17	3.A.1	Enteric Fermentation - Non-Dairy Cattle	CH4	6702.59	6697.92	10.88	1.08	85.82
18	5.A	Solid Waste Disposal	CH4	1318.08	767.78	1.25	1.02	88.00
19	3.A.2	Enteric Fermentation - Sheep	CH4	1176.34	670.59	1.09	0.93	89.99
20	1.A.2	Manufacturing Industries & Construction - Solid Fuels	CO2	871.24	436.33	0.71	0.78	91.65
21	1.A.4.c	Agriculture/Fishing - Liquid Fuels	CO2	747.23	547.83	0.89	0.41	92.54
22	1.A.4.b	Residential - Peat Fuel	CH4	227.65	61.82	0.10	0.28	93.13
23	1.A.3.d	Navigation - Liquid Fuels	CO2	84.90	263.69	0.43	0.25	93.67
24	1.A.2	Manufacturing Industries & Construction - Non-Renewable waste	CO2	0.00	161.96	0.26	0.24	94.17
25	1.A.4.b	Residential - Solid Fuels	CH4	196.51	56.14	0.09	0.24	94.68
26	1.B.2.b	Fugitive emissions - Natural gas	CH4	156.05	20.04	0.03	0.22	95.16
27	2.F.4	Product Uses as Substitutes for ODS -Aerosols (incl. MDIs)	HFC	0.64	133.61	0.22	0.19	95.58
28	3.B.1.1	Manure Management - Non-Dairy Cattle	CH4	684.58	640.79	1.04	0.17	95.95
29	1.A.1	Energy Industries - Other Fuels	CO2	0.00	86.12	0.14	0.13	96.22
30	3.D.2	Agricultural Soils - Indirect Soil Emissions	N2O	557.23	535.95	0.87	0.12	96.48
31	5.C.1 & 2	Incineration and open burning of waste - Incineration (fossil C)	CO2	90.61	22.64	0.04	0.11	96.73
32	1.A.3.e	Other Transport - Gaseous Fuels	CO2	62.04	139.90	0.23	0.10	96.95
33	1.A.1	Energy Industries - Gaseous Fuels	N2O	10.21	77.09	0.13	0.10	97.15
34	2.A.2	Lime Production	CO2	214.08	173.90	0.28	0.09	97.35

Ranking	IPCC Sub-Category	Emission Source / Activity	Direct GHG	1990 Emissions (Kt CO_2 eq)	2016 Emissions (Kt CO_2 eq)	2016 Level assessment (%)	2016 trend assessment (%)	Cumulative total (%)
35	1.A.3.b	Road Transport - Liquid Fuels	N2O	48.95	114.11	0.19	0.09	97.54
36	2.E.1	Electronics Industry - Integrated circuit or semiconductor	HFC, PFC, SF6, NF3	1.17	57.04	0.09	0.08	97.72
37	3.B.1.2	Manure Management - Sheep	CH4	99.19	59.52	0.10	0.07	97.88
38	3.B.1.1	Manure Management - Dairy Cattle	CH4	354.22	344.28	0.56	0.07	98.03
39	1.A.3.a	Domestic Aviation - Liquid Fuels	CO2	51.13	9.66	0.02	0.07	98.18
40	1.B.1.a	Fugitive Emissions - Coal Mining and Handling	CH4	55.56	19.24	0.03	0.06	98.31
41	1.A.3.b	Road Transport - Liquid Fuels	CH4	48.13	13.23	0.02	0.06	98.44
42	1.A.3.c	Rail Transport - Liquid Fuels	CO2	133.19	111.93	0.18	0.05	98.55
43	2.F.3	Product Uses as Substitutes for ODS -Fire protection	HFC	0.00	32.45	0.05	0.05	98.65
44	3.G.1	Liming - Limestone CaCO3	CO2	355.04	425.60	0.69	0.05	98.75
45	3.B.1.3	Manure Management - Swine	CH4	206.49	260.35	0.42	0.05	98.85
46	3.B.1.4	Manure Management - Other livestock	CH4	61.58	97.29	0.16	0.04	98.94
47	1.A.4.c	Agriculture/Fishing - Liquid Fuels	N2O	69.96	51.74	0.08	0.04	99.02
48	2.D.1	Lube oil from Transport	CO2	35.97	20.56	0.03	0.03	99.08
49	5.D	Wastewater treatment and discharge	CH4	61.10	50.43	0.08	0.03	99.14
50	2.D.2	Paraffin wax use	CO2	5.87	21.55	0.04	0.02	99.18
51	3.H.	Urea Application	CO2	44.47	35.80	0.06	0.02	99.22
52	5.D	Wastewater treatment and discharge	N2O	75.14	96.69	0.16	0.02	99.27
53	1.A.1	Energy Industries - Peat Fuel	N2O	52.07	45.18	0.07	0.02	99.31
54	5.B.1	Biological treatment of solid waste - Composting	CH4	0.00	11.58	0.02	0.02	99.34
55	3.A.1	Enteric Fermentation - Dairy Cattle	CH4	3398.80	3780.92	6.14	0.02	99.38
56	2.G.2	Other Product Manufacture and Use - SF6 and PFCs from other product use	SF6	12.90	3.24	0.01	0.02	99.41
57	1.A.4.b	Residential - Peat Fuel	N2O	12.66	3.44	0.01	0.02	99.45
58	3.B.2.2	Manure Management - Sheep	N2O	22.67	14.83	0.02	0.02	99.48
59	1.A.4.b	Residential - Solid Fuels	N2O	11.71	3.35	0.01	0.01	99.51
60	2.D.3	Urea based catalysts	CO2	0.00	9.06	0.01	0.01	99.54
61	1.A.1	Energy Industries - Biomass	N2O	0.00	8.78	0.01	0.01	99.56
62	3.B.2.1	Manure Management - Dairy Cattle	N2O	51.18	48.29	0.08	0.01	99.59
63	5.B.1	Biological treatment of solid waste - Composting	N2O	0.00	8.28	0.01	0.01	99.62
64	1.A.4.a	Commercial/Institutional - Biomass	CH4	0.00	8.18	0.01	0.01	99.64
65	2.G.3.a	Other Product Manufacture and Use - Other (Anaesthesia in medical applications)	N2O	31.34	42.57	0.07	0.01	99.67
66	2.D.3	Solvents	CO2	72.64	87.76	0.14	0.01	99.69
67	3.A.3	Enteric Fermentation - Swine	CH4	41.37	52.21	0.08	0.01	99.71
68	1.A.4.b	Residential - Liquid Fuels	CH4	3.71	10.31	0.02	0.01	99.73

Ranking	IPCC Sub-Category	Emission Source / Activity	Direct GHG	1990 Emissions (Kt CO_2 eq)	2016 Emissions (Kt CO_2 eq)	2016 Level assessment (%)	2016 trend assessment (%)	Cumulative total (%)
69	1.A.4.b	Residential - Biomass	CH4	14.08	10.13	0.02	0.01	99.75
70	1.A.2	Manufacturing Industries & Construction - Biomass	N2O	3.04	8.57	0.01	0.01	99.76
71	2.A.4.a	Other process uses of carbonates - ceramics	CO2	5.23	0.78	0.00	0.01	99.78
72	3.B.2.1	Manure Management - Non-Dairy Cattle	N2O	212.61	240.61	0.39	0.01	99.79
73	1.A.4.b	Residential - Liquid Fuels	N2O	2.48	7.28	0.01	0.01	99.81
74	1.A.4.a	Commercial/Institutional - Liquid Fuels	CH4	6.28	2.54	0.00	0.01	99.82
75	1.A.3.c	Rail Transport - Liquid Fuels	N2O	15.49	13.01	0.02	0.01	99.83
76	2.G.1	Other Product Manufacture and Use - Electrical equipment	SF6	20.52	19.06	0.03	0.01	99.85
77	3.A.4	Enteric Fermentation - Other livestock	CH4	37.87	45.63	0.07	0.01	99.86
78	1.A.2	Manufacturing Industries & Construction - Peat Fuel	CO2	0.00	3.48	0.01	0.01	99.87
79	1.A.2	Manufacturing Industries & Construction - Biomass	CH4	1.91	5.40	0.01	0.00	99.88
80	1.A.4.a	Commercial/Institutional - Liquid Fuels	N2O	4.47	1.80	0.00	0.00	99.89
81	1.A.2	Manufacturing Industries & Construction - Solid Fuels	N2O	4.12	2.06	0.00	0.00	99.90
82	1.A.2	Manufacturing Industries & Construction - Liquid Fuels	N2O	4.83	2.92	0.00	0.00	99.90
83	1.A.4.b	Residential - Gaseous Fuels	CH4	0.61	2.95	0.00	0.00	99.91
84	1.A.4.a	Commercial/Institutional - Gaseous Fuels	CH4	0.51	2.45	0.00	0.00	99.92
85	1.A.1	Energy Industries - Biomass	CH4	0.00	1.85	0.00	0.00	99.92
86	1.A.1	Energy Industries - Solid Fuels	N2O	7.74	6.87	0.01	0.00	99.93
87	1.B.1.a	Fugitive Emissions - Coal Mining and Handling	CO2	0.03	1.61	0.00	0.00	99.93
88	1.A.1	Energy Industries - Gaseous Fuels	CH4	3.43	2.29	0.00	0.00	99.94
89	1.A.2	Manufacturing Industries & Construction - Solid Fuels	CH4	2.30	1.15	0.00	0.00	99.94
90	1.A.3.d	Navigation - Liquid Fuels	N2O	0.67	2.14	0.00	0.00	99.95
91	1.A.4.a	Commercial/Institutional - Biomass	N2O	0.00	1.30	0.00	0.00	99.95
92	1.A.1	Energy Industries - Liquid Fuels	N2O	1.47	0.37	0.00	0.00	99.96
93	1.A.1	Energy Industries - Other Fuels	N2O	0.00	1.22	0.00	0.00	99.96
94	3.B.2.3	Manure Management - Swine	N2O	10.08	12.25	0.02	0.00	99.96
95	1.A.2	Manufacturing Industries & Construction - Liquid Fuels	CH4	2.06	1.28	0.00	0.00	99.97
96	5.C.1 & 2	Incineration and open burning of waste - Incineration	N2O	1.04	0.24	0.00	0.00	99.97
97	1.A.4.b	Residential - Biomass	N2O	2.23	1.60	0.00	0.00	99.97
98	5.C.1 & 2	Incineration and open burning of waste - Incineration	CH4	0.83	0.07	0.00	0.00	99.97
99	1.A.1	Energy Industries - Other Fuels	CH4	0.00	0.77	0.00	0.00	99.98
100	1.A.3.e	Other Transport - Gaseous Fuels	N2O	0.67	1.49	0.00	0.00	99.98
101	1.A.2	Manufacturing Industries & Construction - Gaseous Fuels	N2O	0.47	1.27	0.00	0.00	99.98
102	3.B.2.4	Manure Management - Other livestock	N2O	11.18	13.12	0.02	0.00	99.98
103	1.A.2	Manufacturing Industries & Construction - Gaseous Fuels	CH4	0.40	1.06	0.00	0.00	99.99
104	1.A.4.b	Residential - Gaseous Fuels	N2O	0.15	0.70	0.00	0.00	99.99

Ranking	IPCC Sub-Category	Emission Source / Activity	Direct GHG	1990 Emissions (Kt CO_2 eq)	2016 Emissions (Kt CO_2 eq)	2016 Level assessment (%)	2016 trend assessment (%)	Cumulative total (%)
105	1.A.3.a	Domestic Aviation - Liquid Fuels	N2O	0.55	0.13	0.00	0.00	99.99
106	1.A.4.c	Agriculture/Fishing - Liquid Fuels	CH4	1.27	0.93	0.00	0.00	99.99
107	1.A.1	Energy Industries - Peat Fuel	CH4	1.90	1.65	0.00	0.00	99.99
108	1.A.4.a	Commercial/Institutional - Gaseous Fuels	N2O	0.12	0.58	0.00	0.00	99.99
109	1.A.3.d	Navigation - Liquid Fuels	CH4	0.20	0.63	0.00	0.00	99.99
110	3.B.2.5	Manure Management - Indirect N2O emissions	N2O	190.76	211.97	0.34	0.00	100.00
111	1.A.2	Manufacturing Industries & Construction - Non-Renewable waste	N2O	0.00	0.31	0.00	0.00	100.00
112	1.A.1	Energy Industries - Liquid Fuels	CH4	0.39	0.15	0.00	0.00	100.00
113	1.A.1	Energy Industries - Solid Fuels	CH4	0.91	0.81	0.00	0.00	100.00
114	2.A.4.d	Other process uses of carbonates - limestone	CO2	0.00	0.16	0.00	0.00	100.00
115	1.A.3.e	Other Transport - Gaseous Fuels	CH4	0.14	0.31	0.00	0.00	100.00
116	1.B.2.a	Fugitive Emissions - Oil Refining	CH4	0.21	0.38	0.00	0.00	100.00
117	1.A.2	Manufacturing Industries & Construction - Non-Renewable waste	CH4	0.00	0.13	0.00	0.00	100.00
118	2.A.4.b	Other process uses of carbonates - soda ash	CO2	0.10	0.04	0.00	0.00	100.00
119	1.A.3.c	Rail Transport - Liquid Fuels	CH4	0.19	0.16	0.00	0.00	100.00
120	1.A.3.a	Domestic Aviation - Liquid Fuels	CH4	0.02	0.01	0.00	0.00	100.00
121	1.A.2	Manufacturing Industries & Construction - Peat Fuel	N2O	0.00	0.02	0.00	0.00	100.00
122	1.A.2	Manufacturing Industries & Construction - Peat Fuel	CH4	0.00	0.00	0.00	0.00	100.00
123	1.A.4.a	Commercial/Institutional - Solid Fuels	CO2	2.56	0.00	0.00	0.00	100.00
124	1.A.4.a	Commercial/Institutional - Peat Fuel	CO2	135.73	0.00	0.00	0.00	100.00
125	1.A.4.a	Commercial/Institutional - Solid Fuels	CH4	0.01	0.00	0.00	0.00	100.00
126	1.A.4.a	Commercial/Institutional - Peat Fuel	CH4	0.33	0.00	0.00	0.00	100.00
127	1.A.4.a	Commercial/Institutional - Solid Fuels	N2O	0.01	0.00	0.00	0.00	100.00
128	1.A.4.a	Commercial/Institutional - Peat Fuel	N2O	0.56	0.00	0.00	0.00	100.00
129	2.A.3	Glass Production	CO2	13.33	0.00	0.00	0.00	100.00
130	2.B.1	Chemical Industry - Ammonia Production	CO2	990.23	0.00	0.00	0.00	100.00
131	2.B.2	Chemical Industry - Nitric Acid Production	N2O	995.32	0.00	0.00	0.00	100.00
132	2.C.1	Metal Production - Steel	CO2	26.08	0.00	0.00	0.00	100.00

Table 1.D 2016 Key Category Analysis Trend Assessment including LULUCF

Ranking	IPCC Sub-Category	Emission Source / Activity	Direct GHG	1990 Emissions (Kt CO_2 eq)	2016 Emissions (Kt CO_2 eq)	2016 Level assessment (%)	2016 trend assessment (%)	Cumulative total (%)
1	1.A.3.b	Road Transport - Liquid Fuels	CO2	4690.42	11623.55	15.27	7.52	15.54
2	4.A.2	LULUCF - Land Converted to Forest Land	CO2	27.26	3692.46	4.85	4.31	24.45
3	4.A.1	LULUCF - Forest land Remaining Forest Land	CO2	2719.66	183.46	0.24	3.36	31.39
4	1.A.1	Energy Industries - Gaseous Fuels	CO2	1880.66	4896.48	6.43	3.29	38.19
5	1.A.4.b	Residential - Peat Fuel	CO2	3123.37	842.41	1.11	3.11	44.62
6	1.A.4.b	Residential - Solid Fuels	CO2	2483.42	721.27	0.95	2.41	49.61
7	1.A.4.b	Residential - Liquid Fuels	CO2	1175.34	3008.64	3.95	2.00	53.74
8	1.A.2	Manufacturing Industries & Construction - Gaseous Fuels	CO2	873.02	2372.52	3.12	1.65	57.14
9	1.A.4.a	Commercial/Institutional - Liquid Fuels	CO2	1870.07	756.06	0.99	1.57	60.38
10	4.C	LULUCF - Grassland	CO2	7343.33	6889.15	9.05	1.54	63.56
11	1.A.1	Energy Industries - Solid Fuels	CO2	4844.66	4281.83	5.63	1.32	66.29
12	2.F.1	Product Uses as Substitutes for ODS -Refrigeration and air-con (incl. MAC)	HFC	0.00	1021.89	1.34	1.20	68.78
13	1.A.4.b	Residential - Gaseous Fuels	CO2	269.73	1316.51	1.73	1.20	71.25
14	1.A.1	Energy Industries - Peat Fuel	CO2	3164.78	2600.14	3.42	1.10	73.52
15	1.A.2	Manufacturing Industries & Construction - Liquid Fuels	CO2	2198.38	1556.14	2.04	1.06	75.70
16	1.A.1	Energy Industries - Liquid Fuels	CO2	1254.90	503.82	0.66	1.06	77.88
17	3.D.1	Agricultural Soils - Direct Soil Emissions	N2O	5296.13	5062.89	6.65	1.00	79.95
18	1.A.4.a	Commercial/Institutional - Gaseous Fuels	CO2	223.49	1094.85	1.44	1.00	82.00
19	2.A.1	Cement Production	CO2	884.00	1793.52	2.36	0.95	83.97
20	3.A.1	Enteric Fermentation - Non-Dairy Cattle	CH4	6702.59	6697.92	8.80	0.92	85.87
21	5.A	Solid Waste Disposal	CH4	1318.08	767.78	1.01	0.83	87.58
22	3.A.2	Enteric Fermentation - Sheep	CH4	1176.34	670.59	0.88	0.76	89.14
23	1.A.2	Manufacturing Industries & Construction - Solid Fuels	CO2	871.24	436.33	0.57	0.63	90.45
24	4.D	LULUCF - Wetlands	CO2	1487.42	2061.28	2.71	0.47	91.42
25	4.G	LULUCF - Harvested wood products	CO2	413.04	799.52	1.05	0.40	92.25
26	1.A.4.c	Agriculture/Fishing - Liquid Fuels	CO2	747.23	547.83	0.72	0.34	92.94
27	1.A.4.b	Residential - Peat Fuel	CH4	227.65	61.82	0.08	0.23	93.41
28	1.A.3.d	Navigation - Liquid Fuels	CO2	84.90	263.69	0.35	0.20	93.82
29	1.A.4.b	Residential - Solid Fuels	CH4	196.51	56.14	0.07	0.19	94.22
30	1.A.2	Manufacturing Industries & Construction - Non-Renewable waste	CO2	0.00	161.96	0.21	0.19	94.61
31	1.B.2.b	Fugitive emissions - Natural gas	CH4	156.05	20.04	0.03	0.18	94.99
32	2.F.4	Product Uses as Substitutes for ODS -Aerosols (incl. MDIs)	HFC	0.64	133.61	0.18	0.16	95.31
33	3.B.1.1	Manure Management - Non-Dairy Cattle	CH4	684.58	640.79	0.84	0.15	95.61
34	4.B.1	LULUCF - Cropland Remaining Cropland	CO2	16.23	131.93	0.17	0.13	95.89
35	4.D	LULUCF - Wetlands	CH4	135.62	64.97	0.09	0.10	96.10

Ranking	IPCC Sub-Category	Emission Source / Activity	Direct GHG	1990 Emissions (Kt CO_2 eq)	2016 Emissions (Kt CO_2 eq)	2016 Level assessment (%)	2016 trend assessment (%)	Cumulative total (%)
36	1.A.1	Energy Industries - Other Fuels	CO2	0.00	86.12	0.11	0.10	96.31
37	3.D.2	Agricultural Soils - Indirect Soil Emissions	N2O	557.23	535.95	0.70	0.10	96.52
38	5.C.1 & 2	Incineration and open burning of waste - Incineration (fossil C)	CO2	90.61	22.64	0.03	0.09	96.71
39	4.A	LULUCF - Forest land	N2O	92.86	175.88	0.23	0.09	96.88
40	1.A.3.e	Other Transport - Gaseous Fuels	CO2	62.04	139.90	0.18	0.08	97.05
41	4.E	LULUCF - Settlements	N2O	6.29	77.02	0.10	0.08	97.23
42	1.A.1	Energy Industries - Gaseous Fuels	N2O	10.21	77.09	0.10	0.08	97.38
43	2.A.2	Lime Production	CO2	214.08	173.90	0.23	0.08	97.54
44	1.A.3.b	Road Transport - Liquid Fuels	N2O	48.95	114.11	0.15	0.07	97.69
45	4.C	LULUCF - Grassland	CH4	267.95	240.02	0.32	0.07	97.83
46	2.E.1	Electronics Industry - Integrated circuit or semiconductor	HFC, PFC, SF6, NF3	1.17	57.04	0.07	0.07	97.97
47	3.B.1.2	Manure Management - Sheep	CH4	99.19	59.52	0.08	0.06	98.09
48	3.B.1.1	Manure Management - Dairy Cattle	CH4	354.22	344.28	0.45	0.06	98.22
49	4.F.2	LULUCF - Land Converted to Other Land	N2O	0.08	50.29	0.07	0.06	98.34
50	1.A.3.a	Domestic Aviation - Liquid Fuels	CO2	51.13	9.66	0.01	0.06	98.45
51	1.B.1.a	Fugitive Emissions - Coal Mining and Handling	CH4	55.56	19.24	0.03	0.05	98.56
52	1.A.3.b	Road Transport - Liquid Fuels	CH4	48.13	13.23	0.02	0.05	98.66
53	1.A.3.c	Rail Transport - Liquid Fuels	CO2	133.19	111.93	0.15	0.04	98.75
54	2.F.3	Product Uses as Substitutes for ODS -Fire protection	HFC	0.00	32.45	0.04	0.04	98.82
55	3.B.1.3	Manure Management - Swine	CH4	206.49	260.35	0.34	0.04	98.90
56	3.G.1	Liming - Limestone CaCO3	CO2	355.04	425.60	0.56	0.03	98.97
57	3.B.1.4	Manure Management - Other livestock	CH4	61.58	97.29	0.13	0.03	99.04
58	1.A.4.c	Agriculture/Fishing - Liquid Fuels	N2O	69.96	51.74	0.07	0.03	99.10
59	4.D	LULUCF - Wetlands	N2O	31.25	10.98	0.01	0.03	99.16
60	2.D.1	Lube oil from Transport	CO2	35.97	20.56	0.03	0.02	99.21
61	5.D	Wastewater treatment and discharge	CH4	61.10	50.43	0.07	0.02	99.25
62	2.D.2	Paraffin wax use	CO2	5.87	21.55	0.03	0.02	99.29
63	4.F.2	LULUCF - Land Converted to Other Land	CO2	0.55	15.21	0.02	0.02	99.32
64	3.H.	Urea Application	CO2	44.47	35.80	0.05	0.02	99.36
65	1.A.1	Energy Industries - Peat Fuel	N2O	52.07	45.18	0.06	0.02	99.39
66	5.D	Wastewater treatment and discharge	N2O	75.14	96.69	0.13	0.02	99.42
67	3.A.1	Enteric Fermentation - Dairy Cattle	CH4	3398.80	3780.92	4.97	0.01	99.45
68	4.C.1	LULUCF - Grassland Remaining Grassland	N2O	15.67	5.77	0.01	0.01	99.48
69	5.B.1	Biological treatment of solid waste - Composting	CH4	0.00	11.58	0.02	0.01	99.51
70	2.G.2	Other Product Manufacture and Use - SF6 and PFCs from other product use	SF6	12.90	3.24	0.00	0.01	99.53
71	1.A.4.b	Residential - Peat Fuel	N2O	12.66	3.44	0.00	0.01	99.56

Ranking	IPCC Sub-Category	Emission Source / Activity	Direct GHG	1990 Emissions (Kt CO_2 eq)	2016 Emissions (Kt CO_2 eq)	2016 Level assessment (%)	2016 trend assessment (%)	Cumulative total (%)
72	3.B.2.2	Manure Management - Sheep	N2O	22.67	14.83	0.02	0.01	99.58
73	1.A.4.b	Residential - Solid Fuels	N2O	11.71	3.35	0.00	0.01	99.61
74	2.D.3	Urea based catalysts	CO2	0.00	9.06	0.01	0.01	99.63
75	3.B.2.1	Manure Management - Dairy Cattle	N2O	51.18	48.29	0.06	0.01	99.65
76	1.A.1	Energy Industries - Biomass	N2O	0.00	8.78	0.01	0.01	99.67
77	5.B.1	Biological treatment of solid waste - Composting	N2O	0.00	8.28	0.01	0.01	99.69
78	1.A.4.a	Commercial/Institutional - Biomass	CH4	0.00	8.18	0.01	0.01	99.71
79	2.G.3.a	Other Product Manufacture and Use - Other (Anaesthesia in medical applications)	N2O	31.34	42.57	0.06	0.01	99.73
80	2.D.3	Solvents	CO2	72.64	87.76	0.12	0.01	99.75
81	1.A.4.b	Residential - Liquid Fuels	CH4	3.71	10.31	0.01	0.01	99.76
82	3.A.3	Enteric Fermentation - Swine	CH4	41.37	52.21	0.07	0.01	99.78
83	1.A.4.b	Residential - Biomass	CH4	14.08	10.13	0.01	0.01	99.79
84	1.A.2	Manufacturing Industries & Construction - Biomass	N2O	3.04	8.57	0.01	0.01	99.80
85	2.A.4.a	Other process uses of carbonates - ceramics	CO2	5.23	0.78	0.00	0.01	99.82
86	1.A.4.b	Residential - Liquid Fuels	N2O	2.48	7.28	0.01	0.01	99.83
87	4.A	LULUCF - Forest land	CH4	58.58	69.88	0.09	0.01	99.84
88	1.A.4.a	Commercial/Institutional - Liquid Fuels	CH4	6.28	2.54	0.00	0.01	99.85
89	1.A.3.c	Rail Transport - Liquid Fuels	N2O	15.49	13.01	0.02	0.01	99.86
90	2.G.1	Other Product Manufacture and Use - Electrical equipment	SF6	20.52	19.06	0.03	0.00	99.87
91	1.A.2	Manufacturing Industries & Construction - Peat Fuel	CO2	0.00	3.48	0.00	0.00	99.88
92	3.A.4	Enteric Fermentation - Other livestock	CH4	37.87	45.63	0.06	0.00	99.89
93	3.B.2.1	Manure Management - Non-Dairy Cattle	N2O	212.61	240.61	0.32	0.00	99.89
94	1.A.2	Manufacturing Industries & Construction - Biomass	CH4	1.91	5.40	0.01	0.00	99.90
95	1.A.4.a	Commercial/Institutional - Liquid Fuels	N2O	4.47	1.80	0.00	0.00	99.91
96	1.A.2	Manufacturing Industries & Construction - Solid Fuels	N2O	4.12	2.06	0.00	0.00	99.92
97	1.A.2	Manufacturing Industries & Construction - Liquid Fuels	N2O	4.83	2.92	0.00	0.00	99.92
98	1.A.4.b	Residential - Gaseous Fuels	CH4	0.61	2.95	0.00	0.00	99.93
99	1.A.4.a	Commercial/Institutional - Gaseous Fuels	CH4	0.51	2.45	0.00	0.00	99.93
100	1.A.1	Energy Industries - Biomass	CH4	0.00	1.85	0.00	0.00	99.94
101	1.A.1	Energy Industries - Solid Fuels	N2O	7.74	6.87	0.01	0.00	99.94
102	1.B.1.a	Fugitive Emissions - Coal Mining and Handling	CO2	0.03	1.61	0.00	0.00	99.94
103	1.A.1	Energy Industries - Gaseous Fuels	CH4	3.43	2.29	0.00	0.00	99.95
104	1.A.2	Manufacturing Industries & Construction - Solid Fuels	CH4	2.30	1.15	0.00	0.00	99.95
105	1.A.3.d	Navigation - Liquid Fuels	N2O	0.67	2.14	0.00	0.00	99.95
106	1.A.4.a	Commercial/Institutional - Biomass	N2O	0.00	1.30	0.00	0.00	99.96
107	1.A.1	Energy Industries - Liquid Fuels	N2O	1.47	0.37	0.00	0.00	99.96
108	4.E.2	LULUCF - Land Converted to Settlements	CO2	80.46	91.06	0.12	0.00	99.96

Ranking	IPCC Sub-Category	Emission Source / Activity	Direct GHG	1990 Emissions (Kt CO_2 eq)	2016 Emissions (Kt CO_2 eq)	2016 Level assessment (%)	2016 trend assessment (%)	Cumulative total (%)
109	1.A.1	Energy Industries - Other Fuels	N2O	0.00	1.22	0.00	0.00	99.97
110	1.A.2	Manufacturing Industries & Construction - Liquid Fuels	CH4	2.06	1.28	0.00	0.00	99.97
111	3.B.2.3	Manure Management - Swine	N2O	10.08	12.25	0.02	0.00	99.97
112	3.B.2.5	Manure Management - Indirect N2O emissions	N2O	190.76	211.97	0.28	0.00	99.97
113	5.C.1 & 2	Incineration and open burning of waste - Incineration	N2O	1.04	0.24	0.00	0.00	99.98
114	1.A.4.b	Residential - Biomass	N2O	2.23	1.60	0.00	0.00	99.98
115	5.C.1 & 2	Incineration and open burning of waste - Incineration	CH4	0.83	0.07	0.00	0.00	99.98
116	1.A.1	Energy Industries - Other Fuels	CH4	0.00	0.77	0.00	0.00	99.98
117	1.A.3.e	Other Transport - Gaseous Fuels	N2O	0.67	1.49	0.00	0.00	99.98
118	1.A.2	Manufacturing Industries & Construction - Gaseous Fuels	N2O	0.47	1.27	0.00	0.00	99.99
119	3.B.2.4	Manure Management - Other livestock	N2O	11.18	13.12	0.02	0.00	99.99
120	1.A.2	Manufacturing Industries & Construction - Gaseous Fuels	CH4	0.40	1.06	0.00	0.00	99.99
121	1.A.4.b	Residential - Gaseous Fuels	N2O	0.15	0.70	0.00	0.00	99.99
122	1.A.4.c	Agriculture/Fishing - Liquid Fuels	CH4	1.27	0.93	0.00	0.00	99.99
123	1.A.3.a	Domestic Aviation - Liquid Fuels	N2O	0.55	0.13	0.00	0.00	99.99
124	1.A.1	Energy Industries - Peat Fuel	CH4	1.90	1.65	0.00	0.00	99.99
125	1.A.4.a	Commercial/Institutional - Gaseous Fuels	N2O	0.12	0.58	0.00	0.00	100.00
126	1.A.3.d	Navigation - Liquid Fuels	CH4	0.20	0.63	0.00	0.00	100.00
127	1.A.2	Manufacturing Industries & Construction - Non-Renewable waste	N2O	0.00	0.31	0.00	0.00	100.00
128	1.A.1	Energy Industries - Liquid Fuels	CH4	0.39	0.15	0.00	0.00	100.00
129	1.A.1	Energy Industries - Solid Fuels	CH4	0.91	0.81	0.00	0.00	100.00
130	2.A.4.d	Other process uses of carbonates - limestone	CO2	0.00	0.16	0.00	0.00	100.00
131	1.A.3.e	Other Transport - Gaseous Fuels	CH4	0.14	0.31	0.00	0.00	100.00
132	1.B.2.a	Fugitive Emissions - Oil Refining	CH4	0.21	0.38	0.00	0.00	100.00
133	1.A.2	Manufacturing Industries & Construction - Non-Renewable waste	CH4	0.00	0.13	0.00	0.00	100.00
134	2.A.4.b	Other process uses of carbonates - soda ash	CO2	0.10	0.04	0.00	0.00	100.00
135	1.A.3.c	Rail Transport - Liquid Fuels	CH4	0.19	0.16	0.00	0.00	100.00
136	1.A.3.a	Domestic Aviation - Liquid Fuels	CH4	0.02	0.01	0.00	0.00	100.00
137	1.A.2	Manufacturing Industries & Construction - Peat Fuel	N2O	0.00	0.02	0.00	0.00	100.00
138	1.A.2	Manufacturing Industries & Construction - Peat Fuel	CH4	0.00	0.00	0.00	0.00	100.00

1.E Information on the level of disaggregation

The disaggregation approach found in Chapter 4.2 of the 2006 IPCC Guidelines has been followed.

1.F Description of methodology used for identifying key categories

Approach 1 in the 2006 IPCC Guidelines has been followed; key categories have been identified using a pre-determined cumulative emissions threshold. Key categories are those that, when summed together in descending order of magnitude, add up to 95 per cent of the total level.

Annex 2

Assessment of Uncertainty

2.A 2016 Uncertainty Assessment excluding LULUCF

2.B 2016 Uncertainty Assessment including LULUCF

2.C Description of methodology used for identifying uncertainties

Table 2.A.i 2016 Uncertainty Assessment excluding LULUCF, CO_2

	KEY CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (kt CO2eq)	Emissions in 2016 (kt CO2eq)	Activity Data (AD) Uncertainty (%)	Emission Factor (EF) Uncertainty (%)	Combined Uncertainty (%)	Contribution to Variance by Category in Year 2016	Combined Emissions Uncertainty Squared	Uncertainty in Trend in Total Emissions due to AD (%)	Uncertainty in Trend in Total Emissions due to EF (%)	Combined Uncertainty in Trend in Total Emissions (%)	Combined Trend Uncertainty Squared
1	1.A.1 Fuel combustion - Energy Industries - Gaseous Fuels	CO2	1880.66	4896.48	1.00	2.50	2.69	0.05	0.00	0.12	0.13	0.18	0.03
2	1.A.1 Fuel combustion - Energy Industries - Liquid Fuels	CO2	1254.90	503.82	1.00	2.50	2.69	0.00	0.00	0.01	-0.04	0.04	0.00
3	1.A.1 Fuel combustion - Energy Industries - Other Fossil Fuels	CO2	0.00	86.12	1.00	5.00	5.10	0.00	0.00	0.00	0.01	0.01	0.00
4	1.A.1 Fuel combustion - Energy Industries - Peat	CO2	3164.78	2600.14	1.00	5.00	5.10	0.05	0.00	0.07	-0.08	0.11	0.01
5	1.A.1 Fuel combustion - Energy Industries - Solid Fuels	CO2	4844.66	4281.83	1.00	5.00	5.10	0.13	0.02	0.11	-0.10	0.15	0.02
6	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	CO2	873.02	2372.52	7.00	3.00	7.62	0.09	0.01	0.42	0.08	0.43	0.18
7	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	CO2	2198.38	1556.14	10.00	2.50	10.31	0.07	0.00	0.40	-0.04	0.40	0.16
8	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Other Fossil Fuels	CO2	0.00	161.96	1.00	5.00	5.10	0.00	0.00	0.00	0.01	0.02	0.00
9	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Peat	CO2	0.00	3.48	2.00	5.00	5.39	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	436.33	2.00	5.00	5.39	0.00	0.00	0.02	-0.05	0.05	0.00
11	1.A.3.a Domestic Aviation	CO2	51.13	9.66	1.00	2.50	2.69	0.00	0.00	0.00	0.00	0.00	0.00
12	1.A.3.b Road Transportation	CO2	4690.42	11623.55	1.25	3.00	3.25	0.38	0.14	0.37	0.35	0.51	0.26
13	1.A.3.c Railways	CO2	133.19	111.93	1.00	1.00	1.41	0.00	0.00	0.00	0.00	0.00	0.00
14	1.A.3.d Domestic Navigation - Liquid Fuels	CO2	84.90	263.69	1.00	2.00	2.24	0.00	0.00	0.01	0.01	0.01	0.00
15	1.A.3.e Other Transportation	CO2	62.04	139.90	1.00	2.50	2.69	0.00	0.00	0.00	0.00	0.00	0.00
16	1.A.4 Other Sectors - Gaseous Fuels	CO2	493.22	2411.36	2.50	2.50	3.54	0.02	0.00	0.15	0.08	0.18	0.03
17	1.A.4 Other Sectors - Liquid Fuels	CO2	3792.64	4312.53	10.00	5.00	11.18	0.61	0.38	1.10	0.01	1.10	1.21
18	1.A.4 Other Sectors - Peat	CO2	3259.11	842.41	10.00	20.00	22.36	0.09	0.01	0.21	-1.00	1.02	1.04
19	1.A.4 Other Sectors - Solid Fuels	CO2	2485.97	721.27	5.00	10.00	11.18	0.02	0.00	0.09	-0.37	0.38	0.14
20	2.A.1 Cement Production	CO2	884.00	1793.52	1.50	1.50	2.12	0.00	0.00	0.07	0.02	0.07	0.01
21	2.A.2 Lime Production	CO2	214.08	173.90	5.00	5.00	7.07	0.00	0.00	0.02	-0.01	0.02	0.00
22	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
23	2.A.4 Other Process Uses of Carbonates	CO2	5.32	0.98	5.00	2.50	5.59	0.00	0.00	0.00	0.00	0.00	0.00
24	2.B.1 Ammonia Production	CO2	990.23	0.00	1.00	5.00	5.10	0.00	0.00	0.00	-0.10	0.10	0.01
25	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
26	2.D Non-energy Products from Fuels and Solvent Use	CO2	114.48	138.94	30.00	5.00	30.41	0.00	0.00	0.11	0.00	0.11	0.01
27	3.G Liming	CO2	355.04	425.60	5.00	50.00	50.25	0.12	0.01	0.05	0.03	0.06	0.00
28	3.H Urea Application	CO2	44.47	35.80	5.00	50.00	50.25	0.00	0.00	0.00	-0.01	0.01	0.00
29	5.C Incineration and Open Burning of Waste	CO2	90.61	22.64	10.00	5.00	11.18	0.00	0.00	0.01	-0.01	0.01	0.00
	Total CO2		**32877.91**	**39926.51**				**1.63**					**3.13**
						Level uncertainty, CO2		**1.27**			**Trend uncertainty, CO2**		**1.77**

Table 2.A.ii 2016 Uncertainty Assessment excluding LULUCF, CH_4

	KEY CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (kt CO2eq)	Emissions in 2016 (kt CO2eq)	Activity Data (AD) Uncertainty (%)	Emission Factor (EF) Uncertainty (%)	Combined Uncertainty (%)	Contribution to Variance by Category in Year 2016	Combined Emissions Uncertainty Squared	Uncertainty in Trend in Total Emissions due to AD (%)	Uncertainty in Trend in Total Emissions due to EF (%)	Combined Uncertainty in Trend in Total Emissions (%)	Combined Trend Uncertainty Squared
1	1.A.1 Fuel combustion - Energy Industries - Biomass	CH4	0.00	1.85	1.00	66.00	66.01	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	2.29	1.00	70.00	70.01	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	0.15	1.00	66.00	66.01	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	0.77	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00
5	1.A.1 Fuel combustion - Energy Industries - Peat	CH4	1.90	1.65	1.00	50.00	50.01	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	0.81	1.00	50.00	50.01	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	5.40	10.00	50.00	50.99	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	1.06	2.50	50.00	50.06	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	2.06	1.28	10.00	50.00	50.99	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	0.13	1.00	50.00	50.01	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
12	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Solid Fuels	CH4	2.30	1.15	2.00	50.00	50.04	0.00	0.00	0.00	0.00	0.00	0.00
13	1.A.3.a Domestic Aviation	CH4	0.02	0.01	1.00	66.00	66.01	0.00	0.00	0.00	0.00	0.00	0.00
14	1.A.3.b Road Transportation	CH4	48.13	13.23	1.25	71.00	71.01	0.00	0.00	0.00	-0.05	0.05	0.00
15	1.A.3.c Railways	CH4	0.19	0.16	1.00	60.00	60.01	0.00	0.00	0.00	0.00	0.00	0.00
16	1.A.3.d Domestic Navigation - Liquid Fuels	CH4	0.20	0.63	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00
17	1.A.3.e Other Transportation	CH4	0.14	0.31	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00
18	1.A.4 Other Sectors - Biomass	CH4	14.08	18.31	10.00	50.00	50.99	0.00	0.00	0.00	0.00	0.01	0.00
19	1.A.4 Other Sectors - Gaseous Fuels	CH4	1.12	5.40	2.50	50.00	50.06	0.00	0.00	0.00	0.00	0.00	0.00
20	1.A.4 Other Sectors - Liquid Fuels	CH4	11.27	13.79	10.00	66.00	66.75	0.00	0.00	0.00	0.00	0.00	0.00
21	1.A.4 Other Sectors - Peat	CH4	227.98	61.82	10.00	50.00	50.99	0.00	0.00	0.02	-0.17	0.17	0.03
22	1.A.4 Other Sectors - Solid Fuels	CH4	196.51	56.14	5.00	50.00	50.25	0.00	0.00	0.01	-0.15	0.15	0.02
23	1.B.1 Fugitive emissions from Solid Fuels	CH4	55.56	19.24	10.00	50.00	50.99	0.00	0.00	0.00	-0.04	0.04	0.00
24	1.B.2.a Fugitive Emissions from Fuels - Oil and Natural Gas - Oil	CH4	0.21	0.38	10.00	50.00	50.99	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	156.08	21.66	10.00	50.00	50.99	0.00	0.00	0.01	-0.14	0.14	0.02
26	3.A.1 Enteric Fermentation-Dairy Cattle	CH4	3398.80	3780.92	1.00	15.00	15.03	0.85	0.73	0.10	0.00	0.10	0.01
27	3.A.1 Enteric Fermentation-Non-Dairy Cattle	CH4	6702.59	6697.92	1.00	15.00	15.03	2.68	7.16	0.17	-0.20	0.26	0.07
28	3.A.2 Enteric Fermentation-Sheep	CH4	1176.34	670.59	1.00	30.00	30.02	0.11	0.01	0.02	-0.34	0.34	0.12
29	3.A.3 Enteric Fermentation-Swine	CH4	41.37	52.21	1.00	30.00	30.02	0.00	0.00	0.00	0.00	0.00	0.00
30	3.A.4 Enteric Fermentation-Other Animals	CH4	37.87	45.63	1.00	30.00	30.02	0.00	0.00	0.00	0.00	0.00	0.00
31	3.B.1.1 Manure Management-Dairy Cattle	CH4	354.22	344.28	1.00	15.00	15.03	0.01	0.00	0.01	-0.01	0.02	0.00
32	3.B.1.1 Manure Management-Non-Dairy Cattle	CH4	684.58	640.79	1.00	15.00	15.03	0.02	0.00	0.02	-0.03	0.04	0.00
33	3.B.1.2 Manure Management-Sheep	CH4	99.19	59.52	1.00	30.00	30.02	0.00	0.00	0.00	-0.03	0.03	0.00

	KEY CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (kt CO2eq)	Emissions in 2016 (kt CO2eq)	Activity Data (AD) Uncertainty (%)	Emission Factor (EF) Uncertainty (%)	Combined Uncertainty (%)	Contribution to Variance by Category in Year 2016	Combined Emissions Uncertainty Squared	Uncertainty in Trend in Total Emissions due to AD (%)	Uncertainty in Trend in Total Emissions due to EF (%)	Combined Uncertainty in Trend in Total Emissions (%)	Combined Trend Uncertainty Squared
34	3.B.1.3 Manure Management-Swine	CH4	206.49	260.35	1.00	30.00	30.02	0.02	0.00	0.01	0.02	0.02	0.00
35	3.B.1.4 Manure Management-Other Animals	CH4	61.58	97.29	1.00	30.00	30.02	0.00	0.00	0.00	0.02	0.02	0.00
36	5.A Solid Waste Disposal	CH4	1318.08	767.78	34.64	34.64	48.99	0.37	0.14	0.68	-0.43	0.80	0.65
37	5.B Biological treatment of solid waste: Composting	CH4	0.00	11.58	10.00	30.00	31.62	0.00	0.00	0.00	0.01	0.01	0.00
38	5.C Incineration and Open Burning of Waste	CH4	0.83	0.07	10.00	30.00	31.62	0.00	0.00	0.00	0.00	0.00	0.00
39	5.D Wastewater Treatment and Discharge	CH4	61.10	50.43	10.00	30.00	31.62	0.00	0.00	0.01	-0.01	0.02	0.00
	Total CH4		**14867.83**	**13706.98**				**4.07**					**0.92**
						Level uncertainty, CH4		**2.02**			**Trend uncertainty, CH4**		**0.96**
	Combined CO2 and CH4		**47745.73**	**53633.49**				**5.69**					**4.05**
					Level uncertainty, CO2 and CH4			**2.39**			**Trend uncertainty, CO2 & CH4**		**2.01**

Table 2.A.iii 2016 Uncertainty Assessment excluding LULUCF, N_2O

	KEY CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (kt CO2eq)	Emissions in 2016 (kt CO2eq)	Activity Data (AD) Uncertainty (%)	Emission Factor (EF) Uncertainty (%)	Combined Uncertainty (%)	Contribution to Variance by Category in Year 2016	Combined Emissions Uncertainty Squared	Uncertainty in Trend in Total Emissions due to AD (%)	Uncertainty in Trend in Total Emissions due to EF (%)	Combined Uncertainty in Trend in Total Emissions (%)	Combined Trend Uncertainty Squared
1	1.A.1 Fuel combustion - Energy Industries - Biomass	N2O	0.00	8.78	1.00	63.00	63.01	0.00	0.00	0.00	0.01	0.01	0.00
2	1.A.1 Fuel combustion - Energy Industries - Gaseous Fuels	N2O	10.21	77.09	1.00	50.00	50.01	0.00	0.00	0.00	0.06	0.06	0.00
3	1.A.1 Fuel combustion - Energy Industries - Liquid Fuels	N2O	1.47	0.37	1.00	50.00	50.01	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	1.22	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00
5	1.A.1 Fuel combustion - Energy Industries - Peat	N2O	52.07	45.18	1.00	50.00	50.01	0.00	0.00	0.00	-0.01	0.01	0.00
6	1.A.1 Fuel combustion - Energy Industries - Solid Fuels	N2O	7.74	6.87	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00
7	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Biomass	N2O	3.04	8.57	10.00	50.00	50.99	0.00	0.00	0.00	0.00	0.01	0.00
8	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	N2O	0.47	1.27	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00
9	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	N2O	4.83	2.92	10.00	50.00	50.99	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	0.31	1.00	20.00	20.02	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	0.02	2.00	50.00	50.04	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	2.06	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00
13	1.A.3.a Domestic Aviation	N2O	0.55	0.13	1.00	66.00	66.01	0.00	0.00	0.00	0.00	0.00	0.00
14	1.A.3.b Road Transportation	N2O	48.95	114.11	1.25	68.00	68.01	0.02	0.00	0.00	0.07	0.07	0.01
15	1.A.3.c Railways	N2O	15.49	13.01	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00
16	1.A.3.d Domestic Navigation - Liquid Fuels	N2O	0.67	2.14	1.00	90.00	90.01	0.00	0.00	0.00	0.00	0.00	0.00
17	1.A.3.e Other Transportation	N2O	0.67	1.49	1.00	25.00	25.02	0.00	0.00	0.00	0.00	0.00	0.00
18	1.A.4 Other Sectors - Biomass	N2O	2.23	2.90	10.00	50.00	50.99	0.00	0.00	0.00	0.00	0.00	0.00
19	1.A.4 Other Sectors - Gaseous Fuels	N2O	0.27	1.29	2.50	50.00	50.06	0.00	0.00	0.00	0.00	0.00	0.00
20	1.A.4 Other Sectors - Liquid Fuels	N2O	76.92	60.81	10.00	50.00	50.99	0.00	0.00	0.02	-0.02	0.03	0.00
21	1.A.4 Other Sectors - Peat	N2O	13.22	3.44	5.00	50.00	50.25	0.00	0.00	0.00	-0.01	0.01	0.00
22	1.A.4 Other Sectors - Solid Fuels	N2O	11.72	3.35	5.00	50.00	50.25	0.00	0.00	0.00	-0.01	0.01	0.00
23	2.B.2 Nitric Acid Production	N2O	995.32	0.00	1.00	10.00	10.05	0.00	0.00	0.00	-0.20	0.20	0.04
24	2.G Other Product Manufacture and Use	N2O	31.34	42.57	5.00	5.00	7.07	0.00	0.00	0.01	0.00	0.01	0.00

	KEY CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (kt CO2eq)	Emissions in 2016 (kt CO2eq)	Activity Data (AD) Uncertainty (%)	Emission Factor (EF) Uncertainty (%)	Combined Uncertainty (%)	Contribution to Variance by Category in Year 2016	Combined Emissions Uncertainty Squared	Uncertainty in Trend in Total Emissions due to AD (%)	Uncertainty in Trend in Total Emissions due to EF (%)	Combined Uncertainty in Trend in Total Emissions (%)	Combined Trend Uncertainty Squared
25	3.B.2.1 Manure Management -Dairy Cattle	N2O	51.18	48.29	11.22	50.00	51.24	0.00	0.00	0.01	-0.01	0.02	0.00
26	3.B.2.1 Manure Management -Non-Dairy Cattle	N2O	212.61	240.61	11.22	50.00	51.24	0.04	0.00	0.07	0.00	0.07	0.00
27	3.B.2.2 Manure Management -Sheep	N2O	22.67	14.83	11.22	50.00	51.24	0.00	0.00	0.00	-0.01	0.01	0.00
28	3.B.2.3 Manure Management -Swine	N2O	10.08	12.25	11.22	50.00	51.24	0.00	0.00	0.00	0.00	0.00	0.00
29	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
30	3.B.2.4 Manure Management -Goats	N2O	0.65	0.37	11.22	50.00	51.24	0.00	0.00	0.00	0.00	0.00	0.00
31	3.B.2.4 Manure Management -Horses	N2O	3.44	5.15	11.22	50.00	51.24	0.00	0.00	0.00	0.00	0.00	0.00
32	3.B.2.4 Manure Management -Mules & Asses	N2O	0.32	0.35	11.22	50.00	51.24	0.00	0.00	0.00	0.00	0.00	0.00
33	3.B.2.4 Manure Management -Poultry	N2O	3.81	5.25	11.22	50.00	51.24	0.00	0.00	0.00	0.00	0.00	0.00
34	3.B.2.4 Manure Management -Fur Animals	N2O	2.72	1.97	50.00	50.00	70.71	0.00	0.00	0.00	0.00	0.00	0.00
35	3.B.2.5 Indirect N2O emissions	N2O	190.76	211.97	11.22	100.00	100.63	0.12	0.01	0.06	0.00	0.06	0.00
36	3.D.1.1 Inorganic N Fertilizer	N2O	2158.39	1951.23	1.00	50.00	50.01	2.51	6.32	0.05	-0.40	0.40	0.16
37	3.D.1.2 Organic N Fertilizers	N2O	683.59	753.14	11.22	100.00	100.63	1.52	2.30	0.22	-0.01	0.22	0.05
38	3.D.1.3 Urine and Dung Deposited by Grazing Animals	N2O	1310.12	1284.31	11.18	50.00	51.23	1.14	1.31	0.37	-0.15	0.40	0.16
39	3.D.1.4 Crop Residues	N2O	374.15	194.34	10.00	100.00	100.50	0.10	0.01	0.05	-0.40	0.40	0.16
40	3.D.1.5 Mineralization/Immobilization Associated with Loss/Gain of Soil Organic Matter	N2O	20.03	21.78	22.57	100.00	102.52	0.00	0.00	0.01	0.00	0.01	0.00
41	3.D.1.6 Cultivation of Organic Soils	N2O	749.85	858.09	12.22	100.00	100.74	1.97	3.89	0.27	0.05	0.27	0.07
42	3.D.2 Indirect N2O Emissions From Managed Soils	N2O	557.23	535.95	11.18	50.00	51.23	0.20	0.04	0.15	-0.07	0.17	0.03
43	5.B Biological treatment of solid waste: Composting	N2O	0.00	8.28	10.00	10.00	14.14	0.00	0.00	0.00	0.00	0.00	0.00
44	5.C Incineration and Open Burning of Waste	N2O	1.04	0.24	10.00	10.00	14.14	0.00	0.00	0.00	0.00	0.00	0.00
45	5.D Wastewater Treatment and Discharge	N2O	75.14	96.69	10.00	10.00	14.14	0.00	0.00	0.02	0.00	0.02	0.00
	Total N2O		**7709.33**	**6645.04**				**7.63**					**0.69**
						Level uncertainty, N2O		**2.76**				**Trend uncertainty, N2O**	**0.83**
	Combined CO2, CH4 and N2O		**55455.06**	**60278.52**				**13.33**					**4.73**
					Level uncertainty, CO2, CH4 & N2O			**3.65**		**Trend uncertainty, CO2, CH4 & N2O**			**2.18**

Table 2.A.iv 2016 Uncertainty Assessment excluding LULUCF – aggregate F-gases and Total for all gases

	KEY CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (kt CO2eq)	Emissions in 2016 (kt CO2eq)	Activity Data (AD) Uncertainty (%)	Emission Factor (EF) Uncertainty (%)	Combined Uncertainty (%)	Contribution to Variance by Category in Year 2016	Combined Emissions Uncertainty Squared	Uncertainty in Trend in Total Emissions due to AD (%)	Uncertainty in Trend in Total Emissions due to EF (%)	Combined Uncertainty in Trend in Total Emissions (%)	Combined Trend Uncertainty Squared
1	2.E Electronics Industry & 2.F Product Uses and Substitutes for ODS	Aggregate F-gases	1.81	1244.99	20.00	10.00	22.36	0.20	0.04	0.63	0.22	0.67	0.45
2	2.G Other Product Manufacture and Use	Aggregate F-gases	33.42	22.30	10.00	0.00	10.00	0.00	0.00	0.01	0.00	0.01	0.00
	Total F-gases		**35.23**	**1267.30**				**0.20**					**0.45**
						Level uncertainty, F-gases		**0.45**			**Trend uncertainty, F-gases**		**0.67**
	TOTAL for all gases		**55490.29**	**61545.82**				**13.53**					**5.19**
					Total level uncertainty for all GHGs			**3.68**		**Total trend uncertainty for all GHGs**			**2.28**

Table 2B.i 2016 Uncertainty Assessment including LULUCF CO_2

	KEY CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (Gg CO2eq)	Emissions in 2016 (kt CO2eq)	Activity Data (AD) Uncertainty (%)	Emission Factor (EF) Uncertainty (%)	Combined Uncertainty (%)	Contribution to Variance by Category in Year 2016	Combined Emissions Uncertainty Squared	Uncertainty in Trend in Total Emissions due to AD (%)	Uncertainty in Trend in Total Emissions due to EF (%)	Combined Uncertainty in Trend in Total Emissions (%)	Combined Trend Uncertainty Squared
1	1.A.1 Fuel combustion - Energy Industries - Gaseous Fuels	CO2	1880.66	4896.48	1.00	2.50	2.69	0.04	0.00	0.12	0.13	0.18	0.03
2	1.A.1 Fuel combustion - Energy Industries - Liquid Fuels	CO2	1254.90	503.82	1.00	2.50	2.69	0.00	0.00	0.01	-0.04	0.04	0.00
3	1.A.1 Fuel combustion - Energy Industries - Other Fossil Fuels	CO2	0.00	86.12	1.00	5.00	5.10	0.00	0.00	0.00	0.01	0.01	0.00
4	1.A.1 Fuel combustion - Energy Industries - Peat	CO2	3164.78	2600.14	1.00	5.00	5.10	0.04	0.00	0.07	-0.08	0.11	0.01
5	1.A.1 Fuel combustion - Energy Industries - Solid Fuels	CO2	4844.66	4281.83	1.00	5.00	5.10	0.11	0.01	0.11	-0.10	0.15	0.02
6	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	CO2	873.02	2372.52	7.00	3.00	7.62	0.07	0.01	0.42	0.08	0.43	0.18
7	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	CO2	2198.38	1556.14	10.00	2.50	10.31	0.06	0.00	0.40	-0.04	0.40	0.16
8	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Other Fossil Fuels	CO2	0.00	161.96	1.00	5.00	5.10	0.00	0.00	0.00	0.01	0.02	0.00
9	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Peat	CO2	0.00	3.48	2.00	5.00	5.39	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	436.33	2.00	5.00	5.39	0.00	0.00	0.02	-0.05	0.05	0.00
11	1.A.3.a Domestic Aviation	CO2	51.13	9.66	1.00	2.50	2.69	0.00	0.00	0.00	0.00	0.00	0.00
12	1.A.3.b Road Transportation	CO2	4690.42	11623.55	1.25	3.00	3.25	0.32	0.10	0.37	0.35	0.51	0.26
13	1.A.3.c Railways	CO2	133.19	111.93	1.00	1.00	1.41	0.00	0.00	0.00	0.00	0.00	0.00
14	1.A.3.d Domestic Navigation - Liquid Fuels	CO2	84.90	263.69	1.00	2.00	2.24	0.00	0.00	0.01	0.01	0.01	0.00
15	1.A.3.e Other Transportation	CO2	62.04	139.90	1.00	2.50	2.69	0.00	0.00	0.00	0.00	0.00	0.00
16	1.A.4 Other Sectors - Gaseous Fuels	CO2	493.22	2411.36	2.50	2.50	3.54	0.02	0.00	0.15	0.08	0.18	0.03
17	1.A.4 Other Sectors - Liquid Fuels	CO2	3792.64	4312.53	10.00	5.00	11.18	0.53	0.28	1.10	0.01	1.10	1.21
18	1.A.4 Other Sectors - Peat	CO2	3259.11	842.41	10.00	20.00	22.36	0.08	0.01	0.21	-1.00	1.02	1.04
19	1.A.4 Other Sectors - Solid Fuels	CO2	2485.97	721.27	5.00	10.00	11.18	0.01	0.00	0.09	-0.37	0.38	0.14
20	2.A.1 Cement Production	CO2	884.00	1793.52	1.50	1.50	2.12	0.00	0.00	0.07	0.02	0.07	0.01
21	2.A.2 Lime Production	CO2	214.08	173.90	5.00	5.00	7.07	0.00	0.00	0.02	-0.01	0.02	0.00
22	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
23	2.A.4 Other Process Uses of Carbonates	CO2	5.32	0.98	5.00	2.50	5.59	0.00	0.00	0.00	0.00	0.00	0.00
24	2.B.1 Ammonia Production	CO2	990.23	0.00	1.00	5.00	5.10	0.00	0.00	0.00	-0.10	0.10	0.01

	KEY CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (Gg CO2eq)	Emissions in 2016 (kt CO2eq)	Activity Data (AD) Uncertainty (%)	Emission Factor (EF) Uncertainty (%)	Combined Uncertainty (%)	Contribution to Variance by Category in Year 2016	Combined Emissions Uncertainty Squared	Uncertainty in Trend in Total Emissions due to AD (%)	Uncertainty in Trend in Total Emissions due to EF (%)	Combined Uncertainty in Trend in Total Emissions (%)	Combined Trend Uncertainty Squared
25	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
26	2.D Non-energy Products from Fuels and Solvent Use	CO2	114.48	138.94	30.00	5.00	30.41	0.00	0.00	0.11	0.00	0.11	0.01
27	3.G Liming	CO2	355.04	425.60	5.00	50.00	50.25	0.10	0.01	0.05	0.03	0.06	0.00
28	3.H Urea Application	CO2	44.47	35.80	5.00	50.00	50.25	0.00	0.00	0.00	-0.01	0.01	0.00
29	4.A.1 Forest Land Remaining Forest Land	CO2	-2719.66	-183.46	51.00	114.00	124.89	-0.34	0.12	-0.21	5.05	5.05	25.51
30	4.A.2 Land Converted to Forest Land	CO2	27.26	-3692.46	51.00	114.00	124.89	-6.94	48.10	-4.30	-6.86	8.09	65.51
31	4.B.1 Cropland Remaining Cropland	CO2	-16.23	-131.93	20.59	69.15	72.15	-0.14	0.02	-0.06	-0.13	0.14	0.02
32	4.C. Grassland	CO2	7343.33	6889.15	12.22	90.00	90.83	9.41	88.56	1.92	-1.45	2.41	5.81
33	4.C.2 Land Converted to Grassland	CO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
34	4.D. Wetlands	CO2	1487.42	2061.28	21.49	101.45	103.70	3.21	10.34	1.01	0.76	1.27	1.60
35	4.D.2 Land Converted to Wetlands	CO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
36	4.E.2 Land Converted to Settlements	CO2	80.46	91.06	39.97	81.83	91.07	0.12	0.02	0.08	0.01	0.08	0.01
37	4.F.2 Land Converted to Other Land	CO2	0.55	15.21	51.93	75.00	91.23	0.02	0.00	0.02	0.02	0.03	0.00
38	4.G Harvested Wood Products	CO2	-413.04	-799.52	25.00	26.92	36.74	-0.44	0.20	-0.46	-0.15	0.48	0.23
39	5.C Incineration and Open Burning of Waste	CO2	90.61	22.64	10.00	5.00	11.18	0.00	0.00	0.01	-0.01	0.01	0.00
	Total CO2		**38667.99**	**44175.85**				**6.30**					**101.82**
						Level uncertainty, CO2		**2.51**			**Trend uncertainty, CO2**		**10.09**

Table 2B.ii 2016 Uncertainty Assessment including LULUCF, CH_4

	KEY CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (Gg CO2eq)	Emissions in 2016 (kt CO2eq)	Activity Data (AD) Uncertainty (%)	Emission Factor (EF) Uncertainty (%)	Combined Uncertainty (%)	Contribution to Variance by Category in Year 2016	Combined Emissions Uncertainty Squared	Uncertainty in Trend in Total Emissions due to AD (%)	Uncertainty in Trend in Total Emissions due to EF (%)	Combined Uncertainty in Trend in Total Emissions (%)	Combined Trend Uncertainty Squared
1	1.A.1 Fuel combustion - Energy Industries - Biomass	CH4	0.00	1.85	1.00	66.00	66.01	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	2.29	1.00	70.00	70.01	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	0.15	1.00	66.00	66.01	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	0.77	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00
5	1.A.1 Fuel combustion - Energy Industries - Peat	CH4	1.90	1.65	1.00	50.00	50.01	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	0.81	1.00	50.00	50.01	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	5.40	10.00	50.00	50.99	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	1.06	2.50	50.00	50.06	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	2.06	1.28	10.00	50.00	50.99	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	0.13	1.00	50.00	50.01	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
12	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Solid Fuels	CH4	2.30	1.15	2.00	50.00	50.04	0.00	0.00	0.00	0.00	0.00	0.00
13	1.A.3.a Domestic Aviation	CH4	0.02	0.01	1.00	66.00	66.01	0.00	0.00	0.00	0.00	0.00	0.00
14	1.A.3.b Road Transportation	CH4	48.13	13.23	1.25	71.00	71.01	0.00	0.00	0.00	-0.05	0.05	0.00
15	1.A.3.c Railways	CH4	0.19	0.16	1.00	60.00	60.01	0.00	0.00	0.00	0.00	0.00	0.00
16	1.A.3.d Domestic Navigation - Liquid Fuels	CH4	0.20	0.63	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00
17	1.A.3.e Other Transportation	CH4	0.14	0.31	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00
18	1.A.4 Other Sectors - Biomass	CH4	14.08	18.31	10.00	50.00	50.99	0.00	0.00	0.00	0.00	0.01	0.00
19	1.A.4 Other Sectors - Gaseous Fuels	CH4	1.12	5.40	2.50	50.00	50.06	0.00	0.00	0.00	0.00	0.00	0.00
20	1.A.4 Other Sectors - Liquid Fuels	CH4	11.27	13.79	10.00	66.00	66.75	0.00	0.00	0.00	0.00	0.00	0.00
21	1.A.4 Other Sectors - Peat	CH4	227.98	61.82	10.00	50.00	50.99	0.00	0.00	0.02	-0.17	0.17	0.03
22	1.A.4 Other Sectors - Solid Fuels	CH4	196.51	56.14	5.00	50.00	50.25	0.00	0.00	0.01	-0.15	0.15	0.02
23	1.B.1 Fugitive emissions from Solid Fuels	CH4	55.56	19.24	10.00	50.00	50.99	0.00	0.00	0.00	-0.04	0.04	0.00

	KEY CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (Gg CO2eq)	Emissions in 2016 (kt CO2eq)	Activity Data (AD) Uncertainty (%)	Emission Factor (EF) Uncertainty (%)	Combined Uncertainty (%)	Contribution to Variance by Category in Year 2016	Combined Emissions Uncertainty Squared	Uncertainty in Trend in Total Emissions due to AD (%)	Uncertainty in Trend in Total Emissions due to EF (%)	Combined Uncertainty in Trend in Total Emissions (%)	Combined Trend Uncertainty Squared
24	1.B.2.a Fugitive Emissions from Fuels - Oil and Natural Gas - Oil	CH4	0.21	0.38	10.00	50.00	50.99	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	156.08	21.66	10.00	50.00	50.99	0.00	0.00	0.01	-0.14	0.14	0.02
26	3A1 Enteric Fermentation-Dairy Cattle	CH4	3398.80	3780.92	1.00	15.00	15.03	0.73	0.53	0.10	0.00	0.10	0.01
27	3A1 Enteric Fermentation-Non-Dairy Cattle	CH4	6702.59	6697.92	1.00	15.00	15.03	2.29	5.26	0.17	-0.20	0.26	0.07
28	3A2 Enteric Fermentation-Sheep	CH4	1176.34	670.59	1.00	30.00	30.02	0.09	0.01	0.02	-0.34	0.34	0.12
29	3A3 Enteric Fermentation-Swine	CH4	41.37	52.21	1.00	30.00	30.02	0.00	0.00	0.00	0.00	0.00	0.00
30	3A4 Enteric Fermentation-Other Animals	CH4	37.87	45.63	1.00	30.00	30.02	0.00	0.00	0.00	0.00	0.00	0.00
31	3B1.1 Manure Management-Dairy Cattle	CH4	354.22	344.28	1.00	15.00	15.03	0.01	0.00	0.01	-0.01	0.02	0.00
32	3B1.1 Manure Management-Non-Dairy Cattle	CH4	684.58	640.79	1.00	15.00	15.03	0.02	0.00	0.02	-0.03	0.04	0.00
33	3B1.2 Manure Management-Sheep	CH4	99.19	59.52	1.00	30.00	30.02	0.00	0.00	0.00	-0.03	0.03	0.00
34	3B1.3 Manure Management-Swine	CH4	206.49	260.35	1.00	30.00	30.02	0.01	0.00	0.01	0.02	0.02	0.00
35	3B1.4 Manure Management-Other Animals	CH4	61.58	97.29	1.00	30.00	30.02	0.00	0.00	0.00	0.02	0.02	0.00
36	4.A LULUCF - Forest Land	CH4	58.58	69.88	30.00	100.00	104.40	0.11	0.01	0.05	0.01	0.05	0.00
37	4.B LULUCF - Cropland	CH4	0.04	0.00	100.00	39.10	107.37	0.00	0.00	0.00	0.00	0.00	0.00
38	4.C LULUCF - Grassland	CH4	267.95	240.02	96.40	91.20	132.70	0.48	0.23	0.53	-0.07	0.53	0.28
39	4.D LULUCF - Wetlands	CH4	135.62	64.97	86.00	66.50	108.71	0.11	0.01	0.13	-0.09	0.15	0.02
40	5.A Solid Waste Disposal	CH4	1318.08	767.78	34.64	34.64	48.99	0.32	0.10	0.68	-0.43	0.80	0.65
41	5.B Biological treatment of solid waste: Composting	CH4	0.00	11.58	10.00	30.00	31.62	0.00	0.00	0.00	0.01	0.01	0.00
42	5.C Incineration and Open Burning of Waste	CH4	0.83	0.07	10.00	30.00	31.62	0.00	0.00	0.00	0.00	0.00	0.00
43	5.D Wastewater Treatment and Discharge	CH4	61.10	50.43	10.00	30.00	31.62	0.00	0.00	0.01	-0.01	0.02	0.00
	Total CH4		**15330.02**	**14081.85**				**4.18**					**1.23**
						Level uncertainty, CH4		**2.04**			**Trend uncertainty, CH4**		**1.11**
	Combined CO2 and CH4		**53998.02**	**58257.70**				**10.48**					**103.05**
					Level uncertainty, CO2 and CH4			**3.24**			**Trend uncertainty, CO2 & CH4**		**10.15**

Table 2B.iii 2016 Uncertainty Assessment including LULUCF, N_2O

	KEY CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (Gg CO2eq)	Emissions in 2016 (kt CO2eq)	Activity Data (AD) Uncertainty (%)	Emission Factor (EF) Uncertainty (%)	Combined Uncertainty (%)	Contribution to Variance by Category in Year 2016	Combined Emissions Uncertainty Squared	Uncertainty in Trend in Total Emissions due to AD (%)	Uncertainty in Trend in Total Emissions due to EF (%)	Combined Uncertainty in Trend in Total Emissions (%)	Combined Trend Uncertainty Squared
1	1.A.1 Fuel combustion - Energy Industries - Biomass	N2O	0.00	8.78	1.00	63.00	63.01	0.00	0.00	0.00	0.01	0.01	0.00
2	1.A.1 Fuel combustion - Energy Industries - Gaseous Fuels	N2O	10.21	77.09	1.00	50.00	50.01	0.00	0.00	0.00	0.06	0.06	0.00
3	1.A.1 Fuel combustion - Energy Industries - Liquid Fuels	N2O	1.47	0.37	1.00	50.00	50.01	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	1.22	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00
5	1.A.1 Fuel combustion - Energy Industries - Peat	N2O	52.07	45.18	1.00	50.00	50.01	0.00	0.00	0.00	-0.01	0.01	0.00
6	1.A.1 Fuel combustion - Energy Industries - Solid Fuels	N2O	7.74	6.87	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00
7	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Biomass	N2O	3.04	8.57	10.00	50.00	50.99	0.00	0.00	0.00	0.00	0.01	0.00
8	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	N2O	0.47	1.27	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00
9	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	N2O	4.83	2.92	10.00	50.00	50.99	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	0.31	1.00	20.00	20.02	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	0.02	2.00	50.00	50.04	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	2.06	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00
13	1.A.3.a Domestic Aviation	N2O	0.55	0.13	1.00	66.00	66.01	0.00	0.00	0.00	0.00	0.00	0.00
14	1.A.3.b Road Transportation	N2O	48.95	114.11	1.25	68.00	68.01	0.01	0.00	0.00	0.07	0.07	0.01
15	1.A.3.c Railways	N2O	15.49	13.01	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.00	0.00

	KEY CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (Gg CO2eq)	Emissions in 2016 (kt CO2eq)	Activity Data (AD) Uncertainty (%)	Emission Factor (EF) Uncertainty (%)	Combined Uncertainty (%)	Contribution to Variance by Category in Year 2016	Combined Emissions Uncertainty Squared	Uncertainty in Trend in Total Emissions due to AD (%)	Uncertainty in Trend in Total Emissions due to EF (%)	Combined Uncertainty in Trend in Total Emissions (%)	Combined Trend Uncertainty Squared
16	1.A.3.d Domestic Navigation - Liquid Fuels	N2O	0.67	2.14	1.00	90.00	90.01	0.00	0.00	0.00	0.00	0.00	0.00
17	1.A.3.e Other Transportation	N2O	0.67	1.49	1.00	25.00	25.02	0.00	0.00	0.00	0.00	0.00	0.00
18	1.A.4 Other Sectors - Biomass	N2O	2.23	2.90	10.00	50.00	50.99	0.00	0.00	0.00	0.00	0.00	0.00
19	1.A.4 Other Sectors - Gaseous Fuels	N2O	0.27	1.29	2.50	50.00	50.06	0.00	0.00	0.00	0.00	0.00	0.00
20	1.A.4 Other Sectors - Liquid Fuels	N2O	76.92	60.81	10.00	50.00	50.99	0.00	0.00	0.02	-0.02	0.03	0.00
21	1.A.4 Other Sectors - Peat	N2O	13.22	3.44	5.00	50.00	50.25	0.00	0.00	0.00	-0.01	0.01	0.00
22	1.A.4 Other Sectors - Solid Fuels	N2O	11.72	3.35	5.00	50.00	50.25	0.00	0.00	0.00	-0.01	0.01	0.00
23	2.B.2 Nitric Acid Production	N2O	995.32	0.00	1.00	10.00	10.05	0.00	0.00	0.00	-0.20	0.20	0.04
24	2.G Other Product Manufacture and Use	N2O	31.34	42.57	5.00	5.00	7.07	0.00	0.00	0.01	0.00	0.01	0.00
25	3.B.2.1 Manure Management -Dairy Cattle	N2O	51.18	48.29	11.22	50.00	51.24	0.00	0.00	0.01	-0.01	0.02	0.00
26	3.B.2.1 Manure Management -Non-Dairy Cattle	N2O	212.61	240.61	11.22	50.00	51.24	0.03	0.00	0.07	0.00	0.07	0.00
27	3.B.2.2 Manure Management -Sheep	N2O	22.67	14.83	11.22	50.00	51.24	0.00	0.00	0.00	-0.01	0.01	0.00
28	3.B.2.3 Manure Management -Swine	N2O	10.08	12.25	11.22	50.00	51.24	0.00	0.00	0.00	0.00	0.00	0.00
29	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
30	3.B.2.4 Manure Management -Goats	N2O	0.65	0.37	11.22	50.00	51.24	0.00	0.00	0.00	0.00	0.00	0.00
31	3.B.2.4 Manure Management -Horses	N2O	3.44	5.15	11.22	50.00	51.24	0.00	0.00	0.00	0.00	0.00	0.00
32	3.B.2.4 Manure Management -Mules & Asses	N2O	0.32	0.35	11.22	50.00	51.24	0.00	0.00	0.00	0.00	0.00	0.00
33	3.B.2.4 Manure Management -Poultry	N2O	3.81	5.25	11.22	50.00	51.24	0.00	0.00	0.00	0.00	0.00	0.00
34	3.B.2.4 Manure Management -Fur Animals	N2O	2.72	1.97	50.00	50.00	70.71	0.00	0.00	0.00	0.00	0.00	0.00
35	3.B.2.5 Indirect N2O emissions	N2O	190.76	211.97	11.22	100.00	100.63	0.10	0.01	0.06	0.00	0.06	0.00
36	3.D.1.1 Inorganic N Fertilizer	N2O	2158.39	1951.23	1.00	50.00	50.01	2.15	4.64	0.05	-0.40	0.40	0.16
37	3.D.1.2 Organic N Fertilizers	N2O	683.59	753.14	11.22	100.00	100.63	1.30	1.69	0.22	-0.01	0.22	0.05

	KEY CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (Gg CO2eq)	Emissions in 2016 (kt CO2eq)	Activity Data (AD) Uncertainty (%)	Emission Factor (EF) Uncertainty (%)	Combined Uncertainty (%)	Contribution to Variance by Category in Year 2016	Combined Emissions Uncertainty Squared	Uncertainty in Trend in Total Emissions due to AD (%)	Uncertainty in Trend in Total Emissions due to EF (%)	Combined Uncertainty in Trend in Total Emissions (%)	Combined Trend Uncertainty Squared
38	3.D.1.3 Urine and Dung Deposited by Grazing Animals	N2O	1310.12	1284.31	11.18	50.00	51.23	0.98	0.96	0.37	-0.15	0.40	0.16
39	3.D.1.4 Crop Residues	N2O	374.15	194.34	10.00	100.00	100.50	0.09	0.01	0.05	-0.40	0.40	0.16
40	3.D.1.5 Mineralization/Immobilization Associated with Loss/Gain of Soil Organic Matter	N2O	20.03	21.78	22.57	100.00	102.52	0.00	0.00	0.01	0.00	0.01	0.00
41	3.D.1.6 Cultivation of Organic Soils	N2O	749.85	858.09	12.22	100.00	100.74	1.69	2.86	0.27	0.05	0.27	0.07
42	3.D.2 Indirect N2O Emissions From Managed Soils	N2O	557.23	535.95	11.18	50.00	51.23	0.17	0.03	0.15	-0.07	0.17	0.03
43	4.A LULUCF - Forest Land	N2O	92.86	175.88	30.00	100.00	104.40	0.28	0.08	0.12	0.12	0.17	0.03
44	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
45	4.C.1 LULUCF - Grassland Remaining Grassland	N2O	15.67	5.77	91.02	100.00	135.22	0.01	0.00	0.01	-0.02	0.02	0.00
46	4.C.2 LULUCF - Land converted to Grassland	N2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
47	4.D.1 LULUCF - Wetlands remaining Wetlands	N2O	31.25	10.98	86.00	100.00	131.89	0.02	0.00	0.02	-0.04	0.04	0.00
48	4.D.2 LULUCF - Land converted to Wetlands	N2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
49	4.E.1. LULUCF-Settlements remaining settlements	N2O	6.29	72.65	45.24	54.69	70.98	0.08	0.01	0.08	0.06	0.10	0.01
50	4.E.2 LULUCF - Land Converted to Settlements	N2O	6.29	72.65	45.24	54.69	70.98	0.08	0.01	0.08	0.06	0.10	0.01
51	4.F.2 LULUCF - Land Converted to Other Land	N2O	0.08	50.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
52	5.B Biological treatment of solid waste: Composting	N2O	0.00	8.28	10.00	10.00	14.14	0.00	0.00	0.00	0.00	0.00	0.00
53	5.C Incineration and Open Burning of Waste	N2O	1.04	0.24	10.00	10.00	14.14	0.00	0.00	0.00	0.00	0.00	0.00
54	5.D Wastewater Treatment and Discharge	N2O	75.14	96.69	10.00	10.00	14.14	0.00	0.00	0.02	0.00	0.02	0.00
	Total N2O		**7855.49**	**6964.98**				**6.93**					**0.73**
						Level uncertainty, N2O		**2.63**			**Trend uncertainty, N2O**		**0.85**
	Combined CO2, CH4 and N2O		**61853.51**	**65222.68**				**17.41**					**103.78**

	KEY CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (Gg CO2eq)	Emissions in 2016 (kt CO2eq)	Activity Data (AD) Uncertainty (%)	Emission Factor (EF) Uncertainty (%)	Combined Uncertainty (%)	Contribution to Variance by Category in Year 2016	Combined Emissions Uncertainty Squared	Uncertainty in Trend in Total Emissions due to AD (%)	Uncertainty in Trend in Total Emissions due to EF (%)	Combined Uncertainty in Trend in Total Emissions (%)	Combined Trend Uncertainty Squared
					Level uncertainty, CO2, CH4 & N2O			**4.17**		**Trend uncertainty, CO2, CH4 & N2O**			**10.19**

Table 2B.iv 2016 Uncertainty Assessment including LULUCF – aggregate F-gases and Total for all gases

	KEY CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Emissions in 1990 (Gg CO2eq)	Emissions in 2016 (kt CO2eq)	Activity Data (AD) Uncertainty (%)	Emission Factor (EF) Uncertainty (%)	Combined Uncertainty (%)	Contribution to Variance by Category in Year 2016	Combined Emissions Uncertainty Squared	Uncertainty in Trend in Total Emissions due to AD (%)	Uncertainty in Trend in Total Emissions due to EF (%)	Combined Uncertainty in Trend in Total Emissions (%)	Combined Trend Uncertainty Squared
1	2.E Electronics Industry & 2.F Product Uses and Substitutes for ODS	Aggregate F-gases	1.81	1244.99	20.00	10.00	22.36	0.18	0.03	0.63	0.22	0.67	0.45
2	2.G Other Product Manufacture and Use	Aggregate F-gases	33.42	22.30	10.00	0.00	10.00	0.00	0.00	0.01	0.00	0.01	0.00
	Total F-gases		**35.23**	**1267.30**				**0.18**					**0.45**
						Level uncertainty, F-gases		**0.42**			**Trend uncertainty, F-gases**		**0.67**
	TOTAL for all gases		**61888.74**	**66489.97**				**17.59**					**104.23**
					Total level uncertainty for all GHGs			**4.19**		**Total trend uncertainty for all GHGs**			**10.21**

2.C Description of methodology used for estimating uncertainties

Approach 1 in 2006 IPCC Guidelines has been followed. Uncertainties for each category and gas have been estimated using equations 3.1 and 3.2 in Volume 1 of the 2006 IPCC Guidelines. A combination of these uncertainties by category has been used to estimate overall uncertainty for 2016 and the uncertainty in the trend.

$$U_{total} = \sqrt{(U_1^2 + U_2^2 + \cdots + U_n^2)}$$ Equation 3.1, Vol 1, 2006 IPCC Guidelines

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

$$U_{total} = \frac{\sqrt{((U_1 \times x_1)+(U_2 \times x_2)^2+\cdots+(U_n \times x_n)^2)}}{|x_1+x_2+\cdots+x_n|}$$ Equation 3.2, Vol 1, 2006 IPCC Guidelines

Where:

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

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

Annex 3.1.A

Energy - Combustion (IPCC Sector 1.A)

3.1.1 – 3.1.2 Calculation Sheets for Energy 2016

3.1.3 – 3.1.5 Comparison of Reference and Sectoral Approach

3.1.6 – 3.1.8 Time-Series of Implied Emission Factors (IEFs) in Categories 1.A.1 and 1.A.2

Table 3.1.1 Calculation Sheet for Emissions from Fuel Combustion 2016 (continued on following pages)

	Sectoral Disaggregation of Fuel Combustion from National Energy Balance			Emission Factors			Emissions		
				CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
	Sector/Fuel	**kTOE**	**TJ**	**kg/TJ**	**kg/TJ**	**kg/TJ**	**Gg**	**Mg**	**Mg**
	1A1a Public Electricity								
1	Coal	1101.22	46106.08	92869	0.7	0.5	4281.83	32.27	23.05
2	Peat	512.94	21475.77	116640	3.0	7.0	2504.93	64.43	150.33
3	Fuel Oil and Gas Oil	63.19	2645.48	77789	0.8	0.3	205.79	2.16	0.84
4	Natural Gas	2068.33	86596.66	56024	1.0	3.0	4851.53	88.68	258.40
5	Biomass (LFG, Wood & MSW biomass)	150.12	6285.23	102641	11.8	4.7	645.12	73.89	29.45
6	MSW (non-renewable, fossil)	24.49	1025.49	83983	30.0	4.0	86.12	30.76	4.10
	Public Electricity Total	**3920.29**	**164134.72**				**11930.20**	**292.20**	**466.18**
	1A1b Refinery Fuel								
7	Refinery Gas	92.06	3854.41	76923	1.0	0.1	296.49	3.85	0.39
8	Natural Gas	53.94	2258.55	7180	1.0	0.1	16.22	2.26	0.23
9	LPG	0.28	11.83	940	1.0	0.1	0.011120	0.01	0.00
10	Gasoil/Diesel/DERV	0.17	7.25	73520	3.0	0.6	0.53	0.02	0.00
	Refinery Total	**146.46**	**6132.03**				**313.25**	**6.15**	**0.62**
	1A1c Peat Briquetting & Natural Gas Refineries								
11	Gas Oil	0.32	13.44	73300	3.0	0.6	0.99	0.04	0.01
12	Kerosene	0.00	0.14	71400	3.0	0.6	0.01	0.00	0.00
13	LPG	0.00	0.05	63700	1.0	0.1	0.00	0.00	0.00
14	Peat	20.51	858.73	110880	2.0	1.5	95.22	1.72	1.29
15	Natural Gas	12.18	510.00	56335	1.0	0.1	28.73	0.51	0.05
	1A1c Total	**33.02**	**1382.36**				**124.95**	**2.27**	**1.35**
	1A2a-1A2g Industry Fuel								
16	Bituminous Coals	110.16	4612.36	94600	10.0	1.5	436.33	46.12	6.92
17	Briquettes	0.84	35.17	98860	2.0	1.5	3.48	0.07	0.05
18	Kerosene	90.58	3792.56	71400	3.0	0.6	270.79	11.38	2.28
19	Fuel Oil	34.57	1447.21	76000	3.0	0.6	109.99	4.34	0.87
20	LPG	113.36	4746.15	63700	1.0	0.1	302.33	4.75	0.47
21	Gasoil/Diesel/DERV	112.57	4713.11	73300	3.0	0.6	345.47	14.14	2.83
22	Pet Coke	133.42	5585.85	94446	3.0	0.6	527.56	16.76	3.35
23	Naphta	-	-	73330	3.0	0.6	-	-	-
24	Natural Gas	1014.64	42480.84	55849	1.0	0.1	2372.52	42.48	4.25
25	Biomass (solid)	171.74	7190.31	112000	30.0	4.0	805.31	215.71	28.76
26	Biomass (gas)	2.37	99.29	54600	1.0	0.1	5.42	0.10	0.01
27	Non Renewable wastes (fossil)	41.70	1745.84	92771	3.0	0.6	161.96	5.24	1.05
	Industry Total	**1825.95**	**76448.67**				**4530.43**	**361.08**	**50.84**

Table 3.1.1 Calculation Sheet for Emissions from Fuel Combustion 2016 (continued from previous page)

	Sectoral Disaggregation of Fuel Combustion from National Energy Balance			Emission Factors			Emissions		
				CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
	Sector/Fuel	**kTOE**	**TJ**	**kg/TJ**	**kg/TJ**	**kg/TJ**	**Gg**	**Mg**	**Mg**
	1A3a Aviation								
28	Domestic Aviation Kerosene & Gasoline	3.25	**135.99**	71038	2.0	3.2	**9.66**	**0.27**	**0.43**
	1A3b Road Transport Fuel								
29	Gasoline	1002.01	41952.23	69960	10.1	1.1	2934.98	422.16	46.00
30	Gasoil/Diesel/DERV	2828.93	118441.68	73300	0.8	2.7	8681.78	89.49	325.32
31	LPG	2.55	106.70	63700	11.3	2.2	6.80	1.20	0.23
32	Liquid Biofuels	118.48	4960.59	70204	3.3	2.3	348.26	16.51	11.36
	Road Transport Total	**3951.97**	**165461.20**				**11623.55**	**529.37**	**382.92**
	1A3c-1A3e Other Transport Fuel								
33	Railway Diesel	36.47	1526.96	73300	4.2	28.6	111.93	6.34	43.67
34	Navigation Fuel Oil	-	-	76000	7.0	2.0	-	-	-
35	Navigation Gasoil	85.92	3597.34	73300	7.0	2.0	263.69	25.18	7.19
36	Gas Distribution Use (Natural Gas)	59.83	2504.83	55852	5.0	2.0	139.90	12.52	5.01
37	Railway Biofuel	-	-	70800	4.2	28.6	-	-	-
	Other Transport Total	**182.22**	**7629.13**				**515.51**	**44.04**	**55.88**
	1A4a Commercial/Institutional Fuel								
38	Bituminous Coal	-	-	94600	10.0	1.5	-	-	-
39	Anthracite + Manufactured Ovoids	-	-	98300	10.0	1.5	-	-	-
40	Lignite	-	-	101000	10.0	1.5	-	-	-
41	Briquettes	-	-	98860	10.0	1.4	-	-	-
42	Fuel Oil	9.85	412.36	76000	10.0	0.6	31.34	4.12	0.25
43	LPG	8.45	353.65	63700	5.0	0.1	22.53	1.77	0.04
44	Gasoil / Diesel/ DERV	228.81	9579.76	73300	10.0	0.6	702.20	95.80	5.75
45	Pet Coke	0.0003	0.01	94446	10.0	0.6	0.0013	0.0001	0.000008
46	Natural Gas	468.20	19602.59	55852	5.0	0.1	1094.85	98.01	1.96
47	Biomass	25.93	1085.65	112000	300.0	4.0	121.59	325.69	4.34
48	Biogas	6.93	290.29	54600	5.0	0.1	15.85	1.45	0.03
	Commercial/Institutional Total	**748.17**	**31324.31**				**1850.92**	**526.85**	**12.36**

Table 3.1.1 Calculation Sheet for Emissions from Fuel Combustion 2016 (continued from previous page)

	Sectoral Disaggregation of Fuel Combustion from National Energy Balance			Emission Factors			Emissions		
				CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
	Sector/Fuel	**kTOE**	**TJ**	**kg/TJ**	**kg/TJ**	**kg/TJ**	**Gg**	**Mg**	**Mg**
	1A4b Residential Fuel								
49	Bituminous Coal	100.73	4217.33	94600	300.0	1.5	398.96	1265.20	6.33
50	Anthracite + Manufactured Ovoids	68.56	2870.39	98300	300.0	1.5	282.16	861.12	4.31
51	Lignite	9.50	397.55	101000	300.0	1.5	40.15	119.26	0.60
52	Sod Peat	127.70	5346.71	104000	300.0	1.4	556.06	1604.01	7.49
53	Briquettes	69.18	2896.52	98860	300.0	1.4	286.35	868.96	4.06
54	Kerosene	815.25	34133.08	71400	10.0	0.6	2437.10	341.33	20.48
55	LPG	39.11	1637.52	63700	5.0	0.1	104.31	8.19	0.16
56	Gasoil / Diesel/ DERV	145.16	6077.43	73300	10.0	0.6	445.48	60.77	3.65
57	Petroleum Coke	5.50	230.31	94446	10.0	0.6	21.75	2.30	0.14
58	Natural Gas	562.99	23571.26	55852	5.0	0.1	1316.51	117.86	2.36
59	Biomass	32.46	1359.09	112000	298.2	3.9	152.22	405.33	5.36
	Residential Total	**1976.14**	**82737.17**				**5888.83**	**5654.33**	**54.92**
	1A4c Agriculture Fuel								
60	Gasoil	159.23	6666.56	73300	4.7	25.8	488.66	31.57	172.00
61	Biomass	-	-	112000	300.0	4.0	-	-	-
	Agriculture Total	**159.23**	**6666.56**				**488.66**	**31.57**	**172.00**
	1A4c Fishing Fuel								
62	Gasoil	**19.28**	**807.18**	73300	7.0	2.0	**59.17**	**5.65**	**1.61**
	Total Energy	**12965.97**	**542859.34**				**37335.13**	**7453.77**	**1199.10**

Table 3.1.2 Emissions from Fuel Combustion Allocated by IPCC Level 1 Source Category 2016

	GREENHOUSE GAS SOURCE AND SINK CATEGORIES	AGGREGATE ACTIVITY DATA	IMPLIED EMISSION FACTORS			EMISSIONS		
		Consumption (TJ)	CO_2 (t/TJ)	CH_4 (kg/TJ)	N_2O (kg/TJ)	CO_2 (Gg)	CH_4 (Gg)	N_2O (Gg)
A	**1.A.1. Energy Industries**	**171,649.12**				**12,368.40**	**0.30**	**0.47**
B	Solid Fuels	46,106.08	92.87	0.70	0.50	4,281.83	0.03	0.02
C	Liquid Fuels	6,532.59	77.12	0.93	0.19	503.82	0.01	0.00
D	Gaseous Fuels	89,365.21	54.79	1.02	2.89	4,896.48	0.09	0.26
E	Peat Fuels	22,334.50	116.42	2.96	6.79	2,600.14	0.07	0.15
F	Biomass	6,285.23	102.64	11.76	4.69	645.12	0.07	0.03
G	Other Fuels	1,025.49	83.98	30.00	4.00	86.12	0.03	0.00
H	**1.A.2 Manufacturing Industries and Construction**	**76,448.67**				**4,530.43**	**0.36**	**0.05**
I	Solid Fuels	4,612.36	94.60	10.00	1.50	436.33	0.05	0.01
J	Liquid Fuels	20,284.87	76.71	2.53	0.48	1,556.14	0.05	0.01
K	Gaseous Fuels	42,480.84	55.85	1.00	0.10	2,372.52	0.04	0.00
L	Peat Fuels	35.17	98.86	2.00	1.50	3.48	0.00	0.00
M	Biomass	7,289.59	111.22	29.61	3.95	810.74	0.22	0.03
N	Other Fuels	1,745.84	92.77	3.00	0.60	161.96	0.01	0.00
O	**1.A.3 Transport**	**173,226.32**				**12,148.72**	**0.57**	**0.44**
P	Solid Fuels	NE,NO	NE,NO	NE,NO	NE,NO	NE,NO	NE,NO	NE,NO
Q	Liquid Fuels	165,760.90	72.45	3.29	2.55	12,008.82	0.54	0.42
R	Gaseous Fuels	2,504.83	55.85	5.00	2.00	139.90	0.01	0.01
S	Biomass	4,960.59	70.20	3.33	2.29	348.26	0.02	0.01
T	**1.A.4 Other Sectors**	**121,535.23**				**8,287.57**	**6.22**	**0.24**
U	Solid Fuels	15,728.49	99.42	300.00	1.45	1,563.68	4.72	0.02
V	Liquid Fuels	59,897.86	72.00	9.21	3.41	4,312.53	0.55	0.20
W	Gaseous Fuels	43,173.85	55.85	5.00	0.10	2,411.36	0.22	0.00
	Biomass	2,735.03	105.91	267.81	3.56	289.66	0.73	0.01
X	**1.A.5 Other *(Not specified elsewhere)*[(6)]**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**
AA	**1.A. Fuel Combustion**	**542,859.34**				**37,335.13**	**7.45**	**1.20**
	Memo Items							
AB	Aviation Bunkers	36,254.41	71.40	0.26	2.34	2,588.56	0.01	0.08
AC	Marine Bunkers	6,686.47	73.48	7.00	2.00	491.32	0.05	0.01
AD	CO_2 from Biomass	21,270.45	98.44			2,093.78	NA	NA

Table 3.1.3 Correspondence between National Disaggregation of Sources and IPCC Combustion Source Categories

	IPCC Source Category/Fuel Groups from Table 3.1.2	National Disaggregated Sources from Table 3.1.1
A	**1.A.1 Energy Industries (A = B+C+D+E+F)**	
B	(a) Solid Fuels	1+2+14
C	(b) Liquid Fuels	3+7+9+10+11+12+13
D	(c) Gaseous Fuels	4+8+15
E	(d) Biomass	5
F	(e) Other Fuels	6
G	**1.A.2 Manufacturing Industries (G = H+I+J+K+L)**	
H	(a) Solid Fuels	16+17
I	(b) Liquid Fuels	18+19+20+21+22+23
J	(c) Gaseous Fuels	24
K	(d) Biomass	25+26
L	(e) Other Fuels	27
M	**1.A.3 Transport (M = N+O+P+Q)**	
N	(a) Solid Fuels	NO
O	(b) Liquid Fuels	28+29+30+31+33+34+35
P	(c) Gaseous Fuels	36
Q	(d) Biomass	32+37
R	**1.A.4 Other Sectors (R = S+T+U+V)**	
S	(a) Solid Fuels	38+39+40+41+50+51+52+53+54
T	(b) Liquid Fuels	42+43+44+45+46+55+56+57+58+61
U	(c) Gaseous Fuels	47+59
V	(d) Biomass	48+49+60+62
W	**1.A.5 Other**	**NO**
X	**1.A Fuel Combustion (X = A+G+M+R+W)**	

Table 3.1.4 Emissions of CO_2 from the Reference Approach in 2016 [CRF 2018 Table 1.A(b)]

FUEL TYPES			Unit	Production	Imports	Exports	International bunkers	Stock change	Apparent consumption	Conversion factor (TJ/Unit)[1]	NCV / GCV [(2)]	Apparent consumption (TJ)	Carbon emission factor (t C/TJ)	Carbon content (kt)	Carbon stored[C excluded] (kt C)	Net carbon emissions ((kt) C)	Fraction of carbon oxidized	Actual CO_2 emissions ((kt) CO_2)
Liquid fossil	Primary fuels	Crude oil	kt	NO	3197.94	NO		-1.91	3199.85	42.81	NCV	136998.89	20.00	2739.98	NO	2739.98	1.00	10046.59
		Orimulsion	kt	NO	NO	NO		NO	NO	NO	NCV	NO	NO	NO	NO	NO	NO	NO
		Natural gas liquids	kt	NO	NO	NO		NO	NO	NO	NCV	NO	NO	NO	NO	NO	NO	NO
	Secondary fuels	Gasoline	kt		746.15	348.33	NO	5.91	391.91	44.59	NCV	17475.12	19.08	333.43	NO	333.43	1.00	1222.56
		Jet kerosene	kt		1065.32	NO	821.79	2.13	241.41	44.10	NCV	10646.01	19.47	207.28	NO	207.28	1.00	760.02
		Other kerosene	kt		493.00	12.09	NO	-3.82	484.73	44.20	NCV	21423.23	19.47	417.11	NO	417.11	1.00	1529.40
		Shale oil	kt		NO	NO		NO	NO	NO	NCV	NO	NO	NO	NO	NO	NO	NO
		Gas/diesel oil	kt		2594.84	113.27	144.15	NO	2337.43	43.31	NCV	101229.84	19.99	2023.58	NO	2023.58	1.00	7419.81
		Residual fuel oil	kt		60.69	1054.86	10.76	4.46	-1009.39	41.24	NCV	-41623.14	20.73	-862.85	NO	-862.85	1.00	-3163.78
		Liquefied petroleum gases (LPG)	kt		121.04	14.85		0.26	105.93	47.16	NCV	4995.24	17.37	86.77	NO	86.77	1.00	318.15
		Ethane	kt		NO	NO		NO	NO	NO	NCV	NO	NO	NO	NO	NO	NO	NO
		Naphtha	kt		NO	72.05		1.85	-73.90	44.00	NCV	-3251.80	20.00	-65.04	NO	-65.04	1.00	-238.47
		Bitumen	kt		255.88	3.13		NO	252.75	37.70	NCV	9528.66	22.00	209.63	209.63	0.00	1.00	0.00
		Lubricants	kt		39.83	7.45	NO	NO	32.38	42.29	NCV	1369.51	20.00	27.39	13.70	13.70	1.00	50.22
		Petroleum coke	kt		195.49	0.08		-1.58	196.99	32.00	NCV	6303.12	25.76	162.36	NO	162.36	1.00	595.30
		Refinery feedstocks	kt		NO	NO		-3.28	3.28	44.59	NCV	146.08	20.00	2.92	NO	2.92	1.00	10.71
		Other oil	kt		NO	NO		NO	NO	NO	NCV	NO	NO	NO	NO	NO	NO	NO
Other liquid fossil												215.31		4.31	4.31	0.00		0.00
		Aviation Gasoline	kt	NO	NO	NO	NO	NO	NO	44.59	NCV	NO	19.10	NO	NO	NO	1.00	NO
		White Spirit	kt	NO	1.55	0.00	NO	NO	1.55	44.00	NCV	68.09	20.00	1.36	1.36	0.00	1.00	0.00
		Paraffin Wax	kt	NO	4.02	0.36	NO	NO	3.66	40.20	NCV	147.22	20.00	2.94	2.94	0.00	1.00	0.00
		Other Petroleum products	kt	NO	NO	NO	NO	NO	NO	40.20	NCV	NO	20.00	NO	NO	NO	1.00	NO
Liquid fossil totals												265456.05		5286.86	227.63	5059.23		18550.51
Solid fossil	Primary fuels	Anthracite[(3)]	kt	NO	43.47	0.11		5.22	38.15	27.84	NCV	1062.15	26.81	28.48	NO	28.48	1.00	104.41
		Coking coal	kt	NO	NO	NO		NO	NO	29.10	NCV	NO	25.80	NO	NO	NO	1.00	NO
		Other bituminous coal	kt	NO	1838.84	12.65	NO	-353.37	2179.56	25.33	NCV	55214.08	25.80	1424.52	NO	1424.52	1.00	5223.25
		Sub-bituminous coal	kt	NO	NO	NO	NO	NO	NO	NO	NCV	NO	NO	NO	NO	NO	NO	NO
		Lignite	kt	NO	20.24	3.37		0.97	15.90	19.82	NCV	315.01	27.55	8.68	NO	8.68	1.00	31.82
		Oil shale and tar sand	kt	NO	NO	NO		NO	NO	NO	NCV	NO	NO	NO	NO	NO	NO	NO
	Secondary fuels	BKB[(4)] and patent fuel	kt		NO	NO		NO	NO	NO	NCV	NO	NO	NO	NO	NO	NO	NO
		Coke oven/gas coke	kt		NO	NO		NO	NO	NO	NCV	NO	NO	NO	NO	NO	1.00	NO
		Coal tar	kt		NO	NO		NO	NO	NO	NCV	NO	NO	NO	NO	NO	NO	NO
Other solid fossil												906.76		24.31	NO	24.31		89.13
		Manufactured Ovoids	kt	NO	42.58	9.86	NO	4.39	28.34	32.00	NCV	906.76	26.81	24.31	NO	24.31	1.00	89.13
Solid fossil totals												57498.00		1485.98	NO	1485.98		5448.61
Gaseous fossil		Natural gas (dry)	TJ	104368.57	71359.37	NO		-2254.75	177982.69	1.00	NCV	177982.69	15.23	2711.50	NO	2711.50	1.00	9942.17
Other gaseous fossil												NO		NO	NO	NO		NO
Gaseous fossil totals												177982.69		2711.50	NO	2711.50		9942.17
Waste (non-biomass fraction)			TJ	2617.73	NO	NO	NO	NO	2617.73	1.00	NCV	2617.73	24.41	63.91	NO	63.91	1.00	234.34
Other fossil fuels												NO		NO	NO	NO		NO
		Other fossil	TJ	NO	NO	NO		NO	NO	NO	NCV	NO	NO	NO	NO	NO	NO	NO
Peat[(5,6)]			TJ	28432.18	NO	195.44	NO	-2488.50	30725.25	1.00	NCV	30725.25	31.30	961.55	NO	961.55	1.00	3525.68
Total												534279.72		10509.81	227.63	10282.18		37701.31
Biomass total												20941.72		597.79	NO	597.79		2191.88
		Solid biomass	TJ	11043.63	1917.03	8.64		47.30	12904.73	1.00	NCV	12904.73	29.43	379.74	NO	379.74	1.00	1392.38
		Liquid biomass	TJ	1021.94	3900.84	NO		285.17	4637.61	1.00	NCV	4637.61	33.14	153.68	NO	153.68	1.00	563.51
		Gas biomass	TJ	2293.58	NO	NO		NO	2293.58	1.00	NCV	2293.58	14.90	34.17	NO	34.17	1.00	125.31
		Other non-fossil fuels (biogenic waste)	TJ	1105.81	NO	NO		NO	1105.81	1.00	NCV	1105.81	27.30	30.19	NO	30.19	1.00	110.69

Table 3.1.5 Comparison of Results from Sectoral Approach and Reference Approach for 2016 (CRF 2018 Table 1.A(c)]

FUEL TYPES	REFERENCE APPROACH			SECTORAL APPROACH[1]		DIFFERENCE[2]	
	Apparent energy consumption[3] (PJ)	Apparent energy consumption (excluding non-energy use, reductants and feedstocks) [4] (PJ)	CO_2 emissions (kt)	Energy consumption (PJ)	CO_2 emissions[5] (kt)	Energy consumption (%)	CO_2 emissions[6] (%)
Liquid fuels (excluding international bunkers)	265.46	254.88	18550.51	252.48	18381.31	0.95	0.92
Solid fuels (excluding international bunkers)	57.50	57.50	5448.61	58.20	5439.43	-1.21	0.17
Gaseous fuels	177.98	177.98	9942.17	177.52	9820.27	0.26	1.24
Other fossil fuels	2.62	2.62	234.34	2.77	248.09	-5.54	-5.54
Peat	30.73	30.73	3525.68	30.61	3446.03	0.37	2.31
Total[5]	534.28	523.70	37701.31	521.59	37335.13	0.41	0.98

Table 3.1.6 Implied emission factors (IEFs) for CO_2 – Liquid Fuels in Sector 1.A.1.a

Energy (TJ)	References	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Heavy Fuel Oil	Energy balance data	13,979	25,319	41,772	30,041	15,749	14,188	8,383	4,335	1,696	1,649	1,394	1,984	2,430	2,189
Gasoil	Energy balance data	303	650	1,213	2,841	580	457	355	1,096	325	304	188	315	796	457
Total		14,282	25,968	42,984	32,882	16,329	14,645	8,738	5,431	2,021	1,953	1,582	2,300	3,226	2,645

Tier 1 EFs (t CO_2/TJ)	References	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Heavy Fuel Oil	IPCC 2006 GLs, Ch2, V2, Table 2.2	77.40	77.40	77.40	77.40	77.40	77.40	77.40	77.40	77.40	77.40	77.40	77.40	77.40	77.40
Gasoil	IPCC 2006 GLs, Ch2, V2, Table 2.2	74.10	74.10	74.10	74.10	74.10	74.10	74.10	74.10	74.10	74.10	74.10	74.10	74.10	74.10

Tier 1 Approach	Units	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Heavy Fuel Oil	kt CO_2 eq	1,082	1,960	3,233	2,325	1,219	1,098	649	336	131	128	108	154	188	169
Gasoil	kt CO_2 eq	22	48	90	211	43	34	26	81	24	23	14	23	59	34
Total CO_2 Emissions	kt CO_2 eq	**1,104**	**2,008**	**3,323**	**2,536**	**1,262**	**1,132**	**675**	**417**	**155**	**150**	**122**	**177**	**247**	**203**
IEF Tier 1	t CO_2/TJ	77.33	77.32	77.31	77.11	77.28	77.30	77.27	76.73	76.87	76.89	77.01	76.95	76.59	76.83

Tier 3 Approach	Units	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Total CO_2 Emissions	**kt CO_2 eq**	**1,087**	**1,986**	**3,484**	**2,563**	**1,284**	**1,143**	**680**	**424**	**158**	**153**	**124**	**182**	**250**	**206**
IEF Tier 3	t CO_2/TJ	76.08	76.47	81.06	77.94	78.65	78.08	77.87	78.03	78.31	78.13	78.54	79.35	77.39	77.79

	Units	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Difference between Tier 1 and Tier 3 IEF	**%**	**-1.65%**	**-1.11%**	**4.63%**	**1.06%**	**1.73%**	**1.00%**	**0.77%**	**1.66%**	**1.84%**	**1.60%**	**1.95%**	**3.02%**	**1.03%**	**1.23%**

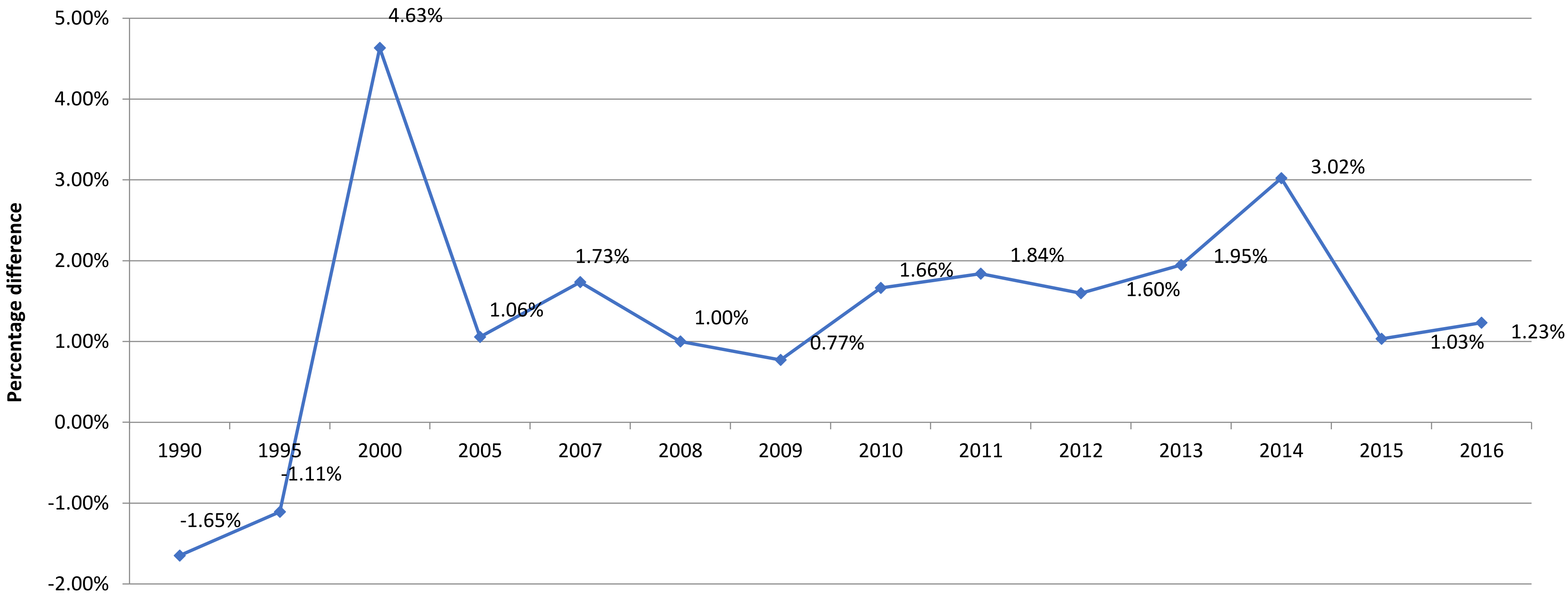


Figure 3.1.1 Percentage Difference between Tier 1 Approach and Tier 3 Approach IEFs for CO_2 – Liquid Fuels in Sector 1.A.1.a

Table 3.1.7 Implied emission factors (IEFs) for CO_2 – Solid Fuels in Sector 1.A.1.a

Energy (TJ)	References	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Coal	Energy balance data	51,972	62,585	59,728	59,308	49,050	41,506	32,444	36,321	38,228	48,572	40,625	39,442	47,181	46,106
Milled Peat	Energy balance data	23,464	23,386	20,022	20,488	18,807	23,857	23,314	20,144	19,800	23,027	20,830	22,686	22,910	21,476
Sod Peat	Energy balance data	1,324	315	-	-	-	-	-	-	-	-	-	-	-	-
Total		**76,759**	**86,285**	**79,750**	**79,796**	**67,856**	**65,363**	**55,758**	**56,465**	**58,028**	**71,599**	**61,456**	**62,128**	**70,092**	**67,582**

Tier 1 EFs (t CO_2/TJ)	References	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Coal	Table 2.2 Vol2 Ch2 of IPCC 2006 GLs	94.60	94.60	94.60	94.60	94.60	94.60	94.60	94.60	94.60	94.60	94.60	94.60	94.60	94.60
Milled Peat		106.00	106.00	106.00	106.00	106.00	106.00	106.00	106.00	106.00	106.00	106.00	106.00	106.00	106.00
Sod Peat		106.00	106.00	106.00	106.00	106.00	106.00	106.00	106.00	106.00	106.00	106.00	106.00	106.00	106.00

Tier 1 Approach	Units	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Coal	kt CO_2 eq	4,916.6	5,920.5	5,650.3	5,610.5	4,640.1	3,926.4	3,069.2	3,435.9	3,616.4	4,594.9	3,843.2	3,731.2	4,463.4	4,361.6
Milled Peat	kt CO_2 eq	2,487.1	2,478.9	2,122.3	2,171.7	1,993.5	2,528.8	2,471.3	2,135.3	2,098.8	2,440.9	2,208.0	2,404.7	2,428.5	2,276.4
Sod Peat	kt CO_2 eq	140.3	33.3	-	-	-	-	-	-	-	-	-	-	-	-
Total CO_2 Emissions	**kt CO_2 eq**	**7,544.0**	**8,432.7**	**7,772.6**	**7,782.2**	**6,633.6**	**6,455.3**	**5,540.5**	**5,571.2**	**5,715.2**	**7,035.8**	**6,051.2**	**6,135.9**	**6,891.8**	**6,638.1**
IEF Tier 1	t CO_2/TJ	98.3	97.7	97.5	97.5	97.8	98.8	99.4	98.7	98.5	98.3	98.5	98.8	98.3	98.2

Tier 3 Approach	Units	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Total CO_2 Emissions	**kt CO_2 eq**	7,909	8,645	8,084	7,910	6,704	6,631	5,766	5,688	5,857	7,228	6,256	6,293	6,995	6,787
IEF Tier 3	t CO_2/TJ	103.04	100.19	101.37	99.12	98.79	101.45	103.40	100.74	100.94	100.96	101.79	101.30	99.79	100.42

	Units	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Difference between Tier 1 and Tier 3 IEF	**%**	**4.62%**	**2.46%**	**3.86%**	**1.61%**	**1.05%**	**2.65%**	**3.90%**	**2.06%**	**2.43%**	**2.67%**	**3.27%**	**2.50%**	**1.47%**	**2.19%**

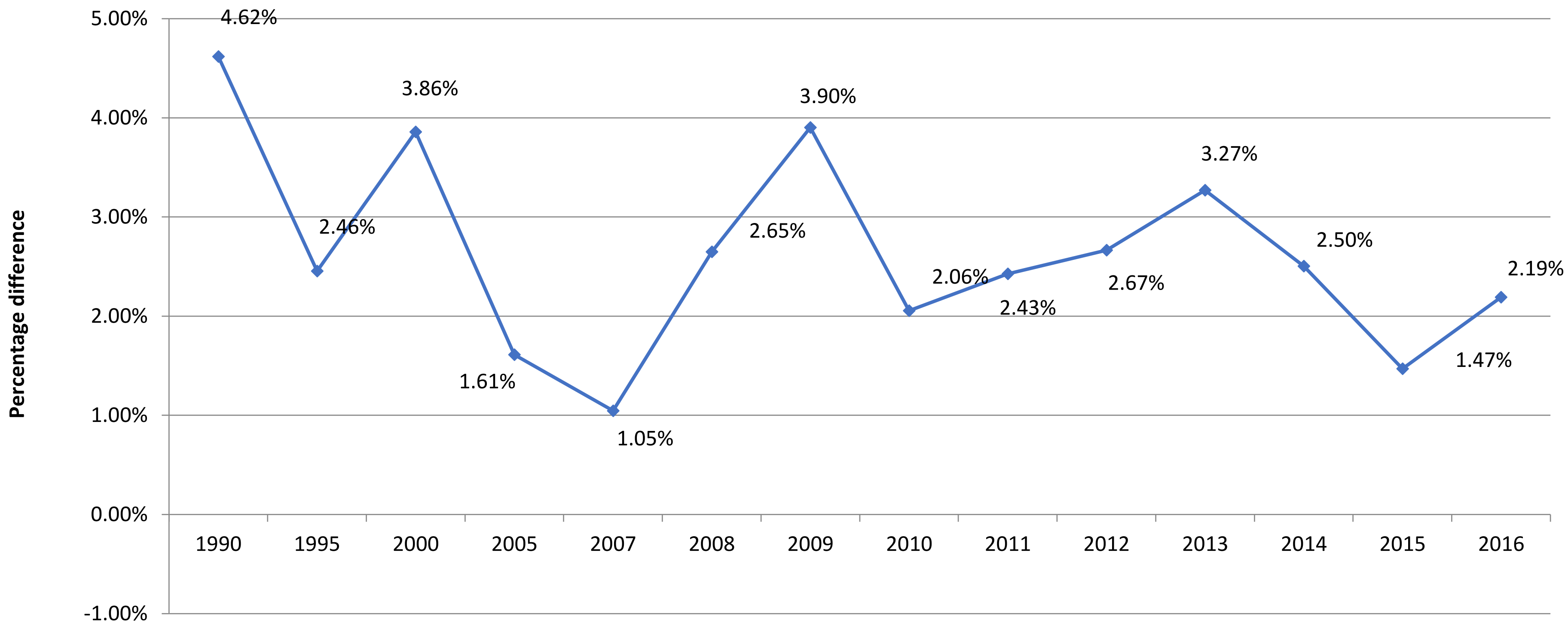


Figure 3.1.2 Percentage Difference between Tier 1 Approach and Tier 3 Approach IEFs for CO_2 – Solid Fuels in Sector 1.A.1.a

Table 3.1.8 Implied emission factors (IEFs) for CO_2 – Liquid Fuels in Sector 1.A.2.f

Energy (TJ)	**References**	**1990**	**1995**	**2000**	**2005**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Kerosene	Energy balance data	29	62	132	459	647	419	568	445	352	300	311	295	341	359
Fuel Oil	Energy balance data	733	858	991	467	714	363	500	378	101	89	197	148	147	134
LPG	Energy balance data	313	244	298	321	162	66	39	50	48	47	57	51	52	55
Gasoil	Energy balance data	677	853	773	2,073	1,802	2,394	2,188	2,070	1,983	1,890	1,639	1,468	1,414	1,485
Petroleum Coke	Energy balance data	1,972	836	1,755	9,924	10,016	9,162	4,817	3,054	2,833	3,800	3,703	4,736	5,195	5,585
Naphta	Energy balance data	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total		**3,724**	**2,852**	**3,950**	**13,243**	**13,340**	**12,403**	**8,112**	**5,997**	**5,316**	**6,125**	**5,906**	**6,698**	**7,149**	**7,618**
Tier 1 EFs (t CO_2/TJ)	**References**	**1990**	**1995**	**2000**	**2005**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Kerosene	Table 2.2 Vol2 Ch2 of IPCC 2006 GLs	71.90	71.90	71.90	71.90	71.90	71.90	71.90	71.90	71.90	71.90	71.90	71.90	71.90	71.90
Fuel Oil	Table 2.2 Vol2 Ch2 of IPCC 2006 GLs	77.40	77.40	77.40	77.40	77.40	77.40	77.40	77.40	77.40	77.40	77.40	77.40	77.40	77.40
LPG	Table 2.2 Vol2 Ch2 of IPCC 2006 GLs	63.10	63.10	63.10	63.10	63.10	63.10	63.10	63.10	63.10	63.10	63.10	63.10	63.10	63.10
Gasoil	Table 2.2 Vol2 Ch2 of IPCC 2006 GLs	74.10	74.10	74.10	74.10	74.10	74.10	74.10	74.10	74.10	74.10	74.10	74.10	74.10	74.10
Petroleum Coke	Table 2.2 Vol2 Ch2 of IPCC 2006 GLs	97.50	97.50	97.50	97.50	97.50	97.50	97.50	97.50	97.50	97.50	97.50	97.50	97.50	97.50
Naphta	Table 2.2 Vol2 Ch2 of IPCC 2006 GLs	73.30	73.30	73.30	73.30	73.30	73.30	73.30	73.30	73.30	73.30	73.30	73.30	73.30	73.30
Tier 1 Approach	**Units**	**1990**	**1995**	**2000**	**2005**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Kerosene	kt CO_2 eq	2	4	10	33	47	30	41	32	25	22	22	21	25	26
Fuel Oil	kt CO_2 eq	57	66	77	36	55	28	39	29	8	7	15	11	11	10
LPG	kt CO_2 eq	20	15	19	20	10	4	2	3	3	3	4	3	3	3
Gasoil	kt CO_2 eq	50	63	57	154	134	177	162	153	147	140	121	109	105	110
Petroleum Coke	kt CO_2 eq	192	81	171	968	977	893	470	298	276	370	361	462	506	545
Naphta	kt CO_2 eq	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total CO_2 Emissions	**kt CO_2 eq**	**321**	**231**	**333**	**1,211**	**1,222**	**1,133**	**714**	**516**	**459**	**542**	**524**	**606**	**650**	**694**
IEF Tier 1	t CO_2/TJ	86.20	80.96	84.42	91.41	91.60	91.35	87.99	85.97	86.39	88.47	88.66	90.54	90.99	91.13
Tier 3 Approach	**Units**	**1990**	**1995**	**2000**	**2005**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Total CO_2 Emissions	**kt CO_2 eq**	**312**	**226**	**325**	**1,185**	**1,176**	**1,089**	**692**	**501**	**445**	**522**	**505**	**583**	**634**	**676**
IEF Tier 3	t CO_2/TJ	83.79	79.21	82.23	89.45	88.18	87.77	85.31	83.59	83.76	85.29	85.51	87.03	88.63	88.69
	Units	**1990**	**1995**	**2000**	**2005**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Difference between Tier 1 and Tier 3 IEF	**%**	**-2.88%**	**-2.21%**	**-2.66%**	**-2.19%**	**-3.88%**	**-4.08%**	**-3.14%**	**-2.85%**	**-3.13%**	**-3.73%**	**-3.68%**	**-4.04%**	**-2.66%**	**-2.75%**
% Share of Fuels	**Units**	**1990**	**1995**	**2000**	**2005**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Kerosene	%	0.79%	2.18%	3.35%	3.46%	4.85%	3.38%	7.00%	7.42%	6.61%	4.90%	5.26%	4.40%	4.77%	4.71%
Fuel Oil	%	19.68%	30.08%	25.09%	3.53%	5.35%	2.92%	6.17%	6.31%	1.89%	1.45%	3.34%	2.21%	2.06%	1.75%
LPG	%	8.40%	8.55%	7.55%	2.42%	1.21%	0.53%	0.48%	0.83%	0.91%	0.76%	0.96%	0.76%	0.72%	0.72%
Gasoil	%	18.18%	29.90%	19.57%	15.65%	13.51%	19.30%	26.97%	34.51%	37.30%	30.85%	27.75%	21.92%	19.78%	19.50%
Petroleum Coke	%	52.95%	29.30%	44.45%	74.94%	75.08%	73.87%	59.38%	50.93%	53.28%	62.03%	62.69%	70.71%	72.66%	73.31%
Naphta	%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	-	-	-	-	-	-

Annex 3.1.B

Energy - Transport (IPCC Sector 1.A.3)

3.1.9 – 3.1.12 Civil aviation data 1990-2016

3.1.13 Vehicle population data 1990-2016

3.1.14 Historic vehicle mileage and speed

Table 3.1.9 Number of Domestic LTOs by departure airport 1990-2016

Domestic LTOs (number)	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
ex Dublin	7,657	7,235	11,018	9,976	10,803	9,611	7,844	6,074	3,331	2,190	2,101	2,058	1,980	2,118
ex Cork	2,872	2,713	4,132	3,649	4,608	3,919	2,872	1,861	809	445	441	382	259	210
ex Shannon	1,737	1,641	2,500	2,809	2,277	1,897	1,349	1,077	834	764	800	696	636	596
ex Galway	1,425	1,347	2,051	1,631	1,815	1,848	1,563	1,746	1,252	51	31	NO	11	1
ex Sligo	620	586	892	759	754	785	741	678	381	35	25	24	20	21
ex Donegal	581	549	836	684	736	754	739	697	721	733	723	732	725	732
ex Knock	445	421	641	565	568	481	510	454	253	79	83	67	60	62
ex Kerry	1,133	1,070	1,630	1,477	1,506	1,418	1,170	1,048	460	781	776	775	778	782
ex Waterford	236	223	340	181	279	456	231	472	707	175	155	67	68	87
ex Other	347	328	499	495	411	476	305	282	277	241	282	191	205	152
Total	**17,053**	**16,113**	**24,538**	**22,226**	**23,757**	**21,645**	**17,324**	**14,389**	**9,025**	**5,494**	**5,417**	**4,992**	**4,742**	**4,761**
Domestic LTOs (%)	**1990**	**1995**	**2000**	**2005**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
ex Dublin	45%	45%	45%	45%	45%	44%	45%	42%	37%	40%	39%	41%	42%	44%
ex Cork	17%	17%	17%	16%	19%	18%	17%	13%	9%	8%	8%	8%	5%	4%
ex Shannon	10%	10%	10%	13%	10%	9%	8%	7%	9%	14%	15%	14%	13%	13%
ex Galway	8%	8%	8%	7%	8%	9%	9%	12%	14%	1%	1%	NA	0%	0%
ex Sligo	4%	4%	4%	3%	3%	4%	4%	5%	4%	1%	0%	0%	0%	0%
ex Donegal	3%	3%	3%	3%	3%	3%	4%	5%	8%	13%	13%	15%	15%	15%
ex Knock	3%	3%	3%	3%	2%	2%	3%	3%	3%	1%	2%	1%	1%	1%
ex Kerry	7%	7%	7%	7%	6%	7%	7%	7%	5%	14%	14%	16%	16%	16%
ex Waterford	1%	1%	1%	1%	1%	2%	1%	3%	8%	3%	3%	1%	1%	2%
ex Other	2%	2%	2%	2%	2%	2%	2%	2%	3%	4%	5%	4%	4%	3%

Table 3.1.10 Distances between airport pairs used to estimate fuel consumption for cruise phase

Nautical Miles		Cork	Galway	Donegal	Dublin	Knock	Kerry	Shannon	Sligo	Waterford	Other
		EICK	EICM	EIDL	EIDW	EIKN	EIKY	EINN	EISG	EIWF	
Cork	EICK		89.18	192.52	124.89	124.88	43.37	54.12	146.58	56.04	89.18
Galway	EICM	89.18		106.92	96.28	36.93	70.51	35.94	60.13	95.09	89.18
Donegal	EIDL	192.52	106.92		121.75	70.16	177.15	142.26	46.80	177.42	89.18
Dublin	EIDW	124.89	96.28	121.75		95.56	139.93	105.34	97.52	79.89	89.18
Knock	EIKN	124.88	36.93	70.16	95.56		106.99	72.70	23.53	121.02	89.18
Kerry	EIKY	43.37	70.51	177.15	139.93	106.99		38.25	130.45	89.97	89.18
Shannon	EINN	54.12	35.94	142.26	105.34	72.70	38.25		95.53	74.21	89.18
Sligo	EISG	146.58	60.13	46.80	97.52	23.53	130.45	95.53		137.05	89.18
Waterford	EIWF	56.04	95.09	177.42	79.89	121.02	89.97	74.21	137.05		89.18
Other		89.18	89.18	89.18	89.18	89.18	89.18	89.18	89.18	89.18	

Table 3.1.11 LTO emissions factors by aircraft type

Aircraft Type	kg of fuel per LTO	CH_4 kg/ LTO	N_2O kg/ LTO
A30B	1,540.55	0.12	0.20
A310	1,540.55	0.63	0.20
A320	802.33	0.06	0.10
A321	802.33	0.14	0.10
A332	2,231.52	0.13	0.20
A333	2,231.52	0.13	0.20
A343	2,231.52	0.39	0.20
AT43	115.20	0.02	0.02
AT72	137.00	0.03	0.02
ATP	569.51	0.10	0.10
B462	569.51	0.14	0.10
B463	569.51	0.14	0.10
B733	825.39	0.08	0.10
B734	825.39	0.08	0.10
B737	784.12	0.09	0.10
B738	763.48	0.07	0.10
B752	1,253.00	0.02	0.10
B762	1,617.09	0.33	0.10
B763	1,617.09	0.12	0.20
B764	1,617.09	0.10	0.20
BE20	51.80	0.06	0.01
BE40	58.30	0.06	0.01
CL30	569.51	0.10	0.10
CL60	569.51	0.10	0.10
DC10	2,381.18	0.24	0.20
GLF2	569.51	0.14	0.10
GLF4	569.51	0.14	0.10
GLF5	569.51	0.03	0.10
H25B	569.51	0.14	0.10
LJ31	569.51	0.14	0.10
LJ45	569.51	0.14	0.10
LJ60	569.51	0.14	0.10
MD11	1,003.06	0.24	0.20
MD82	1,003.06	0.19	0.10
MD83	1,003.06	0.19	0.10
T154	2,190.00	7.59	0.20
Other	49.57	0.02	0.10

Table 3.1.12 Weighted Cruise fuel use per flight (IEF) by departure airport 1990-2016

Airport	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
ex Dublin	494.8	494.8	494.8	459.8	496.4	510.5	526.2	490.8	409.1	390.2	359.3	348.4	394.5	349.1
ex Cork	394.2	394.2	394.2	266.9	410.7	439.8	494.8	501.9	394.4	173.2	168.7	188.6	256.9	254.9
ex Shannon	979.8	979.8	979.8	1055.9	978.1	990.0	938.6	826.5	625.6	655.3	549.0	573.7	710.4	679.6
ex Galway	167.3	167.3	167.3	160.3	176.9	196.1	160.5	159.2	147.9	124.7	102.8	NO	89.6	36.5
ex Sligo	165.7	165.7	165.7	164.1	165.6	163.6	167.6	168.0	143.7	108.2	97.6	92.5	91.6	93.6
ex Donegal	213.7	213.7	213.7	210.6	215.2	212.4	216.0	215.6	191.0	126.4	127.0	127.4	208.0	213.5
ex Knock	214.5	214.5	214.5	202.7	244.8	230.1	201.6	186.8	176.0	240.2	232.3	323.4	276.9	251.6
ex Kerry	421.1	421.1	421.1	247.8	242.4	452.1	757.9	753.8	533.6	242.7	240.6	229.9	229.6	239.0
ex Waterford	158.9	158.9	158.9	109.8	210.1	287.0	130.4	164.8	151.2	101.9	72.7	88.4	87.5	83.3
ex Other	150.6	150.6	150.6	157.6	165.4	139.9	140.7	141.8	159.7	138.0	128.0	143.8	136.8	113.5
Average	**454.5**	**454.5**	**454.5**	**433.5**	**451.1**	**467.0**	**485.6**	**440.6**	**334.9**	**326.7**	**298.9**	**303.9**	**354.8**	**332.5**

Table 3.1.13 Vehicle numbers, by technology class 1990-2016

Vehicle by Sector, Subsector, Technology*	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
PC,Small (<1.4L),PRE ECE	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PC,Small (<1.4L),ECE 15/00-01	38455	5224	0	0	0	0	0	0	0	0	0	0	0	0
PC,Small (<1.4L),ECE 15/02	62490	15673	37	0	0	0	0	0	0	0	0	0	0	0
PC,Small (<1.4L),ECE 15/03	187469	104488	6941	0	0	0	0	0	0	0	0	0	0	0
PC,Small (<1.4L),ECE 15/04	192276	245547	124459	25246	11489	3758	3111	2349	2016	1901	949	810	668	490
PC,Small (<1.4L),Open Loop	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PC,Small (<1.4L),E 1	0	151508	229196	130173	77929	81303	56760	41730	28922	22019	7739	6483	5344	3918
PC,Small (<1.4L),E 2	0	0	333506	359730	307589	365013	336509	286154	253098	216941	201061	171676	141522	103767
PC,Small (<1.4L),E 3	0	0	0	273777	258354	295682	299096	287708	285219	280034	276634	268402	255527	232825
PC,Small (<1.4L),E 4	0	0	0	0	143395	204450	223224	240298	243904	248206	251944	255692	259576	263219
PC,Small (<1.4L),E 5	0	0	0	0	0	0	0	0	14814	27035	39297	56471	59174	63026
PC,Small (<1.4L),E 6	0	0	0	0	0	0	0	0	0	0	0	0	21423	48887
PC,Medium (1.4L-2.0L),PRE ECE	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PC,Medium (1.4L-2.0L),ECE 15/00-01	18263	3153	0	0	0	0	0	0	0	0	0	0	0	0
PC,Medium (1.4L-2.0L),ECE 15/02	29677	9459	22	0	0	0	0	0	0	0	0	0	0	0
PC,Medium (1.4L-2.0L),ECE 15/03	89030	63061	4191	0	0	0	0	0	0	0	0	0	0	0
PC,Medium (1.4L-2.0L),ECE 15/04	91313	148194	75149	18190	9511	2199	1786	1387	1146	1046	504	409	316	216
PC,Medium (1.4L-2.0L),Open Loop	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PC,Medium (1.4L-2.0L),E 1	0	91439	138389	93792	64507	47570	32588	24352	16717	12425	4434	3269	2530	1723
PC,Medium (1.4L-2.0L),E 2	0	0	201371	259194	254611	213566	193205	166989	143831	119396	106786	86566	67003	45629
PC,Medium (1.4L-2.0L),E 3	0	0	0	197262	213856	173002	171724	168168	162071	154101	146907	135659	121309	102698
PC,Medium (1.4L-2.0L),E 4	0	0	0	0	118698	119622	128163	143356	140996	138768	136307	131619	125851	119089
PC,Medium (1.4L-2.0L),E 5	0	0	0	0	0	0	0	0	8750	15439	21812	29962	29736	29848
PC,Medium (1.4L-2.0L),E 6	0	0	0	0	0	0	0	0	0	0	0	0	10809	23795
PC,Large (>2.0L),PRE ECE	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PC,Large (>2.0L),ECE 15/00-01	1319	199	0	0	0	0	0	0	0	0	0	0	0	0
PC,Large (>2.0L),ECE 15/02	2144	596	2	0	0	0	0	0	0	0	0	0	0	0
PC,Large (>2.0L),ECE 15/03	6431	3971	377	0	0	0	0	0	0	0	0	0	0	0
PC,Large (>2.0L),ECE 15/04	6596	9332	6767	2192	1353	188	149	118	86	73	33	26	19	13
PC,Large (>2.0L),E 1	0	5758	12463	11303	9174	4072	2713	1912	1408	1012	425	205	153	101
PC,Large (>2.0L),E 2	0	0	18134	31235	36208	18283	16082	13114	10753	8375	7055	5433	4052	2665
PC,Large (>2.0L),E 3	0	0	0	23772	30413	14810	14294	13367	12108	10800	9699	8655	7470	6111
PC,Large (>2.0L),E 4	0	0	0	0	16880	10241	10668	11967	11303	10464	9733	9122	8471	7827
PC,Large (>2.0L),E 5	0	0	0	0	0	0	0	0	732	1248	1723	2423	2373	2391
PC,Large (>2.0L),E 6	0	0	0	0	0	0	0	0	0	0	0	0	922	2214
PC,Small (<2L),Conventional	69656	92660	30950	7170	4309	780	659	543	501	430	182	210	160	107
PC,Small (<2L),E 1	0	37847	53969	36971	29228	17728	12052	9011	6615	4943	1452	1403	1068	716
PC,Small (<2L),E 2	0	0	78532	102168	115363	66463	62641	54765	50321	42158	38544	30567	23266	15602
PC,Small (<2L),E 3	0	0	0	77756	96897	115476	127136	127691	133178	131765	132268	125665	115035	98142

Vehicle by Sector, Subsector, Technology*	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
PC,Small (<2L),E 4	0	0	0	0	53781	121117	163082	221145	245016	264644	288016	305440	312971	316958
PC,Small (<2L),E 5	0	0	0	0	0	0	0	0	53087	106094	160045	238024	260723	291452
PC,Small (<2L),E 6	0	0	0	0	0	0	0	0	0	0	0	0	74986	167013
PC,Large (>2.0L),Conventional	6057	6974	3439	1071	760	189	135	109	88	68	26	27	19	12
PC,Large (>2.0L),E 1	0	2849	5997	5525	5158	4295	2472	1814	1167	783	209	183	126	77
PC,Large (>2.0L),E 2	0	0	8726	15267	20358	16100	12847	11023	8877	6678	5545	3985	2753	1687
PC,Large (>2.0L),E 3	0	0	0	11619	17100	27973	26074	25702	23493	20873	19029	16384	13611	10609
PC,Large (>2.0L),E 4	0	0	0	0	9491	29339	33446	44513	43222	41923	41435	39823	37030	34262
PC,Large (>2.0L),E 5	0	0	0	0	0	0	0	0	9365	16807	23025	31036	30867	31673
PC,Large (>2.0L),E 6	0	0	0	0	0	0	0	0	0	0	0	0	8950	18152
PC,Mini,E 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PC,Small,E 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PC,Large-SUV-Executive,E 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PC,Small,Conventional	2830	1434	220	0	0	0	0	0	0	0	0	0	0	0
PC,Small,E 1	0	0	259	211	183	164	144	125	106	88	72	59	47	37
PC,Small,E 2	0	0	200	163	137	123	113	97	83	69	57	46	37	30
PC,Small,E 3	0	0	0	90	81	79	76	72	68	63	57	51	45	39
PC,Small,E 4	0	0	0	90	81	79	76	72	68	63	57	51	45	39
PC,Small,E 5	0	0	0	0	0	0	0	0	0	0	0	36	61	86
PC,Small,E 6	0	0	0	0	0	0	0	0	0	0	0	0	9	13
LDV,N1-II (<3.5t),Conventional	22695	8488	1579	141	49	33	25	17	11	5	4	3	2	2
LDV,N1-II (<3.5t),E 1	0	1927	1423	357	134	99	79	60	45	34	28	22	18	15
LDV,N1-II (<3.5t),E 2	0	0	1872	797	381	307	263	207	160	120	101	82	72	58
LDV,N1-II (<3.5t),E 3	0	0	0	937	496	442	425	372	312	256	236	215	203	168
LDV,N1-II (<3.5t),E 4	0	0	0	0	337	404	419	414	357	306	292	280	280	255
LDV,N1-II (<3.5t),E 5	0	0	0	0	0	0	0	0	30	53	78	117	123	124
LDV,N1-II (<3.5t),E 6 up to 2017	0	0	0	0	0	0	0	0	0	0	0	0	51	108
LDV,N1-II (<3.5t),Conventional	99834	87988	54858	15614	10621	8121	6516	4747	3498	1972	1441	1149	926	640
LDV,N1-II (<3.5t),E 1	0	19973	49440	39654	29131	24051	20170	16613	14285	12392	10951	8846	7111	6126
LDV,N1-II (<3.5t),E 2	0	0	65017	88477	82841	74651	67336	57256	51017	43655	39482	32627	28803	24504
LDV,N1-II (<3.5t),E 3	0	0	0	104091	107724	107448	108917	103239	99411	93224	92220	85789	80673	70449
LDV,N1-II (<3.5t),E 4	0	0	0	0	73131	98078	107365	114809	113696	111249	113834	111983	111688	107205
LDV,N1-II (<3.5t),E 5	0	0	0	0	0	0	0	0	9620	19152	30260	46815	49091	52071
LDV,N1-II (<3.5t),E 6 up to 2017	0	0	0	0	0	0	0	0	0	0	0	0	20497	45305
HDV,>3,5 t,Conventional	294	231	167	71	44	42	38	30	25	23	24	24	21	17
HDV,Rigid <=7,5 t,Conventional	9628	8222	3892	952	589	432	336	247	200	132	108	81	63	43
HDV,Rigid <=7,5 t,E I	0	873	2335	1423	986	759	596	454	390	318	287	223	173	126
HDV,Rigid <=7,5 t,E II	0	0	3882	3820	3282	2790	2361	1904	1667	1359	1228	992	844	703
HDV,Rigid <=7,5 t,E III	0	0	0	4504	4267	4016	3802	3432	3247	2920	2868	2608	2364	2092
HDV,Rigid <=7,5 t,E IV	0	0	0	0	2897	3677	3737	3827	3714	3485	3541	3405	3273	3126

Vehicle by Sector, Subsector, Technology*	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
HDV,Rigid <=7,5 t,E V	0	0	0	0	0	0	0	0	305	609	932	1424	1439	1505
HDV,Rigid <=7,5 t,E VI	0	0	0	0	0	0	0	0	0	0	0	0	601	1327
HDV,Rigid 7,5 - 12 t,Conventional	9219	10448	5889	1434	830	550	387	281	225	150	129	103	84	66
HDV,Rigid 7,5 - 12 t,E I	0	1109	3533	2143	1389	967	687	517	440	359	345	283	232	194
HDV,Rigid 7,5 - 12 t,E II	0	0	5874	5753	4626	3554	2724	2171	1878	1535	1477	1259	1128	1080
HDV,Rigid 7,5 - 12 t,E III	0	0	0	6784	6015	5116	4386	3914	3660	3299	3450	3309	3160	3217
HDV,Rigid 7,5 - 12 t,E IV	0	0	0	0	4084	4685	4311	4364	4185	3937	4258	4320	4375	4807
HDV,Rigid 7,5 - 12 t,E V	0	0	0	0	0	0	0	0	343	688	1121	1806	1923	2314
HDV,Rigid 7,5 - 12 t,E VI	0	0	0	0	0	0	0	0	0	0	0	0	803	2040
HDV,Rigid 12 - 14 t,Conventional	1414	2048	1791	612	401	265	176	124	103	71	66	53	44	33
HDV,Rigid 12 - 14 t,E I	0	217	1075	915	671	465	313	229	202	171	176	146	122	97
HDV,Rigid 12 - 14 t,E II	0	0	1787	2457	2234	1710	1240	960	860	730	754	650	593	541
HDV,Rigid 12 - 14 t,E III	0	0	0	2897	2905	2462	1996	1731	1677	1570	1761	1709	1661	1612
HDV,Rigid 12 - 14 t,E IV	0	0	0	0	1972	2254	1962	1930	1918	1873	2173	2231	2300	2409
HDV,Rigid 12 - 14 t,E V	0	0	0	0	0	0	0	0	157	327	572	933	1011	1160
HDV,Rigid 12 - 14 t,E VI	0	0	0	0	0	0	0	0	0	0	0	0	422	1023
HDV,Rigid 14 - 20 t,Conventional	273	403	511	245	187	145	104	80	68	48	43	35	30	27
HDV,Rigid 14 - 20 t,E I	0	43	307	366	314	254	184	147	134	114	114	97	84	78
HDV,Rigid 14 - 20 t,E II	0	0	510	982	1044	934	728	618	571	488	487	430	410	436
HDV,Rigid 14 - 20 t,E III	0	0	0	1158	1358	1344	1172	1114	1112	1049	1137	1131	1148	1299
HDV,Rigid 14 - 20 t,E IV	0	0	0	0	922	1231	1152	1242	1272	1251	1403	1477	1589	1942
HDV,Rigid 14 - 20 t,E V	0	0	0	0	0	0	0	0	104	219	370	617	698	935
HDV,Rigid 14 - 20 t,E VI	0	0	0	0	0	0	0	0	0	0	0	0	292	824
HDV,Rigid 20 - 26 t,Conventional	0	0	0	1	0	0	0	0	0	0	0	0	0	0
HDV,Rigid 20 - 26 t,E I	0	0	0	1	1	1	0	0	0	0	0	0	0	0
HDV,Rigid 20 - 26 t,E II	0	0	0	2	2	2	2	2	2	1	1	1	1	1
HDV,Rigid 20 - 26 t,E III	0	0	0	3	3	3	3	3	3	3	3	3	3	4
HDV,Rigid 20 - 26 t,E IV	0	0	0	0	2	3	3	3	4	3	4	4	4	6
HDV,Rigid 20 - 26 t,E V	0	0	0	0	0	0	0	0	0	1	1	2	2	3
HDV,Rigid 20 - 26 t,E VI	0	0	0	0	0	0	0	0	0	0	0	0	1	2
HDV,Rigid 26 - 28 t,Conventional	0	0	0	1	0	0	0	0	0	0	0	0	0	0
HDV,Rigid 26 - 28 t,E I	0	0	0	1	1	1	0	0	0	0	0	0	0	0
HDV,Rigid 26 - 28 t,E II	0	0	0	2	2	2	2	2	2	1	1	1	1	1
HDV,Rigid 26 - 28 t,E III	0	0	0	3	3	3	3	3	3	3	3	3	3	4
HDV,Rigid 26 - 28 t,E IV	0	0	0	0	2	3	3	3	4	3	4	4	4	6
HDV,Rigid 26 - 28 t,E V	0	0	0	0	0	0	0	0	0	1	1	2	2	3
HDV,Rigid 26 - 28 t,E VI	0	0	0	0	0	0	0	0	0	0	0	0	1	2
HDV,Rigid 28 - 32 t,Conventional	0	0	0	1	0	0	0	0	0	0	0	0	0	0
HDV,Rigid 28 - 32 t,E I	0	0	0	1	1	1	0	0	0	0	0	0	0	0
HDV,Rigid 28 - 32 t,E II	0	0	0	2	2	2	2	2	2	1	1	1	1	1

Vehicle by Sector, Subsector, Technology*	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
HDV,Rigid 28 - 32 t,E III	0	0	0	3	3	3	3	3	3	3	3	3	3	4
HDV,Rigid 28 - 32 t,E IV	0	0	0	0	2	3	3	3	4	3	4	4	4	6
HDV,Rigid 28 - 32 t,E V	0	0	0	0	0	0	0	0	0	1	1	2	2	3
HDV,Rigid 28 - 32 t,E VI	0	0	0	0	0	0	0	0	0	0	0	0	1	2
HDV,Rigid >32 t,Conventional	0	0	0	1	0	0	0	0	0	0	0	0	0	0
HDV,Rigid >32 t,E I	0	0	0	1	1	1	0	0	0	0	0	0	0	0
HDV,Rigid >32 t,E II	0	0	0	2	2	2	2	2	2	1	1	1	1	1
HDV,Rigid >32 t,E III	0	0	0	3	3	3	3	3	3	3	3	3	3	4
HDV,Rigid >32 t,E IV	0	0	0	0	2	3	3	3	4	3	4	4	4	6
HDV,Rigid >32 t,E V	0	0	0	0	0	0	0	0	0	1	1	2	2	3
HDV,Rigid >32 t,E VI	0	0	0	0	0	0	0	0	0	0	0	0	1	2
HDV,Articulated 40 - 50 t,Conventional	0	0	0	1	0	0	0	0	0	0	0	0	0	0
HDV,Articulated 40 - 50 t,E I	0	0	0	1	1	1	0	0	0	0	0	0	0	0
HDV,Articulated 40 - 50 t,E II	0	0	0	2	2	2	2	2	2	1	1	1	1	1
HDV,Articulated 40 - 50 t,E III	0	0	0	3	3	3	3	3	3	3	3	3	3	4
HDV,Articulated 40 - 50 t,E IV	0	0	0	0	2	3	3	3	4	3	4	4	4	6
HDV,Articulated 40 - 50 t,E V	0	0	0	0	0	0	0	0	0	1	1	2	2	3
HDV,Articulated 40 - 50 t,E VI	0	0	0	0	0	0	0	0	0	0	0	0	1	2
HDV,Articulated 50 - 60 t,Conventional	0	0	0	1	0	0	0	0	0	0	0	0	0	0
HDV,Articulated 50 - 60 t,E I	0	0	0	1	1	1	0	0	0	0	0	0	0	0
HDV,Articulated 50 - 60 t,E II	0	0	0	2	2	2	2	2	2	1	1	1	1	1
HDV,Articulated 50 - 60 t,E III	0	0	0	3	3	3	3	3	3	3	3	3	3	4
HDV,Articulated 50 - 60 t,E IV	0	0	0	0	2	3	3	3	4	3	4	4	4	6
HDV,Articulated 50 - 60 t,E V	0	0	0	0	0	0	0	0	0	1	1	2	2	3
HDV,Articulated 50 - 60 t,E VI	0	0	0	0	0	0	0	0	0	0	0	0	1	2
Urban Buses Standard 15 - 18 t,Conventional	1642	1107	553	295	213	181	136	105	97	88	93	114	34	27
Urban Buses Standard 15 - 18 t,E I	0	655	383	268	240	227	197	175	170	160	161	174	70	56
Urban Buses Standard 15 - 18 t,E II	0	0	732	711	655	615	554	502	464	421	389	370	246	197
Urban Buses Standard 15 - 18 t,E III	0	0	0	516	656	636	596	566	548	524	510	503	404	411
Urban Buses Standard 15 - 18 t,E IV	0	0	0	0	205	367	412	400	405	409	425	455	434	441
Urban Buses Standard 15 - 18 t,E V	0	0	0	0	0	0	0	54	88	149	213	242	320	326
Urban Buses Standard 15 - 18 t,E VI	0	0	0	0	0	0	0	0	0	0	0	0	424	549
Coaches Standard <=18 t,Conventional	3396	2827	2170	1194	808	657	461	319	273	233	267	371	59	0
Coaches Standard <=18 t,E I	0	1650	1444	1097	1012	987	897	807	754	654	574	550	279	55
Coaches Standard <=18 t,E II	0	0	2783	2958	2859	2825	2774	2682	2624	2550	2461	2366	2448	2061
Coaches Standard <=18 t,E III	0	0	0	2061	2637	2606	2553	2468	2423	2368	2314	2270	2397	2204
Coaches Standard <=18 t,E IV	0	0	0	0	776	1461	1718	1717	1808	1884	2046	2298	2617	2513
Coaches Standard <=18 t,E V	0	0	0	0	0	0	0	111	210	465	677	667	706	856
Coaches Standard <=18 t,E VI	0	0	0	0	0	0	0	0	0	0	0	0	419	1728
Mopeds 2-stroke <50 cm³,Conventional	637	657	686	394	344	331	377	297	241	208	188	163	142	125

Vehicle by Sector, Subsector, Technology*	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Mopeds 2-stroke <50 cm³,E I	0	0	172	423	406	408	471	400	341	321	296	282	267	250
Mopeds 2-stroke <50 cm³,E II	0	0	0	144	208	210	256	206	181	170	161	146	142	141
Mopeds 2-stroke <50 cm³,E III	0	0	0	0	83	155	242	240	241	246	251	265	284	316
Mopeds 4-stroke <50 cm³,Conventional	637	657	686	394	344	331	377	297	240	208	188	162	142	125
Mopeds 4-stroke <50 cm³,E I	0	0	172	422	406	408	471	400	341	321	295	282	267	250
Mopeds 4-stroke <50 cm³,E II	0	0	0	144	208	210	256	206	180	170	161	145	142	141
Mopeds 4-stroke <50 cm³,E III	0	0	0	0	83	154	242	240	240	246	251	265	284	316
Motorcycles 2-stroke >50 cm³,Conventional	2320	2392	3125	3499	3792	4020	4335	4024	3714	3438	3329	3178	3077	3082
Motorcycles 4-stroke <250 cm³,Conventional	2320	2392	2500	1434	1251	1206	1214	1046	891	756	699	604	523	462
Motorcycles 4-stroke <250 cm³,E I	0	0	625	1539	1479	1487	1517	1408	1263	1169	1099	1049	985	924
Motorcycles 4-stroke <250 cm³,E II	0	0	0	525	758	764	823	724	669	619	599	540	523	524
Motorcycles 4-stroke <250 cm³,E III	0	0	0	0	303	563	780	845	891	894	932	985	1046	1171
Motorcycles 4-stroke 250 - 750 cm³,Conventional	15148	15619	16324	9366	8171	7874	7104	6508	5864	5215	5325	4874	4460	4076
Motorcycles 4-stroke 250 - 750 cm³,E I	0	0	4081	10051	9657	9711	8880	8761	8308	8060	8368	8466	8396	8153
Motorcycles 4-stroke 250 - 750 cm³,E II	0	0	0	3427	4952	4987	4820	4505	4398	4267	4564	4361	4460	4620
Motorcycles 4-stroke 250 - 750 cm³,E III	0	0	0	0	1981	3675	4567	5256	5864	6164	7100	7953	8920	10327
Motorcycles 4-stroke >750 cm³,Conventional	1683	1735	1814	1041	908	875	789	723	652	579	592	542	496	453
Motorcycles 4-stroke >750 cm³,E I	0	0	453	1117	1073	1079	987	973	923	896	930	941	933	906
Motorcycles 4-stroke >750 cm³,E II	0	0	0	381	550	554	536	501	489	474	507	485	496	513
Motorcycles 4-stroke >750 cm³,E III	0	0	0	0	220	408	507	584	652	685	789	884	991	1148

**PC=Passenger Cars (Large PCs are SUV-Executive); LDV= Light Duty/Commercial Vehicle & HDV= Heavy Duty Vehicle/Truck; E= Euro Standard*

3.1.14 Historic vehicle mileage and speed

The mileage data for the above vehicle categories 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.

*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^2 was 0.59 and validation R^2 was 0.58 (Max. VIF<8).

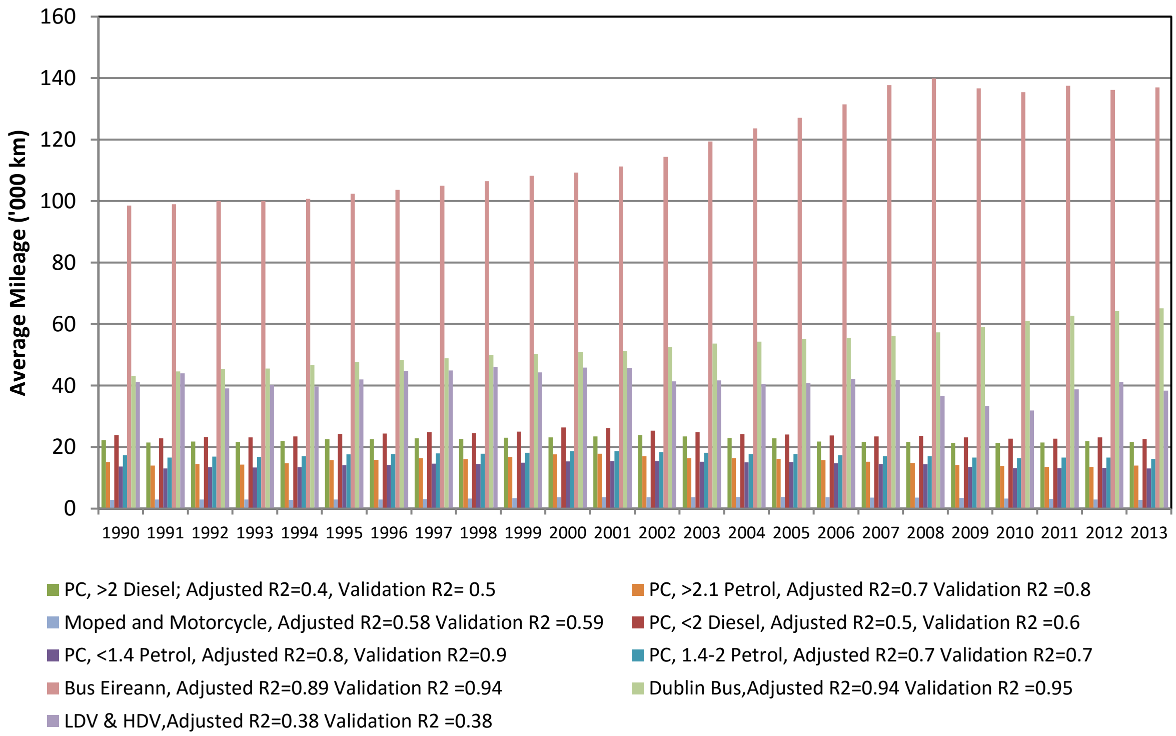


Figure 3.1.3 Average vehicle mileage by vehicle type (1990-2013)

Vehicle speeds in different roads were adopted from the reports published by Road Safety Authority in Figure 3.1.4 below. The detailed methodology is available in Alam et al. 2017.

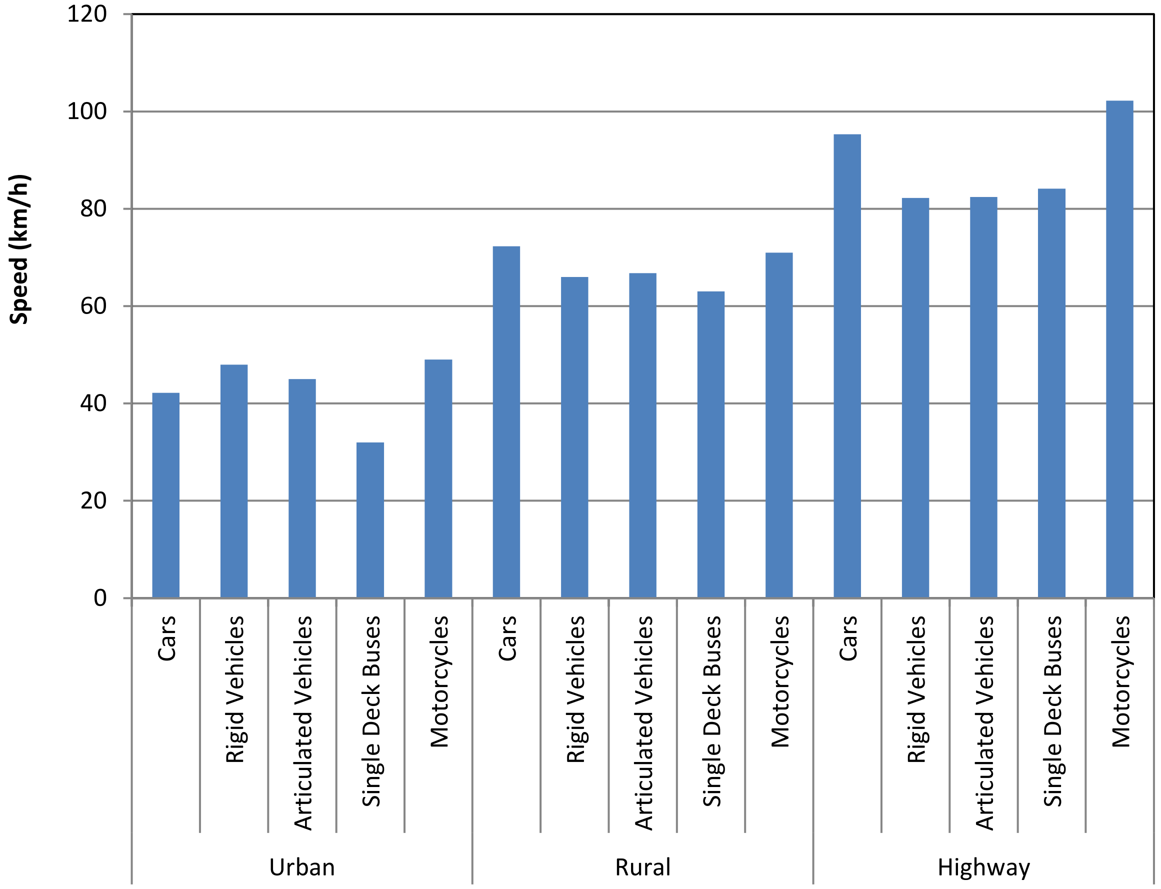


Figure 3.1.4 Vehicle speeds by vehicle type and road type

Annex 3.2

Industrial Processes (IPCC Sector 2)

3.2.A Cement production (IPCC sector 2.A.1)

3.2.B Lime production (IPCC sector 2.A.2)

3.2.C Glass Production (IPCC sector 2.A.3)

3.2.D Other process uses of carbonates (IPCC sector 2.A.4.a & 2.A.4.d)

3.2.E Soda ash use (IPCC sector 2.A.4.b)

Table 3.2.A Cement production 1990-2016 – Activity data, emission factors and emissions

IPCC Sector 2A1 Cement	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Clinker production (kilotonnes)															
Cement Plant 1	925	921	1,399	1,669	1,665	1,685	1,424	706	579	564	853	904	1,032	1,087	1,098
Cement Plant 2	685	680	908	957	900	934	902	501	362	283	254	274	468	634	809
Cement Plant 3	NO	NO	802	1,228	1,227	1,214	1,010	790	745	545	615	407	642	771	833
Cement Plant 4	NO	NO	NO	547	608	609	557	441	367	413	466	479	540	528	535
Total	**1,610**	**1,601**	**3,109**	**4,400**	**4,400**	**4,441**	**3,893**	**2,438**	**2,053**	**1,805**	**2,189**	**2,065**	**2,682**	**3,021**	**3,275**
Emission Factor t CO_2/t Clinker Produced															
Cement Plant 1	0.546	0.546	0.546	0.536	0.537	0.534	0.536	0.537	0.533	0.534	0.537	0.535	0.539	0.539	0.542
Cement Plant 2	0.553	0.553	0.553	0.533	0.535	0.536	0.544	0.542	0.534	0.536	0.533	0.532	0.553	0.553	0.541
Cement Plant 3	NA	NA	0.542	0.536	0.531	0.537	0.550	0.558	0.552	0.546	0.546	0.542	0.550	0.553	0.557
Cement Plant 4	NA	NA	NA	0.540	0.528	0.529	0.535	0.533	0.523	0.523	0.530	0.546	0.544	0.547	0.554
IEF t CO_2/t Clinker	**0.549**	**0.549**	**0.547**	**0.536**	**0.534**	**0.535**	**0.541**	**0.544**	**0.538**	**0.535**	**0.538**	**0.538**	**0.545**	**0.547**	**0.548**
Emissions CO_2 (kilotonnes)															
Cement Plant 1	505	503	764	894	894	900	763	379	309	301	458	483	556	586	596
Cement Plant 2	379	376	502	510	481	500	491	272	193	152	136	146	258	351	438
Cement Plant 3	NO	NO	435	658	651	652	555	441	411	297	336	221	353	426	464
Cement Plant 4	NO	NO	NO	295	321	322	298	235	192	216	247	262	294	289	296
Total	**884**	**879**	**1,701**	**2,357**	**2,348**	**2,374**	**2,107**	**1,327**	**1,105**	**966**	**1,177**	**1,112**	**1,461**	**1,652**	**1,794**

Table 3.2.B Lime Production 1990-2016 – Activity data, emission factors and emissions

IPCC Sector 2A2 Lime	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Tonnes of Lime															
Lime Plant 1	84.4	97.9	90.5	100.9	102.2	116.6	125.9	94.7	114.1	119.7	132.9	127.9	121.9	133.5	131.1
Lime Plant 2	170.8	125.6	157.8	135.7	129.0	136.5	121.3	111.0	138.5	143.0	149.5	123.5	135.8	102.9	98.4
Total	**255.2**	**223.5**	**248.3**	**236.7**	**231.2**	**253.0**	**247.1**	**205.7**	**252.6**	**262.7**	**282.4**	**251.4**	**257.6**	**236.4**	**229.4**
Emission Factors															
Lime Plant 1	0.757	0.827	0.801	0.791	0.791	0.818	0.760	0.764	0.761	0.767	0.761	0.752	0.749	0.755	0.759
Lime Plant 2	0.879	0.849	0.747	0.764	0.771	0.760	0.759	0.764	0.769	0.760	0.767	0.756	0.719	0.744	0.756
IEF t CO_2/t Lime	**0.839**	**0.839**	**0.767**	**0.775**	**0.780**	**0.787**	**0.760**	**0.764**	**0.765**	**0.763**	**0.764**	**0.754**	**0.733**	**0.750**	**0.758**
Lime Plant 1	63.9	80.9	72.5	79.8	80.8	95.3	95.7	72.4	86.9	91.8	101.2	96.2	91.3	100.8	99.5
Lime Plant 2	150.2	106.6	117.9	103.6	99.5	103.7	92.1	84.9	106.5	108.7	114.7	93.4	97.7	76.6	74.4
Total (kilotonnes CO_2)	**214.1**	**187.5**	**190.4**	**183.5**	**180.3**	**199.1**	**187.8**	**157.2**	**193.4**	**200.5**	**215.9**	**189.6**	**189.0**	**177.3**	**173.9**

Table 3.2.C Glass Production 1990-2016 – Activity data, emission factors and emissions

IPCC Sector 2A3 Glass production	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Carbonate use (kilotonnes)															
Glass plant 1	0.412	0.412	0.412	0.328	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Glass plant 2	1.720	1.549	1.273	0.472	0.701	0.600	0.422	0.063	NO	NO	NO	NO	NO	NO	NO
Glass bottle	60.000	60.000	60.000	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Glass wool	1.746	1.746	2.057	0.628	0.708	0.699	0.461	NO	NO	NO	NO	NO	NO	NO	NO
Total	**63.878**	**63.707**	**63.742**	**1.428**	**1.409**	**1.299**	**0.882**	**0.063**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**
Emission Factor t CO_2/t Carbonate Use															
Glass plant 1	0.275	0.275	0.275	0.275	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Glass plant 2	0.275	0.275	0.275	0.275	0.275	0.275	0.275	0.275	NA	NA	NA	NA	NA	NA	NA
Glass bottle	0.200	0.178	0.156	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Glass wool	0.441	0.441	0.441	0.415	0.415	0.415	0.415	NA	NA	NA	NA	NA	NA	NA	NA
IEF t CO_2/t Carbonate Use	**0.209**	**0.188**	**0.168**	**0.337**	**0.345**	**0.350**	**0.348**	**0.275**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**
Emissions CO_2 (kilotonnes)															
Glass plant 1	0.113	0.113	0.113	0.090	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Glass plant 2	0.473	0.426	0.350	0.130	0.193	0.165	0.116	0.017	NO	NO	NO	NO	NO	NO	NO
Glass bottle	11.970	10.658	9.345	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Glass wool	0.769	0.769	0.906	0.261	0.294	0.290	0.191	NO	NO	NO	NO	NO	NO	NO	NO
Total	**13.325**	**11.966**	**10.714**	**0.481**	**0.487**	**0.455**	**0.307**	**0.017**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**

Table 3.2.D Bricks, Ceramics, Limestone 1990-2016 – Activity data, emission factors and emissions

IPCC Sector 2A4 Other process uses of carbonates	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Carbonate uses (includes clays, shale, bricks, tiles, flues and limestone) (kilotonnes)															
2A4a Ceramics	**110.73**	**118.73**	**140.20**	**158.60**	**152.13**	**137.45**	**83.21**	**16.35**	**15.83**	**22.54**	**0.75**	**0.62**	**NO**	**14.73**	**25.80**
Ceramics Plant 1	30.75	30.75	30.75	41.21	34.32	33.81	16.52	2.73	0.17	0.57	0.75	0.62	NA	14.73	25.80
Ceramics Plant 2	40.00	40.00	43.14	46.06	47.71	45.06	26.22	13.62	15.66	21.96	NO	NO	NO	NO	NO
Ceramics Plant 3	39.98	47.98	66.30	52.51	48.85	38.83	21.27	NO	NO	NO	NO	NO	NO	NO	NO
Ceramics Plant 4	NO	NO	NO	18.83	21.25	19.74	19.19	NO	NO	NO	NO	NO	NO	NO	NO
2A4d Limestone use	**NO**	**NO**	**NO**	**9.54**	**5.46**	**4.84**	**5.77**	**3.55**	**2.40**	**2.41**	**1.01**	**0.49**	**0.64**	**1.02**	**0.36**
Power plant 1	NO	NO	NO	8.32	5.28	4.76	4.81	2.20	2.32	1.88	0.82	0.33	0.30	0.74	0.01
Power plant 2	NO	NO	NO	NO	NO	0.09	0.96	1.35	0.08	0.53	0.19	0.16	0.34	0.22	0.36
Sugar processing	NE	NE	NE	1.216	0.178	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Power plant 3	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	0.063	NO
Total	**110.73**	**118.73**	**140.20**	**168.14**	**157.59**	**142.29**	**88.98**	**19.90**	**18.22**	**24.95**	**1.76**	**1.11**	**0.64**	**15.76**	**26.16**
Emission Factor (t CO_2/t Carbonate uses)															
2A4a Ceramics	**0.047**	**0.048**	**0.048**	**0.048**	**0.050**	**0.051**	**0.050**	**0.033**	**0.027**	**0.037**	**0.041**	**0.053**	NA	**0.034**	**0.030**
Ceramics Plant 1	0.045	0.045	0.045	0.046	0.048	0.048	0.048	0.055	0.056	0.054	0.041	0.053	NA	0.034	0.030
Ceramics Plant 2	0.044	0.044	0.044	0.044	0.044	0.044	0.034	0.028	0.026	0.036	NA	NA	NA	NA	NA
Ceramics Plant 3	0.052	0.052	0.051	0.051	0.053	0.053	0.056	NA	NA	NA	NA	NA	NA	NA	NA
Ceramics Plant 4	NA	NA	NA	0.051	0.062	0.069	0.068	NA	NA	NA	NA	NA	NA	NA	NA
2A4d Limestone use	**NA**	**NA**	**NA**	**0.437**	**0.436**	**0.436**	**0.437**	**0.434**	**0.430**	**0.433**	**0.432**	**0.436**	**0.437**	**0.436**	**0.439**
Power plant 1	NA	NA	NA	0.436	0.436	0.436	0.436	0.430	0.430	0.431	0.431	0.436	0.436	0.436	0.436
Power plant 2	NA	NA	NA	NA	NA	0.440	0.440	0.440	0.440	0.440	0.440	0.437	0.437	0.437	0.439
Sugar processing	NA	NA	NA	0.440	0.438	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Power plant 3	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	0.437	NO
Emissions CO_2 (kilotonnes)															
2A4a Ceramics	**5.23**	**5.64**	**6.66**	**7.53**	**7.66**	**7.04**	**4.18**	**0.53**	**0.42**	**0.83**	**0.03**	**0.03**	NO	**0.50**	**0.78**
Ceramics Plant 1	1.39	1.39	1.39	1.88	1.65	1.63	0.80	0.15	0.01	0.03	0.03	0.03	NO	0.50	0.78
Ceramics Plant 2	1.76	1.76	1.90	2.03	2.10	1.98	0.89	0.38	0.41	0.80	NO	NO	NO	NO	NO
Ceramics Plant 3	2.07	2.49	3.37	2.66	2.59	2.05	1.19	NO	NO	NO	NO	NO	NO	NO	NO
Ceramics Plant 4	NO	NO	NO	0.97	1.32	1.37	1.30	NO	NO	NO	NO	NO	NO	NO	NO
2A4d Limestone use	**NO**	**NO**	**NO**	**4.17**	**2.38**	**2.11**	**2.52**	**1.54**	**1.03**	**1.04**	**0.44**	**0.21**	**0.28**	**0.45**	**0.16**
Power plant 1	NO	NO	NO	3.63	2.30	2.07	2.10	0.94	1.00	0.81	0.36	0.15	0.13	0.32	0.00
Power plant 2	NO	NO	NO	NO	NO	0.04	0.42	0.60	0.04	0.23	0.08	0.07	0.15	0.10	0.16
Sugar processing	NE	NE	NE	0.54	0.08	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Power plant 3	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	0.03	NO
Total	**5.23**	**5.64**	**6.66**	**11.70**	**10.04**	**9.15**	**6.70**	**2.07**	**1.45**	**1.87**	**0.47**	**0.25**	**0.28**	**0.94**	**0.94**

Table 3.2.E Soda ash use 1990-2016 – Activity data, emission factors and emissions

IPCC Sector 2A4 Soda ash use	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Soda ash used (kilotonnes)															
Lime Plant 2	0.237	0.168	0.171	0.202	0.150	0.136	0.106	0.132	0.177	0.166	0.211	0.153	0.166	0.143	0.108
Emission Factor t CO_2/t Soda ash used															
IEF t CO_2/t Soda ash use	0.411	0.411	0.411	0.411	0.413	0.411	0.411	0.411	0.411	0.411	0.415	0.415	0.415	0.415	0.415
Emissions CO_2 (kilotonnes)															
Lime Plant 2	0.097	0.069	0.070	0.083	0.062	0.056	0.044	0.054	0.073	0.068	0.087	0.063	0.069	0.059	0.045

Annex 3.3

Agriculture (IPCC Sector 3)

3.3.A Animal Populations 1990-2016

3.3.B Methane Emission Factors for Enteric Fermentation

3.3.C Methane Emission Factors for Manure Management

3.3.D.1 Allocation of Animal Wastes to Manure Management Systems – Cattle

3.3.D.2 Allocation of Animal Wastes to Manure Management Systems – Other Livestock

3.3.E Nitrogen excretion values for Livestock 1990-2016

3.3.F Input Parameters for the calculation of N_2O Emissions from Agricultural Soils

3.3.G Nitrogen application to agricultural soils from sewage sludge (3.D.1.2.b) 1990-2016

3.3.H Activity data, parameters and emission factors for Crop Residue (3.D.1.4) 1990-2016

Table 3.3.A Animal Populations 1990-2016

1000 head	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Total Cattle	6,822	7,009	7,012	6,951	6,827	6,828	6,801	6,555	6,428	6,691	6,829	6,840	6,926	7,173
Dairy Cows	1,341	1,239	1,165	1,025	1,054	1,060	1,060	1,039	1,076	1,101	1,123	1,177	1,268	1,347
All Other Cattle	5,481	5,770	5,847	5,926	5,773	5,768	5,742	5,516	5,352	5,590	5,706	5,663	5,658	5,827
Other Cows	730	1,022	1,171	1,121	1,185	1,198	1,169	1,125	1,103	1,138	1,118	1,085	1,065	1,073
Dairy Heifers	172	230	205	214	197	195	196	234	252	268	271	317	331	325
Other Heifers	80	123	133	191	212	180	156	170	202	181	149	174	188	184
Cattle < 1 yrs	1,716	1,746	1,752	1,962	1,941	1,959	1,889	1,761	1,846	2,036	1,969	1,878	2,042	2,126
Cattle < 1 yrs - male	903	915	919	958	947	969	918	827	892	1,023	959	902	994	1,046
Cattle < 1 yrs - female	813	831	833	1,005	994	990	971	935	954	1,013	1,009	977	1,048	1,080
Cattle 1 - 2 yrs	1,663	1,586	1,517	1,642	1,466	1,496	1,542	1,408	1,270	1,376	1,551	1,469	1,373	1,517
Cattle 1 - 2 yrs - male	986	964	912	972	818	832	851	760	673	770	873	821	790	873
Cattle 1 - 2 yrs - female	677	622	605	670	648	664	690	647	597	606	678	648	583	644
Cattle > 2 yrs	1,093	1,023	1,016	734	715	687	738	772	640	554	609	701	628	579
Cattle > 2 yrs - male	826	712	722	537	510	476	501	506	426	361	388	456	424	391
Cattle > 2 yrs - female	266	311	295	197	206	211	237	265	214	193	221	245	204	188
Bulls	27	40	53	61	57	54	52	47	38	37	39	38	33	22
Total Sheep	8,021	8,364	7,957	6,431	5,656	5,105	4,727	4,328	4,429	4,843	4,918	5,019	4,870	4,770
Ewes Lowland	2,397	2,427	2,814	2,627	2,207	2,057	1,928	1,920	1,954	2,036	2,016	1,978	1,960	1,964
Ewes Upland	1,961	1,986	1,206	657	552	514	482	480	489	509	504	494	490	491
Rams Lowland	64	66	77	77	69	63	58	59	59	61	62	60	60	61
Rams Upland	53	54	33	19	17	16	14	15	15	15	15	15	15	15
Other Sheep>1 - Lowland	164	113	143	124	109	112	103	96	101	116	112	97	110	70
Other Sheep>1 - Upland	134	92	61	31	27	28	26	24	25	29	28	24	27	17
Lambs - Lowland	1,787	1,994	2,535	2,317	2,140	1,853	1,693	1,387	1,429	1,661	1,745	1,880	1,766	1,722

1000 head	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Lambs - Upland	1,462	1,632	1,086	579	535	463	423	347	357	415	436	470	442	430
Total Pigs	1,222	1,546	1,727	1,679	1,544	1,486	1,444	1,508	1,551	1,532	1,511	1,530	1,506	1,561
Gilts in Pig	21	24	21	20	21	21	20	19	19	20	19	20	20	19
Gilts not yet Served	12	18	18	20	16	16	17	15	15	15	15	15	15	16
Sows in Pig	83	100	110	100	96	91	89	92	90	84	82	83	82	82
Other Sows for Breeding	31	31	32	34	28	25	27	29	27	25	29	30	27	30
Boars	6	5	4	2	2	2	2	2	1	1	1	1	1	1
Pigs 20 Kg +	749	952	1,038	1,010	939	932	911	953	965	960	926	941	934	977
Pigs Under 20 Kg	319	417	504	494	443	400	378	400	434	426	438	440	427	436
Total Poultry	11,772	14,438	15,680	16,573	13,324	13,258	15,277	15,212	15,032	15,631	14,989	16,504	16,993	17,181
Layer	1,868	1,371	1,572	1,950	1,813	1,813	2,145	2,145	2,145	2,600	2,828	2,917	3,268	3,318
Broiler	8,035	11,092	12,426	12,818	9,696	9,696	11,904	11,904	11,520	11,520	10,764	12,127	12,223	12,318
Turkey	1,509	1,616	1,322	1,274	1,330	1,330	874	874	1,078	1,222	1,125	1,189	1,231	1,273
Ducks	347	347	347	520	475	409	344	279	279	279	265	265	265	265
Geese	12	12	12	11	10	10	10	10	10	10	7	7	7	7
Horses	62	68	70	80	89	96	98	106	106	111	102	95	93	92
Mules	8	7	5	6	7	9	9	8	9	10	8	8	9	9
Goats	17	16	8	7	7	9	10	11	11	10	9	9	11	10
Farmed Deer	12	16	12	10	10	10	9	5	3	2	2	2	1	1
Mink	185	124	146	149	149	149	190	183	183	198	198	198	198	198
Fox	26	7	4	2	3	1	0.4	0.04	0.1	NO	NO	NO	NO	NO
Fertiliser (1000's tonnes/N)	379	429	408	352	322	309	307	362	296	297	353	332	331	339

Table 3.3.B CH_4 Emission Factors for Enteric Fermentation (kg/head/year)

Animal Category	Animal Liveweight (kg)	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Cattle															
Dairy cows	535.0	101.4	104.1	106.8	111.3	111.3	109.9	108.4	112.7	112.9	110.4	111.1	110.9	113.4	112.3
Beef cows (Suckler Cows)	600.0	74.0	74.1	74.2	75.5	73.2	74.9	72.8	72.9	74.1	75.5	73.1	73.7	74.7	74.3
Dairy heifers	388.0	51.8	51.2	50.5	50.2	50.2	50.2	50.2	50.2	50.2	50.2	50.2	50.2	50.2	50.2
Beef heifers	450.0	55.4	54.8	54.1	53.7	53.7	53.7	53.7	53.7	53.7	53.7	53.7	53.7	53.7	53.7
Bulls for breeding	500.0	86.4	84.5	82.7	81.5	81.5	81.5	81.5	81.5	81.5	81.5	81.5	81.5	81.5	81.5
Cattle 1 - 2 yrs - male															
< 1 year	140.0	30.5	30.1	29.7	29.7	29.7	29.7	29.8	29.1	29.8	30.1	30.3	30.0	30.1	30.4
1 - 2 years	388.0	62.2	61.6	60.9	58.9	59.2	59.1	58.6	60.0	58.0	56.6	56.2	57.9	57.6	56.0
> 2 years*	500.0	55.1	47.0	38.9	37.7	38.6	37.0	38.8	39.8	38.3	37.2	37.3	36.4	36.5	35.5
Cattle > 2 yrs - female															
< 1 year	140.0	27.0	27.3	27.6	27.7	27.6	27.6	27.6	27.5	27.6	27.7	27.7	27.6	27.7	27.8
1 - 2 years	388.0	53.5	50.1	46.7	45.6	46.6	47.0	47.7	48.6	47.9	48.0	48.1	49.5	49.1	48.8
> 2 years*	500.0	21.7	22.0	22.3	22.4	22.4	22.5	22.6	22.6	22.7	22.7	22.6	22.5	22.3	22.3
Sheep															
Lowland Sheep		8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Upland Sheep		8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Rams		8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Sheep > 1 yrs		8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Lambs		2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
Horses		18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0
Mules		10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Goats		5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Deer		20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Pigs															
Gilts in Pig	160.0	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Gilts not yet Served	120.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Sows in Pig	200.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Other Sows for Breeding	210.0	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Boars	225.0	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
Pigs > 20 Kg	58.0	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
Pigs < 20 Kg	13.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Poultry	2.4	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE

* Note: This value is low because this category of animal only live part of their third year

Table 3.3.C CH_4 Emission Factors for Manure Management (kg/head/year)

	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Cattle														
Dairy cows	10.6	10.4	10.2	10.3	10.2	10.2	10.1	10.3	10.3	10.2	10.2	10.2	10.3	10.2
Beef cows(Suckler Cows)	6.6	6.6	6.5	6.6	6.4	6.6	6.4	6.4	6.5	6.7	6.4	6.5	6.6	6.6
Dairy heifers	4.6	4.3	4.0	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8
Beef heifers	5.3	5.0	4.6	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4
Bulls for breeding	10.5	9.7	8.9	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4
Male cattle														
< 1 year	4.5	4.3	4.0	4.0	4.0	4.0	4.0	4.1	4.0	4.1	4.1	4.0	4.0	4.1
1 - 2 years	7.1	6.7	6.3	5.9	5.9	5.9	5.9	6.0	5.7	5.5	5.4	5.7	5.6	5.3
> 2 years*	3.0	2.2	1.4	1.3	1.3	1.2	1.4	1.4	1.3	1.2	1.2	1.2	1.2	1.1
Female cattle														
< 1 year	4.0	4.0	3.9	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8
1 - 2 years	6.3	5.4	4.5	4.1	4.2	4.3	4.4	4.6	4.4	4.4	4.5	4.7	4.6	4.5
> 2 years*	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Sheep														
Lowland Ewes	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Upland Ewes	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Rams	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Sheep >1 yrs	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Lambs	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Horses	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1
Mules	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Goats	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Deer	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Mink	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Fox	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Pigs														
Gilts in Pig	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5
Gilts not yet Served	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8
Sows in Pig	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5
Other Sows for Breeding	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0
Boars	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9
Pigs > 20 Kg	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Pigs < 20 Kg	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8
Poultry														
Layers	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Broilers	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Turkeys	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Ducks	0.5	0.5	0.5	0.3	0.4	0.4	0.5	0.6	0.6	0.6	0.7	0.7	0.7	0.7
Geese	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

* Note: This value is low because this category of animal only live part of their third year.

Table 3.3.D.1 Allocation of Animal Wastes to Animal Waste Management Systems – Cattle

Cattle	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Number of days housed														
Dairy Cows	118	118	118	118	117	117	117	117	117	117	117	117	117	117
Suckler Cows	141	141	141	142	141	141	141	141	141	142	141	141	142	141
Dairy Heifer	128	128	128	128	128	128	128	128	128	128	128	128	128	128
Other Heifer	139	139	139	139	139	139	139	139	139	139	139	139	139	139
Under1yr	221	221	221	222	222	223	223	227	224	224	223	222	221	221
Oneto2yrs	156	156	156	155	154	154	156	157	154	153	153	156	155	153
Over2yrs	23	23	23	26	26	23	26	26	23	21	22	22	28	26
Bulls	156	156	156	155	154	154	156	157	154	153	153	156	155	153
Number of days grazing														
Dairy Cows	247	247	247	247	248	248	248	248	248	248	248	248	248	248
Suckler Cows	224	224	224	223	224	224	224	224	224	223	224	224	223	224
Dairy Heifer	237	237	237	237	237	237	237	237	237	237	237	237	237	237
Other Heifer	226	226	226	226	226	226	226	226	226	226	226	226	226	226
Under1yr	144	144	144	143	143	142	142	138	141	141	142	143	144	144
Oneto2yrs	209	209	209	210	211	211	209	208	211	212	212	209	210	212
Over2yrs	342	342	342	339	339	342	339	339	342	344	343	343	337	339
Bulls	209	209	209	210	211	211	209	208	211	212	212	209	210	212
Proportion to Pit Storage (fraction)														
Dairy Cows	0.32	0.31	0.30	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.28	0.28
Suckler Cows	0.26	0.26	0.26	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
Dairy Heifer	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Other Heifer	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
Under1yr	0.41	0.41	0.41	0.41	0.41	0.42	0.42	0.42	0.42	0.42	0.42	0.41	0.41	0.41
Oneto2yrs	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.33	0.33	0.33	0.34	0.34	0.33
Over2yrs	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.04	0.04	0.04
Bulls	0.42	0.41	0.39	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
Proportion to Deep Bedding (fraction)														
Dairy Cows	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Suckler Cows	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Dairy Heifer	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
Other Heifer	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
Under1yr	0.19	0.19	0.19	0.19	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.19	0.19	0.19
Oneto2yrs	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Over2yrs	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.03	0.03	0.03
Bulls	0.14	0.14	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Proportion to Pasture (fraction)														
Dairy Cows	0.66	0.67	0.68	0.69	0.69	0.69	0.69	0.70	0.70	0.69	0.69	0.69	0.70	0.70
Suckler Cows	0.64	0.64	0.64	0.64	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63
Dairy Heifer	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
Other Heifer	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
Under1yr	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.38	0.39	0.39	0.39	0.39	0.39	0.39
Oneto2yrs	0.57	0.57	0.57	0.58	0.58	0.58	0.57	0.57	0.58	0.58	0.58	0.57	0.57	0.58
Over2yrs	0.94	0.94	0.94	0.93	0.93	0.94	0.93	0.93	0.94	0.94	0.94	0.94	0.92	0.93
Bulls	0.44	0.46	0.48	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49

Table 3.3.D.2 Allocation of Animal Wastes to Animal Waste Management Systems – Other Livestock

Animal Category	Days housed	% housed	% outwintered	Liquid system		Solid storage & dry lot		Pit-storage		Deep bedding		Litter		Pasture	
				allocation	MCF	allocation	MCF	allocation	MCF	allocation	MCF	allocation	MCF	allocation	MCF
Sheep															
Lowland Ewes	84	89.49	10.51	NA	NA	NA	NA	NA	NA	0.11	17.0%	NA	NA	0.89	1.0%
Upland Ewes	85	47.07	52.93	NA	NA	NA	NA	NA	NA	0.10	17.0%	NA	NA	0.90	1.0%
Lowland Rams	56	44.34	55.66	NA	NA	NA	NA	NA	NA	0.03	17.0%	NA	NA	0.97	1.0%
Upland Rams	56	44.34	55.66	NA	NA	NA	NA	NA	NA	0.03	17.0%	NA	NA	0.97	1.0%
Lowland Other Sheep>1yrs	67	89.49	10.51	NA	NA	NA	NA	NA	NA	0.01	17.0%	NA	NA	0.99	1.0%
Upland Other Sheep>1yrs	67	47.07	52.93	NA	NA	NA	NA	NA	NA	0.01	17.0%	NA	NA	0.99	1.0%
Lowland lambs	28	6.85	93.15	NA	NA	NA	NA	NA	NA	0.08	17.0%	NA	NA	0.92	1.0%
Upland lambs	28	6.85	93.15	NA	NA	NA	NA	NA	NA	0.08	17.0%	NA	NA	0.92	1.0%
Pigs															
Gilts in pig	365	100.00	0.00	NA	NA	NA	NA	1.00	17.0%	NA	NA	NA	NA	NA	NA
Gilts not yet served	365	100.00	0.00	NA	NA	NA	NA	1.00	17.0%	NA	NA	NA	NA	NA	NA
Sows in pig	365	100.00	0.00	NA	NA	NA	NA	1.00	17.0%	NA	NA	NA	NA	NA	NA
Other sows for breeding	365	100.00	0.00	NA	NA	NA	NA	1.00	17.0%	NA	NA	NA	NA	NA	NA
Boars	365	100.00	0.00	NA	NA	NA	NA	1.00	17.0%	NA	NA	NA	NA	NA	NA
Pigs < 20 kg	365	100.00	0.00	NA	NA	NA	NA	1.00	17.0%	NA	NA	NA	NA	NA	NA
Pigs > 20 kg	365	100.00	0.00	NA	NA	NA	NA	1.00	17.0%	NA	NA	NA	NA	NA	NA
Poultry															
Laying hens	365	88.00	12.00	NA	NA	NA	NA	0.74	65.0%	NA	NA	0.14	1.5%	0.12	1.5%
Broilers	365	100.00	0.00	NA	NA	NA	NA	NA	NA	NA	NA	1.00	1.5%	NA	NA
Turkeys	365	100.00	0.00	NA	NA	NA	NA	NA	NA	NA	NA	1.00	1.5%	NA	NA
Ducks	365	100.00	0.00	NA	NA	NA	NA	0.57	65.0%	NA	NA	0.43	1.5%	NA	NA
Geese	365	100.00	0.00	NA	NA	NA	NA	NA	65.0%	NA	NA	1.00	1.5%	NA	NA
Horses	180	100.00	0.00	NA	NA	0.49	2.0%	NA	NA	NA	NA	NA	NA	0.51	1.0%
Mule	180	100.00	0.00	NA	NA	0.49	2.0%	NA	NA	NA	NA	NA	NA	0.51	1.0%
Goat	84	100.00	0.00	NA	NA	NA	NA	NA	NA	0.62	17.0%	NA	NA	0.38	1.0%
Deer	84	100.00	0.00	NA	NA	NA	NA	NA	NA	0.23	17.0%	NA	NA	0.77	1.0%
Fur animals	365	100.00	0.00	0.40	17.0%	0.48	2.0%	0.12	17.0%	NA	NA	NA	NA	NA	NA

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:

$$N_{ex(T)} = N_{\text{intake}(T)} \bullet (1 - N_{retention(T)})$$ Eq 10.31 (2006 IPCC Guidelines)

Where

$N_{ex(T)}$ = annual N excretion rate, kg N animal^{-1} year^{-1}

$N_{\text{intake}(T)}$= annual N intake per head, kg N animal^{-1} year^{-1}

$N_{retention(T)}$= fraction of annual N intake that is retained by the animal per head

The annual N intake by the animal $N_{\text{intake}(T)}$ is calculated based on the dietary assumptions used in the development of Tier 2 emission factors for CH_4 from enteric fermentation and manure management (O'Mara, 2006) as discussed in sections 5.2.1.1 and 5.3.1.1 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 $N_{retention(T)}$ (equation 10.33, section 10.5.2 Chapter 10, Volume 4 of the 2006 IPCC guidelines) as follows:

$$Nintake\ (T) = \frac{GE}{18.8} x \frac{CP\%/100}{6.25}$$ Eq 10.32 (2006 IPCC Guidelines)

Where:

$N_{\text{intake}(T)=}$ annual N intake per head, kg N animal^{-1} year^{-1}

GE = gross energy intake of the animal (MJ animal^{-1} day^{-1}) sourced from the Tier 2 model for the estimation of CH_4 emissions from enteric fermentation and manure management (O'Mara, 2006).

18.8 = conversion factor for dietary GE per kg of dry matter, MJ kg^{-1} (O'Mara, 2006)

CP% = percent crude protein in the diet

6.25 = conversion factor from kg dietary protein to kg of dietary N, kg feed protein (kg N)$^{-1}$

The annual N retention by the animal $N_{retention(T)}$ is calculated based on the dietary assumptions used in the development of the Tier 2 emission factors for CH_4 from eneteric fermentation and manure management (O'Mara, 2006) as discussed in 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.

$$N_{retention(T)} = \left[\frac{Milk \bullet \left(\frac{Milk\ PR\%}{100} \right)}{6.38} \right] + \left[\frac{WG \bullet \left[268 - \left(\frac{7.03 \bullet NE_g}{WG} \right) \right]}{6.25} \right]$$ Eq 10.33 (2006 IPCC Guidelines)

Where:

$N_{retention(T)}$= fraction of annual N intake that is retained by the animal per head

Milk = milk production, kg animal^{-1} day^{-1} (CSO)

Milk PR % = percent of protein in milk (CSO)

6.38 = conversion from milk protein to milk N, kg Protein (kg N)$^{-1}$

WG = weight gain, kg day^{-1} (O'Mara, 2006)

268 and 7.03 = constants from Equation 3-8 in NRC (1996)

NE_g = net energy for growth, MJ day^{-1} (O'Mara, 2006)

Partitioning of nitrogen excretion from cattle into nitrogen excreted in dung and nitrogen excreted in urine

Once the nitrogen excreted (N_{ex}) is calculated as described in the previous section the proportion of N in both urine (N_{urine}) and dung (N_{dung}) can be determined with the following equation:

$N_{ex(T)} = N_{urine} + N_{dung}$

Where:

$N_{ex(T)}$ = annual N excretion rate, kg N animal^{-1} year^{-1}

N_{urine} = N excreted in urine, kg N animal^{-1} year^{-1}

N_{dung} = N excreted in dung kg N animal^{-1} year^{-1}

For dairy cattle (dairy cows), N_{dung} is estimated based on the proportion of dry matter intake (0.008 kg N per kg dry matter intake) which is excreted as nitrogen in dung (Burke et al., 2008). Dry matter intake values are those used in the development of the Tier 2 emission factors for CH_4 emissions from enteric fermentation and manure management (O'Mara, 2006) as discussed in sections 5.2.1.1 and 5.3.1.1. N_{urine} is then estimated as the difference between $N_{ex(T)}$ and N_{dung}.

For all other cattle categories, N_{urine} is estimated based on the regression of De Prado et al (2006):

$$N_{urine} = ((0.1369 \times \% \text{ Nitrogen in diet})+0.262)$$

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_4 emissions from enteric fermentation and manure management (O'Mara, 2006) as discussed in sections 5.2.1.1 and 5.3.1.1. N_{dung} is then estimated as the difference between $N_{ex(T)}$ and N_{urine}.

Relationship between the nitrogen excretion values presented in S 31 of 2014 and the values used for livestock (excluding cattle) in national inventory estimates

Table 3.3.E.a Nitrogen excretion values for Livestock 1990-2016

N excretion (kg/head/year)	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Dairy Cows	95.5	97.3	99.1	102.1	101.7	100.7	99.6	102.3	102.4	100.8	100.9	100.4	101.4	100.9
Suckler Cows	76.5	76.5	76.5	77.7	75.7	77.2	75.3	75.5	76.5	77.8	75.6	76.1	77.1	76.7
Dairy Heifer	70.7	70.3	69.9	69.6	69.6	69.6	69.6	69.6	69.6	69.6	69.6	69.6	69.6	69.6
Other Heifer	75.1	74.6	74.1	73.8	73.8	73.8	73.8	73.8	73.8	73.8	73.8	73.8	73.8	73.8
Under 1yr male	33.7	32.7	31.7	30.9	30.8	30.8	30.6	28.9	30.7	31.1	31.3	31.2	31.5	31.9
Under 1yr female	29.4	29.4	29.4	29.3	29.0	29.1	29.1	29.1	29.1	29.4	29.5	29.5	29.7	29.8
One to 2yrs male	75.1	73.5	72.0	70.3	70.1	70.4	70.2	71.0	70.9	71.5	71.5	71.1	71.3	71.8
One to 2yrs female	66.2	67.9	69.7	72.1	72.1	71.6	71.1	71.1	72.2	72.1	71.3	70.4	70.8	71.2
Over 2yrs male	50.7	48.9	47.0	46.4	46.5	46.4	46.6	47.0	46.6	46.4	46.4	46.3	46.3	46.1
Over 2yrs female	44.1	44.7	45.4	45.7	45.7	45.9	46.1	46.1	46.3	46.3	46.1	45.8	45.5	45.4
Bulls	83.7	83.2	82.7	82.4	82.4	82.4	82.4	82.4	82.4	82.4	82.4	82.4	82.4	82.4
Ewes Lowland	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3
Ewes Upland	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
Rams - lowland	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Rams - upland	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Other Sheep>1 - lowland	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
Other Sheep>1 - upland	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2
Lambs - lowland	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Lambs - upland	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Gilts in pig	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Gilts not yet served	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2
Sows in pig	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Other breeding sows	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Boars	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0
Fatteners > 20 kg	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2
Fatteners < 20 kg	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Laying hen per bird place	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Broiler per bird place	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Turkey per bird place	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Ducks	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Geese	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Horses	48.4	48.4	48.4	48.4	48.4	48.4	48.4	48.4	48.4	48.4	48.4	48.4	48.4	48.4
Mules	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0
Goats	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9
Deer (red) 6 months - 2 years	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3
Deer (red) > 2 years	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5
Deer (fallow) 6 months-2 years	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7
Deer (fallow) > 2 years	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3
Deer (sika) 6 months - 2 years	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6
Deer (sika) > 2 years	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0
Mink	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6
Fox	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1

Table 3.3.E.b Derivation of nitrogen excretion values for livestock from SI 31 of 2014

	SI 31	SI 31 underlying data tables	Inventory value
Sheep			
Lowland ewe & lambs	13	13.4	12.3
Assumes 1.3 lambs per ewe = 1.5 kg N; 0.4 kg N gaseous loss; N excretion = 13.4+0.4-1.5= 12.3 kg N			
Upland ewe and lambs	7	7.3	6.49
Assumes 0.8 lambs per ewe = 0.78 kg N; N excretion= 7.3 - 0.78= 6.49 kg N			
Rams	NA	10	10
Other Sheep >1 yrs - lowland	6	6.28	6.48
Gaseous loss = 0.19 kg N; N excretion = 6.28+0.19=6.48 kg N			
Other Sheep >1 yrs - upland	4	4.21	4.21
Goats	9	10.35	12.93
Gaseous loss = 2.59 kg N; N excretion = 10.3+2.59 = 12.93 kg N			
Horse (2-3 years old)	44	NA	48.4
Gaseous loss = 4.4 kg N; N excretion = 44+4.4 = 48.4 kg N			
Mules	30	NA	33
Gaseous loss = 3.0 kg N; N excretion = 30+3 = 33 kg N			
Deer (red) 6 months - 2 years	13	NA	14.3
Gaseous loss = 1.3 kg; N excretion = 13+1.3 = 14.3 kg N			
Deer (red) > 2 years	25	NA	27.5
Gaseous loss = 2.5 kg; N excretion = 25+2.5 = 27.5 kg N			
Deer (fallow) > 6 months - 2 years	7	NA	7.7
Gaseous loss = 0.7 kg; N excretion = 7.0+0.7 = 7.7 kg N			
Deer (fallow) > 2 years	13	NA	14.3
Gaseous loss = 1.3 kg; N excretion = 13+1.3 = 14.3 kg N			
Deer (sika) 6 months - 2 years	6	NA	6.6
Gaseous loss = 0.6 kg N; N excretion = 6.0+0.6= 6.6 kg N			
Deer (sika) > 2 years	10	NA	11
Gaseous loss = 1.0 kg N; N excretion = 10.0+1.0= 11.0 kg N			
Pigs			
Gilts in pig	NA	20	20
Gilts not yet served	NA	9.2	9.2
Sows in pig	NA	20	20
Other breeding sows	NA	20	20
Boars	NA	16	16
Fatteners> 20 kg	NA	9.2	9.2
Fatteners < 20 kg	NA	3	3
Poultry			
Laying hen Gaseous loss = 0.25 kg N; N excretion = 0.59 (0.56 kg = 97% occupancy) +0.25 = 0.84 kg N	0.56	0.84	0.84
Broiler Gaseous loss = 0.1 kg N; N excretion = 0.24 +0.1 = 0.35 kg N	0.24	0.35	0.35
Turkey Gaseous loss = 0.54 kg N; N excretion = 1.0 +0.54 = 1.54 kg N	1.00	1.54	1.54

Annex 3.3.F. Input Parameters for the calculation of N_2O Emissions from Agricultural Soils

The input parameters for the calculation of N_2O emissions from agricultural soils are presented in Table 3.3.F.2. Specific information in relation to EF_1 for synthetic nitrogen fertiliser application and EF_3 for urine and dung deposited on grazed pasture by cattle is discussed as follows.

Country specific emission factors from synthetic nitrogen fertiliser application (EF_1)

The default value for EF_1, (0.010 kg N_2O-N/kg N) the emission factor associated with the application of synthetic nitrogen fertiliser application to agricultural soils does not differentiate between nitrogen fertiliser formulation or rates of application. However numerous scientific studies have found that N_2O emissions from nitrate containing fertilisers tend to be higher than those from urea based fertilisers, particularly in regions which have mild, wet climates and soils with a high organic matter content (Harty et al., 2016).

In Ireland, the 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 2016, CAN accounted for over 85 percent of total N fertiliser sales with urea and inhibited urea accounting for 14.4 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_2O emission factors from synthetic fertiliser nitrogen application disaggregated by fertiliser type and application to grassland and cropland to assess potential mitigation strategies to reduce N_2O emissions from fertiliser nitrogen application (Harty et al., 2016; Roche et al., 2016).

Harty et al (2016) investigated the effect of fertiliser type over a two year period at three grassland locations covering a range of soil and climatic conditions. The treatments investigated were: CAN, Urea, Urea+NBPT (n-butyl thiophosphoric triamide), Urea+DCD (Dicyandiamide), Urea+NBPT+DCD and a control (zero N). The nitrification inhibitor DCD is a compound that delays the bacterial oxidation of NH_4^+ by impeding the activities of soil-nitrifying bacteria. Thus by retaining nitrogen in the form of NH_4^+ for longer the inhibitor reduces losses through denitrification and leaching of nitrate and potentially increase the efficiency of the nitrogen applied. N-butyl thiophosphoric triamide on the other hand is a urease inhibitor and works by inhibiting the hydrolytic action of soil urease, which catalyses the hydrolysis of urea to ammonium carbonate.

Roche et al. (2016) investigated the effect of the same fertiliser types described above, but on arable land. Based on the results of Harty et al (2016) and Roche et al (2016) country specific emission factors for CAN, Urea and inhibited urea (+NBPT) have been estimated. A weighted emission factor for CAN based on the relative proportion of grassland and arable land (92:8) was then calculated. Table 3.3.F.1 presents the emission factors derived for each product. On the basis of the emission factors presented and weighted according to fertiliser type the value for EF_1 now used in the national inventory is on average 24 per cent higher (0.0124 kg N_2O-N/kg N) than the default value present for EF_1 in the 2006 IPCC guidelines.

Table 3.3.F.1 Fertiliser type specific emission factors

Fertiliser type	Grassland emission factor	Arable emission factor	Combined Emission factor
		EF_1 kg N_2O-N/ kg N	
CAN	0.0149	0.0035	0.0140
Urea	0.0025	0.0027	0.0025
Urea + NBPT	0.0040	0.0020	0.0040

Country specific emission factors for urine and dung deposited by grazing cattle ($EF_{3,PRP}$)

The largest inputs of nitrogen to agricultural soils are manure from grazing livestock and synthetic nitrogen fertilisers. 62.2 per cent 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 increase, the amount of nitrogen excreted in urine increases. In addition, it has also been shown that urine patches are important sources of nitrogen loss in the form of ammonia, N_2O and nitrate leaching. The default emissions factor, EF_3 applies one single value (0.02 kg N_2O-N/kg N) to the total N excreted in urine and dung that may not necessarily reflect country-specific conditions. Additionally, the default emission factor does not take into account soil type, climatic conditions, timing of deposition or excreta form, all of which can influence the magnitude and duration of N_2O emissions (Krol et al 2016).

As part of the Agricultural Greenhouse Gas Initiative for Ireland (AGRI-I, http://www.agri-i.ie/) funded by the Department of Agriculture, Food and the Marine, a project was undertaken to develop country specific N_2O emission factors from urine and dung and to assess the effect of soil type and season of application on the magnitude of N_2O losses (Krol et al., 2016). Cattle, dung and artificial urine treatments were applied in spring, summer and autumn to three temperate grassland sites with varying soil and weather conditions. Nitrous oxide emissions were measured over a period of 12 months to generate annual N_2O emission factors. Further details of the research are available in Krol et (2016). The results of this study indicate that the mean emission factor for dung is 0.0031 kg N_2O-N/kg N and 0.012 kg N_2O-N/kg N for urine.

The above emission factors are then combined with the values of $N_{ex(T)}$ partitioned into N_{urine} and N_{dung} described in the annex 3.3.E to derive country specific assessments of N_2O emissions from urine and dung deposition on pasture. The resultant combined implied emission factor of 0.0086 kg N_2O-N/kg N as a result of this analysis is 56 per cent lower than the default emission factor for EF_3.

Table 3.3.F.2 Input Parameters for the calculation of N_2O Emissions from Agricultural Soils

Input Parameter	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
$Frac_{GASF}$	0.03	0.02	0.03	0.02	0.02	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.03
$Frac_{GRAZ}$	0.63	0.63	0.63	0.61	0.62	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61
$Frac_{GASM1}$	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.09
$Frac_{GASM2}$	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
$Frac_{LEACH}$	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
EF_{1CAN}	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140	0.0140
EF_{1Urea}	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025
$EF_{1Urea+NBPT}$	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040
EF_{3pp}	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200
EF_{3so}	0.0100	0.0100	0.0100	0.0100	0.0100	0.0100	0.0100	0.0100	0.0100	0.0100	0.0100	0.0100	0.0100	0.0100
EF_{3cdung}	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031
$EF_{3curine}$	0.0120	0.0120	0.0120	0.0120	0.0120	0.0120	0.0120	0.0120	0.0120	0.0120	0.0120	0.0120	0.0120	0.0120
F_{SN} (tonnes/year)	379,311	428,826	407,598	352,165	321,553	308,960	306,806	362,395	295,795	296,536	353,044	331,782	330,959	339,104
F_{AM} (tonnes/year)	145,813	151,909	151,819	153,846	148,449	149,034	147,553	142,503	141,607	149,148	150,458	149,914	152,301	158,561
F_S (tonnes/year)	166	166	758	3,001	3,012	3,192	3,310	4,134	2,885	3,416	2,600	2,124	2,335	2,267
F_{CR} (tonnes/year)	79,897	78,082	81,125	58,138	28,764	44,693	41,316	39,604	43,361	37,461	43,145	45,783	45,743	41,501
F_{PRP} (tonnes/year)	318,091	326,490	326,409	310,359	299,943	297,582	293,261	287,869	284,623	292,399	298,556	301,422	304,747	314,898

Table 3.3.G Nitrogen application to agricultural soils from sewage sludge (3.D.1.2.B) 1990-2016

	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
N applied (t/year)	165.54	165.54	757.75	3,000.95	3,011.60	3,191.57	3,309.70	4,133.50	2,884.95	3,416.45	2,599.80	2,124.15	2,334.85	2,267.20

Table 3.3.H Activity data, parameters and emission factors for Crop Residue (3.D.1.4) 1990-2016

	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Crop T (kg d.m. ha^{-1})														
Maize	-	-	13,071	13,071	13,071	13,071	13,071	13,071	13,071	13,071	13,071	13,071	13,071	13,071
Winter Wheat	8,010	7,743	8,811	7,832	7,743	8,544	7,654	7,921	9,078	6,586	8,277	9,078	9,790	8,633
Spring Wheat	5,963	6,230	7,209	6,764	6,853	5,874	6,052	6,764	7,387	5,429	7,209	7,387	7,654	7,120
Oats	5,874	5,785	6,675	5,963	6,675	6,764	6,319	6,675	7,031	5,874	6,408	7,120	7,476	7,031
Barley	5,251	5,429	6,408	5,518	5,963	6,141	5,607	6,230	6,942	5,785	6,764	7,120	7,654	6,942
Beans and Peas	4,459	3,640	4,641	4,641	4,004	4,095	4,823	5,005	5,187	4,368	4,732	5,187	5,915	5,187
Potatoes	5,478	6,072	7,392	7,634	7,480	6,754	6,072	7,568	7,568	5,676	8,404	8,910	9,306	8,558
Turnips	51,512	50,854	56,400	-	-	-	-	-	-	-	-	-	-	-
Sugarbeet	43,052	41,454	53,392	41,830	-	43,863	43,863	43,863	43,863	43,863	43,863	43,863	43,863	43,863
Fodder Beat	61,100	62,792	66,082	-	-	-	-	-	-	-	-	-	-	-
$R_{AG(T)}$ (kg d.m)														
Maize	-	-	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08
Winter Wheat	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.65	1.67	1.66	1.65	1.65	1.66
Spring Wheat	1.42	1.41	1.39	1.40	1.40	1.42	1.41	1.40	1.39	1.43	1.39	1.39	1.39	1.40
Oats	1.06	1.06	1.04	1.06	1.04	1.04	1.05	1.04	1.04	1.06	1.05	1.04	1.03	1.04
Barley	1.09	1.09	1.07	1.09	1.08	1.08	1.09	1.07	1.06	1.08	1.07	1.06	1.06	1.06
Beans and Peas	1.32	1.36	1.31	1.31	1.34	1.34	1.31	1.30	1.29	1.32	1.31	1.29	1.27	1.29
Potatoes	0.29	0.27	0.24	0.24	0.24	0.26	0.27	0.24	0.24	0.29	0.23	0.22	0.21	0.22
Turnips	1.10	1.10	1.10	-	-	-	-	-	-	-	-	-	-	-
Sugarbeet	1.11	1.11	1.10	1.11	-	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11
Fodder Beat	1.10	1.09	1.09	-	-	-	-	-	-	-	-	-	-	-
$R_{BG(T)}$														
Maize	-	-	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46
Winter Wheat	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61
Spring Wheat	0.68	0.67	0.67	0.67	0.67	0.68	0.68	0.67	0.67	0.68	0.67	0.67	0.67	0.67
Oats	0.52	0.52	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.52	0.51	0.51	0.51	0.51
Barley	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.45	0.46	0.45	0.45	0.45	0.45
Beans and Peas	0.44	0.45	0.44	0.44	0.45	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.43	0.44
Potatoes	0.26	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.26	0.25	0.24	0.24	0.24
Turnips	0.42	0.42	0.42	-	-	-	-	-	-	-	-	-	-	-
Sugarbeet	0.42	0.42	0.42	0.42	-	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
Fodder Beat	0.42	0.42	0.42	-	-	-	-	-	-	-	-	-	-	-

	1990	1995	2000	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Crop Residues (F_{CR}) (t N_2O-N/yr)														
Maize	-	-	1,767	1,843	2,638	3,093	3,118	2,878	2,399	1,730	1,831	1,755	1,629	1,376
Winter Wheat	6,999	6,209	7,994	7,878	7,755	11,543	7,621	7,328	10,875	8,666	5,807	9,112	8,333	8,049
Spring Wheat	1,183	1,712	1,982	2,953	1,940	1,989	1,781	1,760	1,742	1,076	1,578	690	1,109	769
Oats	1,479	1,332	1,277	1,155	1,619	1,762	1,477	1,498	1,705	1,608	1,957	1,498	1,970	1,848
Barley	15,287	13,627	16,222	12,733	13,939	16,010	15,218	15,151	17,320	15,600	20,535	21,184	21,321	18,145
Beans and Peas	189	253	98	241	166	146	283	320	208	253	298	251	864	897
Potatoes	1,224	1,195	809	721	706	636	651	742	632	462	695	641	590	592
Turnips	8,587	6,330	2,775	-	-	-	-	-	-	-	-	-	-	-
Sugarbeet	32,802	34,360	40,330	30,613	-	9,514	11,168	9,927	8,480	8,066	10,445	10,651	9,927	9,824
Fodder Beat	12,148	13,064	7,871	-	-	-	-	-	-	-	-	-	-	-
EF_1	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Emissions (kt N_2O)														
Maize	-	-	0.03	0.03	0.04	0.05	0.05	0.05	0.04	0.03	0.03	0.03	0.03	0.02
Winter Wheat	0.11	0.10	0.13	0.12	0.12	0.18	0.12	0.12	0.17	0.14	0.09	0.14	0.13	0.13
Spring Wheat	0.02	0.03	0.03	0.05	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.01	0.02	0.01
Oats	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.03	0.03	0.03	0.02	0.03	0.03
Barley	0.24	0.21	0.25	0.20	0.22	0.25	0.24	0.24	0.27	0.25	0.32	0.33	0.34	0.29
Beans and Peas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01
Potatoes	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Turnips	0.13	0.10	0.04	-	-	-	-	-	-	-	-	-	-	-
Sugarbeet	0.52	0.54	0.63	0.48	-	0.15	0.18	0.16	0.13	0.13	0.16	0.17	0.16	0.15
Fodder Beat	0.19	0.21	0.12	-	-	-	-	-	-	-	-	-	-	-
Total	**1.26**	**1.23**	**1.27**	**0.91**	**0.45**	**0.70**	**0.65**	**0.62**	**0.68**	**0.59**	**0.68**	**0.72**	**0.72**	**0.65**

Annex 3.4

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 (GPG 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.A.4 Allometric Equations for Biomass

3.4.A.5 Growth Models and Pre-processing Functions for CARBWARE v5

3.4.B Detailed Non-Forest Land Use Change Matrice

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 (GPG 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 (±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 that forest in the 2000 and 2006 time series. The resulting polygons were then intersected with a national soils map using ARC GIS to derive a land use change and soil type matrix to the periods 1990 to 2000 and 2000-2006. The resulting forest and soils GIS layers were then sampled using the NFI sample grid as discussed in the following sections below.

3.4.A.2 Sampling approach: NFI grid points and aerial photography (modified IPCC guidelines approach 3)

This sampling approach is a modification of approach 3, where the grids or centroids are sampled using a systematic sampling procedure adopted in the NFI. Note:

- The NFI was not designed to track land use change because the systematic grid (2 x 2 km) sample weighting factor is used to derive total areas statistics in 400 ha (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.

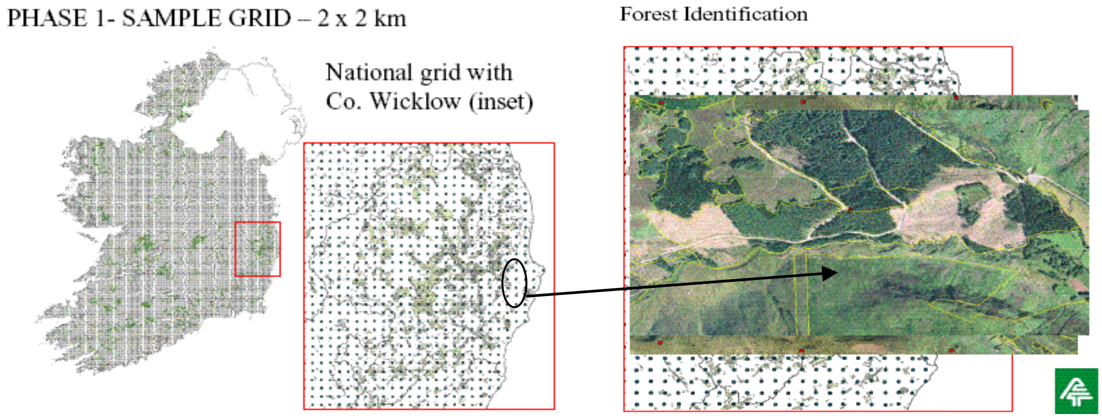


Figure 3.4.A2-1: The NFI systematic sample approach used to classify land use for each permanent sample plot (PSP)

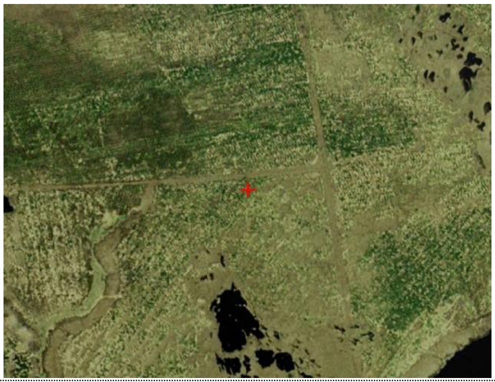
The use of the NFI stratified sample 2x2 km grid of PSP is described in chapters 6 and 11. Assessment of ca.18,000 point intersects with aerial photographs from 2000 and 2006 provides the opportunity to assess deforestation for this period. This method identified 15 NFI PSP grid samples which were deemed 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.

Conversion to Wetlands

Young forest in 2000



EU peat restoration in 2006

Conversion to Grassland

Mature forest in 2000

Grassland in 2006

Conversion to Development

Young forest in 2000

Mushroom factory in 2006

Figure 3.4.A2-2: Examples of NFI PSP (as indicated by the red cross) which were classified forests in 2000 but have since been converted to other land uses in 2006

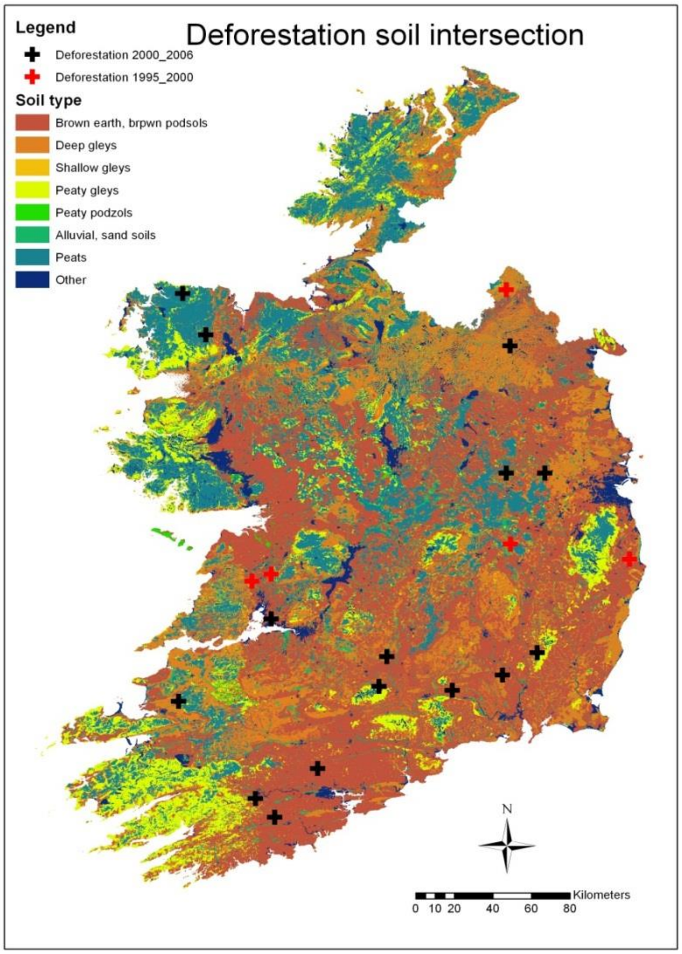


Figure 3.4.A2-3 The Irish soils map showing intersection with NFI PSP plots determined to be deforested between 1995 and 2006

3.4.A.3 Modification to deforestation records from 2006 onwards

The current methods for recording deforestation from 2006 onwards include the use of felling licence records. However, a QA exercise conducted in 2010 highlighted that 134 to 268 ha per year of land deforested since 2006 was not included in the felling licence records, if forests were less than 10 years old. These areas 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 is being compiled to capture the land use change and soil type if the information is available. However, until this information does become available, the land use and soil type matrices from the felling record data for corresponding years will be used. The biomass, litter and DOM losses associated with deforestation will be based on the NFI, PSP average of all 10 year old forest areas.

A combination of the three different approaches was used to produce deforestation data for the entire time series (Table 3.4.A3).

Table 3.4.A3 The new deforestation, land use change and soil type matrix

Period	Source	Land use	Soil category	Area (ha) per year	% for period
1990-1994	**CLC1990-2000**			**20.6**[14]	**100**
		Grassland	Mineral	2.5	12.2
		Grassland	Peat		
		Grassland	Peaty mineral	5.7	27.9
		Settlement	Mineral	10.2	49.4
		Settlement	Peat		
		Settlement	Peaty mineral		
		Wetland	Mineral		
		Wetland	Peat		
		Wetland	Peaty mineral		
		Other	Mineral	2.2	10.5
		Other	Peat		
		Other	Peaty mineral		
1995-1999	**NFI-FIPs 95**			**333.3**[15]	**100**
		Grassland	Mineral	266.7	80
		Grassland	Peat		
		Grassland	Peaty mineral		
		Settlement	Mineral		
		Settlement	Peat		
		Settlement	Peaty mineral		
		Wetland	Mineral		
		Wetland	Peat		
		Wetland	Peaty mineral		
		Other	Mineral	66.6	20
2000-2005	**NFI-2000-2006**			**857.1**[16]	**100**
		Grassland	Mineral	342.8	40
		Grassland	Peat		0
		Grassland	Peaty mineral	57.4	6.7
		Settlement	Mineral	171.4	20
		Settlement	Peat		0
		Settlement	Peaty mineral		0

[14] The CLC 1990-1994 area was calculated using the values show in table 1a to be, where annual deforestation area 1990-1994 = $\frac{area\_1990 \rightarrow 2000}{10 \times 5} \times 5$

[15] NFI 1995-1999 area was calculated using the values show in table 2a to be, where the annual deforested area 1995-1999 = $\frac{area\_1995 \rightarrow 2000}{6 \times 5} \times 5$

[16] NFI 2000-2005 area was calculated using the values show in table 2b to be, where the annual deforested area 2000-2005 = $\frac{area\_2000 \rightarrow 2006}{7 \times 6} \times 6$

		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
2006	**Felling licence and land taken out**			**376.44**	**100**
	242.34+134.1	Grassland	Mineral	5.3	1.4
	(LFL+LTO)[17]	Grassland	Peat		0
		Grassland	Peaty mineral	19.7	5.2
		Settlement	Mineral	17.1	4.5
		Settlement	Peat		0
		Settlement	Peaty mineral	0.6	0.2
		Wetland	Mineral		0
		Wetland	Peat	299.9	79.7
		Wetland	Peaty mineral	30.8	8.2
		Other	Mineral	3.1	0.8
		Other	Peat		0
		Other	Peaty mineral		0
2007	**Felling licence and land taken out**			**338.7**	**100**
	174.83+163.9	Grassland	Mineral	0.6	0.2
	(LFL+LTO)[4]	Grassland	Peat	14.5	4.3
		Grassland	Peaty mineral		0
		Settlement	Mineral	4.7	1.4
		Settlement	Peat	0.8	0.3
		Settlement	Peaty mineral		0
		Wetland	Mineral		0
		Wetland	Peat	297.2	87.7
		Wetland	Peaty mineral		0
		Other	Mineral	8.6	2.5
		Other	Peat	12.4	3.6
		Other	Peaty mineral		
2008	**Felling licence and land taken out**			**294.5**	**100**
	26.42+268	Grassland	Mineral	80.2	27.2
	(LFL+LTO)[4]	Grassland	Peat	0.04	0.01
		Grassland	Peaty mineral		0
		Settlement	Mineral	66.4	22.6
		Settlement	Peat		0
		Settlement	Peaty mineral		0
		Wetland	Mineral		0
		Wetland	Peat	24.5	8.3
		Wetland	Peaty mineral	21.2	7.2

[17] LFL is areas from limited felling licence records and LTO is the areas from lands taken out

		Other	Mineral	100.9	34.3
		Other	Peat		0
		Other	Peaty mineral	1.1	0.4
2009	**Felling licence and land taken out**			**196.9**	**100**
	49.9+147	Grassland	Mineral	5.1	2.6
	(LFL+LTO)[4]	Grassland	Peat		
		Grassland	Peaty mineral		
		Settlement	Mineral	15.4	7.8
		Settlement	Peat	1.5	0.7
		Settlement	Peaty mineral	1.5	0.8
		Wetland	Mineral		0
		Wetland	Peat		0
		Wetland	Peaty mineral		0
		Other	Mineral	121.1	61.5
		Other	Peat	19.9	10.1
		Other	Peaty mineral	32.4	16.4
2010	**Felling licence and land taken out**			**124**	**100**
	26+98	Grassland	Mineral	39.7	39.1
	(LFL+LTO)[4]	Grassland	Peat		
		Grassland	Peaty mineral		
		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.A.4 Allometric Equations for Biomass

Table 3.4.A.4.a: Allometric equations used to calculate biomass component for individual trees (kg d.wt tree^{-1})

Similar species are grouped into 6 different cohorts based on available research information (Spruces, Pines, Larches, Other conifers, fast growing broadleaves and slow growing broadleaves). Abbreviations: AB-above ground, TB-total biomass, BB-below ground, FB-foliage, SB-stem (i.e. timber >7cm diameter), L_{HR}= lop and top from harvest residues, DBH diameter at breast height (1.3 m) in cm, H –height in m.

Eq	Function	Range	Equation	Coefficients				r^2	RMSE	Slope	Source
				a	b	c	d				
Spruce											
1	AB	H>4.5m	$a \times DBH^b + c \times H^d$	0.23	2.12	5 x 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	L_{HR}		AB-SB								
Pines											
8	AB	H>3.8m	$a \times DBH^b + c \times H^d$	0.07	2.42	0.039	2.51	0.93	0.13	0.94	ii, iii
9	AB	H<3.8m	$a \times H^b$	0.12	3.91			0.95	0.74	0.95	i, ii
10	TB		$\exp[Ln(a) + b \times Ln(AG)]$	1.15	1.01			0.96	0.4	1.01	ii, iii
4	BB		TB-AB								
5	FB		$AB \times a + b \times \exp[-c \times AB]$	0.025	0.089	0.003		0.68	3.4	0.98	i, ii
11	SB		$\exp[Ln(a) + b \times Ln(AG)]$	0.71	1.005			0.97	0.27	0.96	ii, iii
7	L_{HR}		AB-SB								
Larch											
12	AB	H>2m	$a \times DBH^b + c \times H^d$	0.11	2.31	0.001	3.29	0.94	0.27	0.94	ii, iii
13	AB	H<2m	$a \times H^b$	0.03	1.91			0.67	0.44	1.2	i, ii
14	TB		$\exp[Ln(a) + b \times Ln(AG)]$	1.43	0.98			0.99	0.25	0.99	ii, iii
4	BB		TB-AB								

Eq	Function	Range	Equation	Coefficients				r^2	RMSE	Slope	Source
				a	b	c	d				
5	FB		$AB \times a + b \times \exp[-c \times AB]$	0.025	0.089	0.003		0.68	3.4	0.98	i, ii
15	SB		$\exp[Ln(a) + b \times Ln(AG)]$	0.903	0.972			0.98	0.28	0.96	ii, iii
7	L_{HR}		AB-SB								
Other conifers											
16	AB	H>3.8m	$a \times DBH^b + c \times H^d$	0.022	2.73	0.19	2.06	0.96	0.46	1.008	ii, iii
17	AB	H<3.8m	$a \times H^b \times c$	0.005	1.58	1.12		0.86	0.28	1.02	i, ii
18	TB		$\exp[Ln(a) + b \times Ln(AG)]$	1.59	0.96			0.99	0.28	1.005	ii, iii
4	BB		TB-AB								
5	FB		$AB \times a + b \times \exp[-c \times AB]$	0.025	0.089	0.003		0.68	3.4	0.98	i, ii
19	SB		$\exp[Ln(a) + b \times Ln(AG)]$	0.89	0.96			0.98	0.57	1.055	ii, iii
7	L_{HR}		AB-SB								
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	L_{HR}		AB-SB								
Slow growing broadleaves											
20	AB	H>3.0m	$a + \left[\frac{b \times DBH^c}{DBH^c + 246872}\right]$	0.06	25000	2.5	246872				iv

Eq	Function	Range	Equation	Coefficients				r^2	RMSE	Slope	Source
				a	b	c	d				
21	AB	H<3.0m	$a \times H^b$	0.031	1.72			0.84	0.88	0.91	i, ii
22	BB		$\exp(-a + Ln(DBH) + b)$	1.509	0.284						iv
27	FB	DBH>3cm	$a + b \times DBH^c$	0.375	0.0024	2.517		0.90			vi
28	FB	DBH<3cm	$AB \times 0.3$					0.78	1.2	0.79	i, ii
29	SB	DBH>35cm	$a \times DBH^b$	0.0001	2.535			0.97			v
30	SB	DBH<9cm	$\frac{AB + BB}{1.4}$								BEF, vii
7	L_{HR}		AB-SB								

i National research harvested tree database (COFORD funded project CARBiFOR)

ii Black et al., Biomass equations for modelling C dynamics in Irish forests (in prep)

iii Forest Research pulled tree database (Brice Nicholl, NRS, Forest Research, UK)

iv Brown S (2002) . Measuring carbon in forests: current status and future challenges. Environmental Pollution 116: 363-372.

v Johansson, T. Dry matter amounts and increment in 21-to 91-year-old common alder and grey alder some practical implicatons. Canadian Journal of Forest Research 29 1679-1690.

vi Bartelink, H.H., Allometric relationship for biomass and leaf area of beech (Fagus sylvatica L). Annals of Forest Science, 1997. 54: p. 39-50.

vii Black K., Tobin B., Saiz G., Byrne K. & Osborne B. (2004). Improved estimates of biomass expansion factors for Sitka spruce. Irish Forestry 61:50-65.

3.4.A.5 Growth Models and Pre-processing Functions for CARBWARE v5

CARBWARE pre-processing functions and growth models

The NFI permanent plot sampling procedure does not sample all trees in a plot. Therefore, it is not possible to derive productivity index information, such as Height index or Yield class, which can be used to drive conventional stand based productivity models. The alternative and most statistically valid procedure adopted was the use of single tree models, to simulate tree growth between NFI cycles. These models can be cross-validated and re-parameterised once a repeat NFI cycle is completed. This section discusses the development of the CARBWARE growth model as presented in International, peer reviewed Scientific Journals.

3.4.A.5.1: Pre-processing functions

Height-Diameter And Crown Ratio Modelling For Six Species Cohorts.

It is common among forestry datasets that tree height (H) or crown ratio (CR) is not measured on every tree. This creates interest in estimating the height of such trees.

A common forest inventory approach used to derive missing H and CR values involves the use of single parameter (DBH) models based on species and plot specific predictions (NFI, 2007; Wykoff et al., 1982). However, is has been suggested that these Chapman-Richards functions, or derivations thereof, are problematic because the function approaches the asymptote too rapidly, particularly when there is a weak relationship between DBH and H in larger trees. In addition, individual plot DBH-H data is sometimes too sparse to parameterise plot specific functions. Generalised DBH-H functions avoid the need to parameterise the relationship for every stand. Since the relationship between DBH and H is influenced by the relative competitive position of trees within a stand and management interventions, site-level stand-density information is often incorporated (Temesgen and Gadow, 2004). Taking their results as a starting point, we address here several issues that arise in the context of our modelling dataset. These include the application of nonlinear mixed effects models which successfully borrow strength across all PSP, thereby facilitating imputation in plots where data is sparse or unevenly distributed. The PSP data, taken from a range of spacing and thinning experiments, used in this study is well suited, albeit not arising by design, to evaluate these stand-density parameters to describe variations in H and CR across different silvicultural conditions.

Materials and methods

Data

Data used were obtained from Coillte Teoranta's (the Irish Forestry Board state commercial forestry company) permanent sample plot record system. The dataset contains records from many silvicultural and thinning trials established during the period 1963 to 2001. The trials were initially established as replicated experimental designs with repeated measurements typically undertaken every five years. This dataset is described in Broad and Lynch (2007).

Incorporating competition covariates

The modelling here follows Temesgen and Gadow (2004) who based their work on Yang et al. (1978) and incorporated competition covariates into the Yang/Weibull function (Table 3.4.A.5.a, Model 2). Their model approach was evaluated and also used to test for differences between management regimes conditional on the DBH-H model by incorporating dummy indicator variables in the linear regression models of the model parameters. Our aim in this section was to test if the inclusion of certain covariates, typically relating to the competition in a forest stand/plot, improved the baseline DBH-H model (3.4.A.5a, Model 1). We also investigated whether the model was improved by including random effects on the level of the plot (Table 3.4.A.5a, Model 3).

The competition covariates are plot basal area (BA, m^2 ha^{-1}), basal area in larger trees (BAL, m^2 ha^{-1}) which is the integral of the empirical frequency distribution of the BA variable from the subject tree to the largest diameter tree in the plot and plot density (DENS, trees ha^{-1}). Models were fitted in a NLMixed procedure in SAS using the Trust-Region algorithm. Grids were specified as starting values for parameters where sensible.

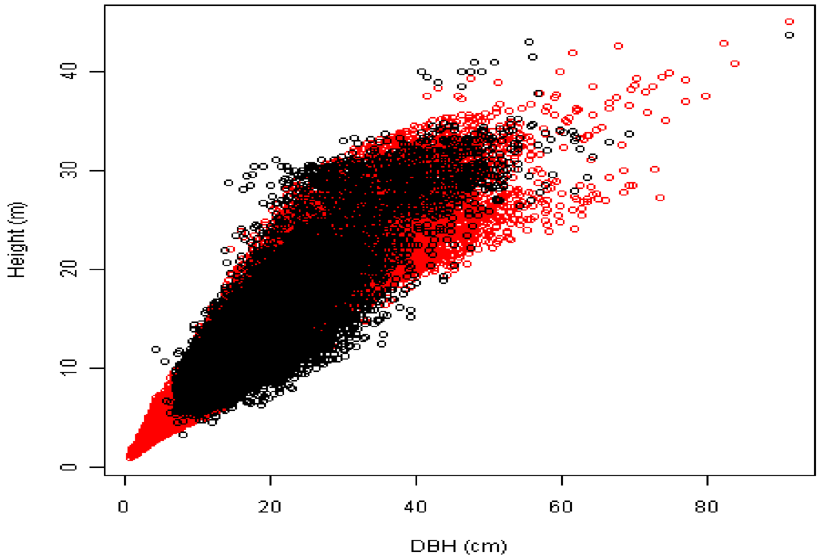


Figure 3.4.A.5a. Model 2 Height estimates (red) and actual heights (black)

The estimates presented here depict a "cloud" because they are conditioned on covariates that vary between trees (BAL) and plots (Density, Basal Area) and over time (BAL, Density, BA).

Table 3.4.A.5a

	Model	-2l	BIC
1	$H = a(1 - \exp(b.DBH^{c}))$	65185	65223
2	$H = (a_1 + a_2 BAL + a_3 BA)(1 - \exp(b.DBH^{(c_1 - c_2 BAL)}))$	58341	58417
3	$H = (Ui + a_1 + a_2 BAL + a_3 DENS + a_4 BA)(1 - \exp(b.DBH^{(c_1 - c_2 BAL)}))$	44980	45034

Table 3.4.A.5b Likelihood statistics for different forms of the DBH-H model

Model 2 is the model used in CARBWARE for the 6 different cohorts. If dependent variables had no significant influence on the H model prediction, these variables were excluded from the model.

Cohort	Model (2 variation)	a1	a2	a3	b	c1	c2
Spruce	$H = (a_1 + a_2 BAL + a_3 BA)(1 - \exp(b.DBH^{(c_1 - c_2 BAL)}))$	33.69	-0.274	0.1603	0.024	0.8846	0.0064
Pine	$H = (a_1 + a_2 BAL + a_3 BA)(1 - \exp(-b.BAL))$	16.905	0.083	0.0803	0.042		
Larch	$H = (a_1 + a_2 BAL + a_3 BA)(1 - \exp(-b.BAL))$	32.59	0.1052	0.1229	0.023		
Conifers	$H = (a_1 + a_2 BAL + a_3 BA)(1 - \exp(-b.DBH^{c_1}))$	23.226	0.1381	0.0703	0.027	1.1021	
FGB	$H = (a_1 + a_2 BAL + a_3 BA)(1 - \exp(-b.DBH))$	14.661	0.1167	0.0187	0.076		
SGB	$H = (a_1 + a_2 BAL)(1 - \exp(-b.DBH^{c}))$	29.677	0.1034		0.044	0.7813	

BAL is the sum of the basal area of all individual trees larger than the subject tree (m^2 per ha)

BA is the basal area of all trees in the plot (normalised to a ha)

DBH is the diameter at breast height (cm)

Table 3.4.A.5c CR models used in CARBWARE for the 6 different cohorts

If dependent variables had no significant influence on the H model prediction, these variables were excluded from the model.

The CR model takes the form of:

$$CR = \frac{\exp(lCR)}{1+\exp(lCR)}$$

where *lCR* is derived from the non-linear equations, which may vary for different cohorts.

Cohort	Model (*lCR* variations)	a1	a2	a3	a4	a5	b	c
Spruce	$lCR = (a_1 + a_2 BAL + a_3 Ln(CCF) + a_4 H + a_5 \left[\frac{H}{BAL}\right] + bDBH^c$	4.8705	-0.017	-0.397	-0.119	-0.296	0.0003	2
Pine	$lCR = (a_1 + a_2 BAL + a_3 Ln(CCF) + a_4 H + bDBH^c$	3.8478	-0.024	-0.213	-0.137		0.0002	2
Larch	$lCR = (a_1 + a_2 BAL + a_3 Ln(CCF) + a_4 H$	5.8306	-0.018	-0.794	-0.039			
Conifers	$lCR = (a_1 + a_2 BAL + a_3 Ln(CCF) + a_4 H + bDBH^c$	4.1759	-0.019	-0.394	-0.965		0.0004	2
FGB	$lCR = (a_1 + a_2 BAL + a_3 Ln(CCF) + a_4 H + a_5 \left[\frac{H}{DBH}\right] + bDBH^c$	2.4539	-0.009	-0.145	-0.045	-0.591	0.0001	2
SGB	$lCR = (a_1 + a_2 BAL + a_3 H + a_5 \left[\frac{H}{BAL}\right]$	1.477	-0.005	-0.017	-0.578			

BAL is the sum of the basal area of all individual trees larger than the subject tree (m^2 per ha)

CCF is the crown competition factor, which is a measure of the crown areas of the subject tree relative to a open grown tree that would not be subjected to crown competition (taken from Hassenhaur, see section B of this appendix)

DBH is the diameter at breast height (cm)

H is height (m) form actual or predicted H estimates (Table 3.4.A.5b)

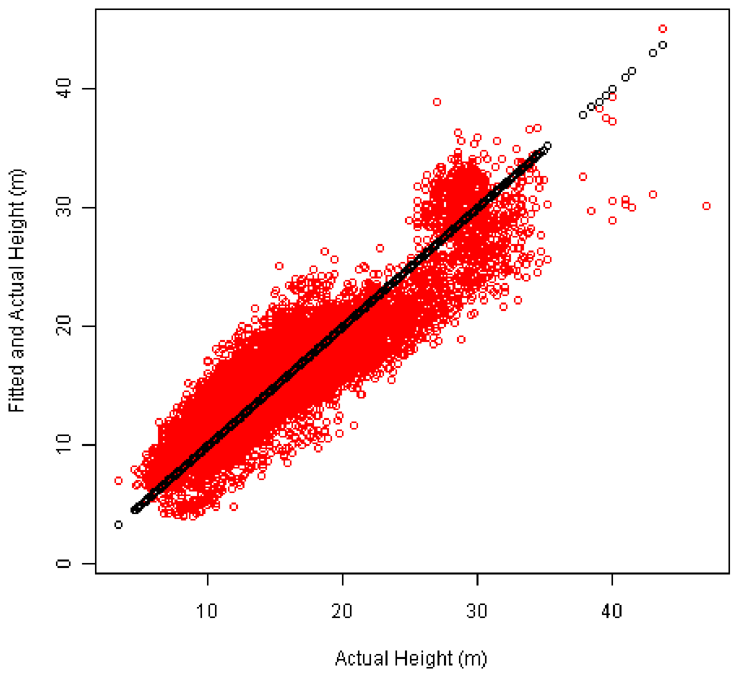


Figure 3.4.A.5b. Fitted and actual height plotted (all cohorts model 2) against actual height

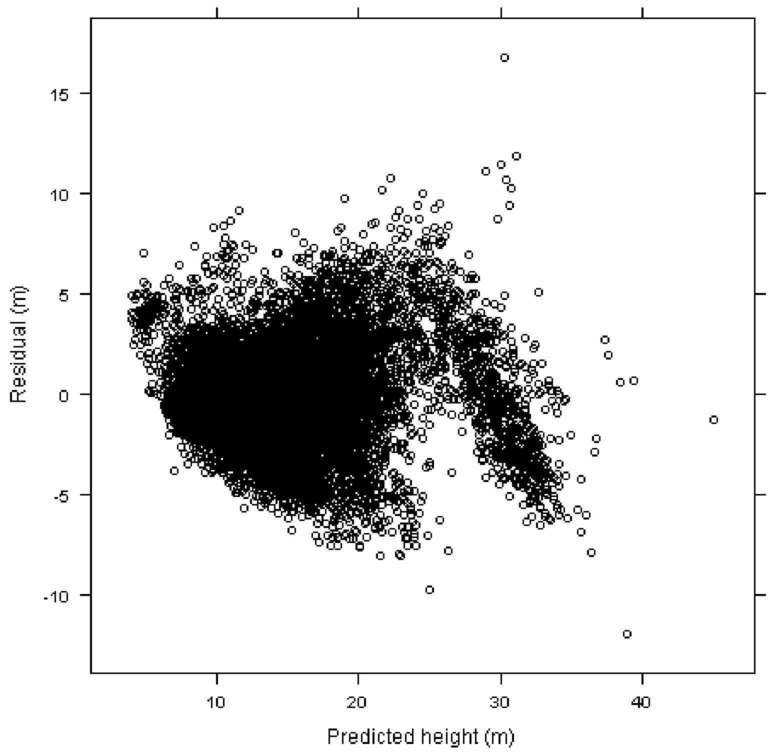


Figure 3.4.A.5c. Raw residuals from the fitted model plotted against the fitted height value

External validation

Based on the data presented above, model 2 was selected for validation against external data sets. In this section we compare model predictions against data from non-research PSP.

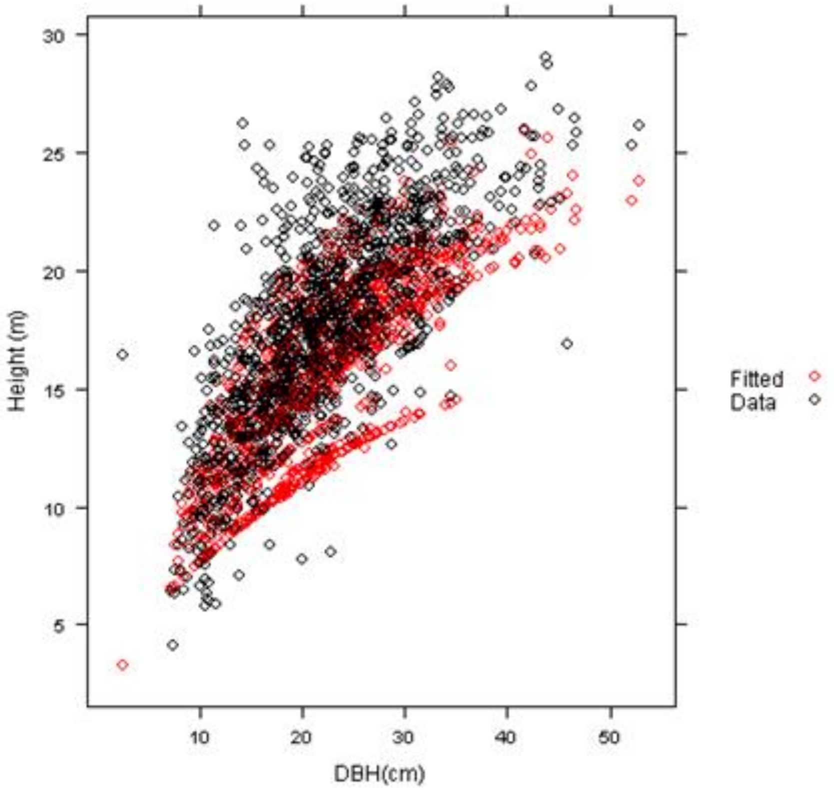


Figure 3.4.A.5d. Estimated and observed validation heights versus DBH

Generalised and plot-specific models

In this section we discuss the implications of using a generalised DBH-H model (i.e. one whose parameters are fitted to the entire dataset) with a plot-specific model (i.e. one whose parameters are estimated for each plot separately). We compare a mixed effects model and a plot-specific model. The former is plot-specific by the inclusion of a random residual plot effect. In what follows, by *mixed model* we mean the random asymptote model (Table 3.4.A.5d, Model 3). To get an idea of the difference between plot-specific and mixed-model results, we extract a plot from the dataset that exhibits a wide range of DBH and H values and then compare the models for that plot. This makes sense because the context of the comparison is how well a given model will perform for a given plot, primarily. In particular we will compare the standard error of prediction for a new tree height for both models. In the case of the mixed model, this standard error of prediction is derived as conditional on the estimated random plot effect.

A plot-specific Yang/Weibull model gives a smaller standard error of prediction than the same model estimated from the entire dataset, because residual variability for any given model will always increase from a subset of the data (plot specific) to the entire dataset (generalised). In other words, the generalised model predictions are less precise than the plot-specific predictions for any given plot, and the model mean estimate tends *towards* the overall mean and *away* from the plot-specific mean.

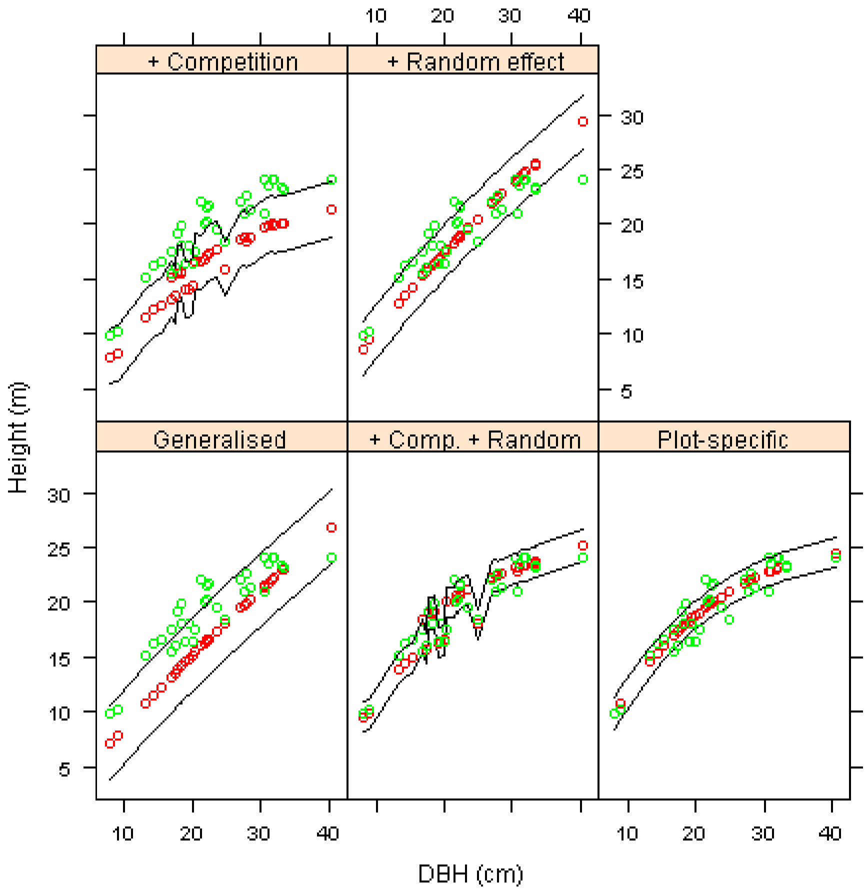


Figure 3.4.A.5e Model predictions for a single plot with various models, all based on the Yang/Weibull funtion (cf. Table 5.2b-A.1)

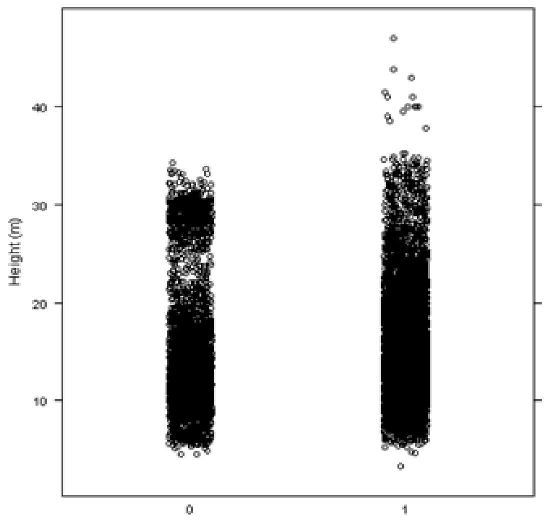
Green, red and black are data, estimates, and single standard error of prediction, respectively. Competition denotes a generalised model with competition covariates (cf. Model 2, Table 3.4.A.5a), Random denotes a plot-specific random asymptote (cf. Model 3, Table 5.2b-A.1), Generalised denotes parameters are estimated from the entire dataset. The smallest standard error of prediction is associated with the Plot-specific model, followed by the + Comp. + Random model. Average s.e.p. for these models are 1.39 and 1.25 respectively.

Thinning effects

All observations in the dataset were categorised as “thinned” or “non-thinned” depending on the general management regime for the plot. The following model was estimated to test for a residual thinning effect, conditioned on other effects. :

$$H = (U_i + a + a_1 BAL + a_2 DENS + a_3 BA + a_4 I(Thinned))(1 - \exp(b.DBH^{(c_1 - c_2 BAL)}))$$

where I(*Thinned*) is an indicator function valued at 1 if the plot was thinned and 0 otherwise. The Bayesian information criterion (BIC) of this model was 45037, and the Wald test for the a_4 parameter (p = 0.08) indicated that the thinning effect was not statistically significant at the 5% level. The a_4 estimate was greater than zero, perhaps reflecting the longer tail in the height distribution for trees in thinned plots (Figure 3.4.A.5f).



0 = Unthinned　　　　　*1 = Thinned*

Figure 3.4.A.5a. Strip-plot of Heights in the calibration dataset

Discussion

It has been shown that it is possible to derive a generalised model that performs well and which by its nature deals with the data sparseness issue by estimating the "typical" parameter value and modifying this value as a function of the plot- and tree-level characteristics. The BIC results and the graphical results suggest that the inclusion of covariates in the model improves the DBH-H model (i.e Model 2), as was shown by Temesgen and von Gadow (2004).

The inclusion of covariates in the model is a move away from the baseline model, which is a generalised approach that presumes that competition (as measured on the scale of the plot by DENS, and BA, and on the scale of the tree by BAL) does not affect the allometric relationship between DBH and H over the tree's lifetime, when subjected to different competition pressure introduced by spacing or thinning. In the next section we address the issue of generalised vs plot specific modelling. However, our results at this point suggest that the Temesgen and von Gadow model that models plot differences through competition variables is a unified single-step approach. By contrast, the plot-specific approach can be seen as a multi-step approach, whereby the DBH-H relationship for each subject is modelled individually, and competition effects are at best implicitly described by the plot-specific fitted parameters. We might suspect that datasets that are heterogeneous across plots might be more accurately modelled using plot-specific approaches. Similarly, a generalised model might perform well on plots that are nearer the centre of the sample space than plots where management conditions are more atypical for a given dataset.

In conclusion, we adopt the use of generalised competition based models in the CARBWARE software because this performs better across all data.

3.4.A.5.2: Growth Modelling

(a) Modelling diameter increments in Irish Forests

Introduction

The modelling approach adapted in this version of CARBWARE v5 is the use of diameter increment models for all trees with a DBH greater that 5cm. This model is a distance independent individual tree growth model parameterised on Coillte permanent plot data recorded every 4 to 6 years since 1954 to 2003. These include pure and mixed species stands at establishment planting densities of 5000 to 1000 trees per ha and with different thinning treatments. The advantage of using a single tree growth model and the nature of the parameterisation data set is that different silvicultural regimes and species mixtures can be handled by one generalised modelling framework. In addition, the application data set, i.e. the data from which models will be run, does not contain explicit complete longitudinal data representing stand variables, which are used in conventional growth models.

Data operations

Two datasets are referred to, Coillte PSP and NFI. Some of the data operations referred to below differ between these because the former has complete enumeration on a plot and is longitudinal, the latter samples from the plot and is cross-sectional.

In general, the modelling framework that we base our work on, PrognAus (see various references below), informed the types of data operations required. The framework involves, using their terminology, site, competition and size variables. Our focus was on the latter variables, and site or plot effects were accounted for using mixed model methods, whereby plot or site effects are random blocking effects, rather than effects whose levels have physical dimension. In any case, site or plot effects are not a feature of the growth simulator. Furthermore, incomplete enumeration of certain independent variables meant that random effects were difficult to estimate because of the sparse data.

The variables described here are those that feature in the diameter increment model that we aim towards calibrating:

$Dinc(cm) = \exp(a_0 + a_1 \ln DBH + a_2 DBH^2 + a_3 . \ln CR + a_4 . \ln CCF + a_5 . BAL)$

See Table 3.4.A.5.2a. below and the text for explanation of symbols.

Data operations were concerned with assembling datasets of the variables used in the growth model, insofar as was feasible. In the following section, we describe any substantive data operations that were performed on the variables of interest. Excluded from this description is any operations related to “data cleaning”. The main data cleaning result was to omit negative diameter increments from the dataset. Such omissions were made after such derived variables as BAL, BA and plot density were calculated. That decision was based on the fact that the omission did not have a significant impact on the results, which suggested that no further modelling was necessary to compensate for the omission. Also, if the trees involved were omitted prior to the calculation of derived variables, those variables would have been subject to an even greater bias.

Table 3.4.A.5.2a. Explanation of some symbols used in the text

Variable	**Formula**	**Scale of measurement**
CR	Crown length/height	Range (0,1)
DBH	Diameter at 1.3 m	Cm
Crown competition factor (CCF)	The “open-grown” (e.g. if every tree had zero competitors) crown area of all trees in a plot expressed as a percentage of plot area.	Percent
BAL	A function for each plot that takes as its argument any tree’s rank in the diameter distribution ordered from smallest to largest and returns the combined basal area of all trees with higher rank.	M^2 ha^{-1}
BA	Plot basal area	M^2 ha^{-1}
Annualised diameter increment (Dinc)	(DBH(t+1)-DBH(t))/([t+1] – [t]). DBH(t) stands for “DBH on the occasion of the t^{th} measurement”. Since measurment intervals vary, this implies that [t +1] – [t] = 1 is not necessarily true, hence the use of the term “annualised”.	cm

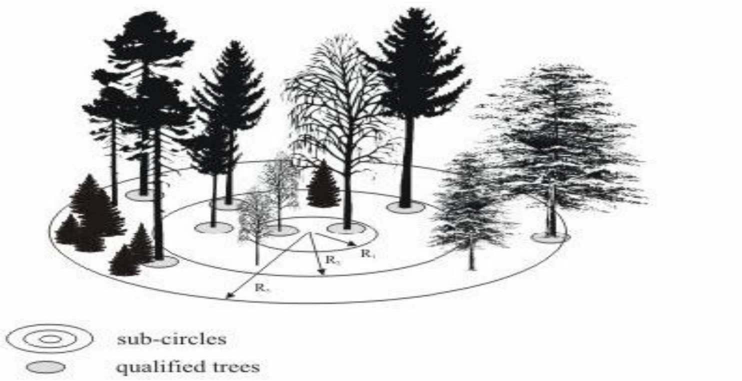
Open-grown crown width (cw), is an intermediary variable in the calculation CCF. The cw value is estimated using equations derived by Hasenauer (1997). These equations return open-grown crown width in *metres*. Hasenauer (1997) derived species-specific equations that we apply in approximation to cohorts,

Spruce	: cw = exp(-**0.3232**)*((DBH)$^{0.6441}$)
Other conifers	: cw = exp(**0.092**) *((DBH)$^{0.538}$)
Pine	: cw = exp(-**0.1797**)*((DBH)$^{0.6267}$)
Larch	: cw = exp(-**0.3396**)*((DBH)$^{0.6823}$)
Slow-growing broadleaves	: cw = exp(-**0.3973**)*((DBH)$^{0.7328}$)
Fast-growing broadleaves	: cw = exp(**0.1366**)*((DBH)$^{0.6183}$)

(where a circumflex denotes exponentiation.)

Open grown crown area (m^2) = (**0.25**)*(**3.141593***cw^2)

NFI and PSP datasets differed primarily in the fact that PSP plots were fully enumerated, whereas NFI plots were sampled. The sampling method, in conjunction with an assumption of homogeneous spatial diameter distribution, informs the calculation of a sampling weight or *expansion factor* 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 of a given tree's inclusion in the sample, based on the trees diameter class. Each tree in the sample is thus duplicated by a number of times equal to its expansion factor. This duplication is allowed for when calculating plot-level derived variables, e.g. Density, by incorporating the expansion factor into the equations. For example, the estimated number of trees on a plot with a single sampled tree of 8cm is $(12.62/3)^2$. See Figure 3.4.A.5.2a. for an explanation.



	R1	R2	R3
Sub-circle radius (m)	3	7	12,62
Sub-circle area (m^2)	28,3	153,9	500
Treshold diameter (mm)	70	120	200

Figure 3.4.A.5.2a.. The NFI sampling scheme at the plot-level

The *expansion factor* for a tree in the *i*th diameter class is $(R_3/R_i)^2$

Diameter increment

The diameter increment model for each cohort was calibrated by fitting to data from the PSP dataset.

$Dinc = exp(a_0 + a_1 lnDBH + a_2 DBH^{\wedge 2} + a_3 . lnCR + a_4 . lnCCF + a_5 . BAL) + e$

Where a_i, i = 1…5 are coefficients and *e* is a residual that was autocorrelated between measurements on the same tree and independent otherwise. The fitting was done in the Glimmix procedure in SAS, and the model is a GLM with Gaussian variance function and a log link. This is slightly different from Monserud and Sterba (1997), who log-transformed the response, where we log-transform the expected value of *Dinc*, and didn't model autocorrelation.

Where fitting was unsatisfactory, i.e. because of parameter instability or data sparseness, a submodel was selected. A criterion of model selection was that the parameters should be qualitatively similar to those estimated by Monserud and Sterba (1997). In this respect, the fitting of the increment models is better described as model calibration than model selection.

The parameters for the fitted models were:

FGB

$E(Dinc) = EXP(-2.8528 + LN(DBH)*1.1729 - 0.00012*DBH^2 + LN(CR)*0.8241 - 0.000015*CCF)$

Larch

$E(Dinc) = EXP(-2.2969 + LN(DBH)*0.6338 - 0.00096*CCF)$

OC

$E(Dinc) = EXP(-1.4191 + LN(DBH)*0.554 - 0.00025*DBH^2 + LN(CR)*0.5549 - 0.00052*CCF - 0.00646*BAL)$

Pine

$E(Dinc) = EXP(-1.3466 + LN(DBH)*0.741 - 0.001*DBH^2 + LN(CR)*0.998 - 0.00066*CCF - 0.00417*BAL)$

SGB

$E(Dinc) = EXP(-2.5897 + LN(DBH)*0.7534 - 0.00068*DBH^{\wedge 2} - 0.0006*CCF - 0.00979*BAL)$

Spruce

$E(Dinc) = EXP(-1.8628 + LN(DBH)*0.9456 - 0.0005*DBH^2 + LN(CR)*1.1639 - 0.000638*CCF-0.00273*BAL)$

Uncertainty:

This section discusses the various measures of the performance for the different models discussed above. The performance measures quoted give rough ideas about how the models perform. It should be noted that performance can be improved somewhat by including plot and site effects but since these are problematic for extrapolation from PSP to NFI, they were omitted from the Dinc model. They were also omitted from within NFI imputation models, thus imputation models were calibrated on NFI data, for similar considerations. They were not omitted from PSP-specific models.

The performance of the various models – DBH-H, CR, Dinc – for the two datasets was examined. Some measures such as those used by Thurig et al (2005), for example, are *accuracy, precision,* and *excess error,* are calculated as follows.

Accuracy : ((Σ(**pred**icted-**obs**erved)/n)*100)/m. Where *m* is E(obs), and *n* is the number of observations.

Precision : SD(pred-obs)

Empirical Excess error (%): ((1-Sec)/Sei)*100. Where *Sec* is the *precision* of the calibration data, and *Sei* the *precision* of the independent data.

Theoretical Excess error : $(1/n)[\Sigma(pred_{(-1)}\text{-}obs)^2\text{-}\ \Sigma(pred\text{-}obs)^2]$. Where pred(-1) is the leave one out prediction error

Note that *empirical excess error* is only viable when doing external validation.

Temesgen and von Gadow (2004), for example, use *root mean squared error* (RMSE) and Bias to evaluate their models.

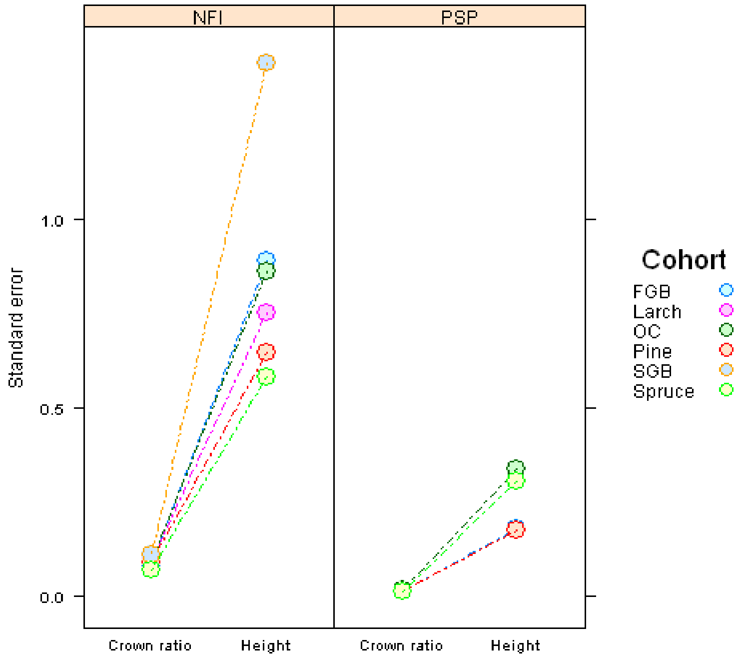
Bias: (Σ(pred-obs)/n)

RMSE : $\sqrt{(\ \Sigma(pred\text{-}obs)^2/n\text{-}p)}$. Where *p* is the number of parameters in the model.

Another measure is *mean absolute error* (MAE).

MAE : Σ |pred-obs|/n

A certain amount of model selection was undertaken, as noted above, when fitting the models to the data in the first place. This ensures that the fitted models are the most parsimonious to minimise residual error. However, model performance is best evaluated by external validation or, failing that, some cross-validation. We conduct leave-k-out cross validation on the Dinc calibration data. *MAE* and *RMSE* are calculated for each cross-validation dataset replicate. External validation data was only available for the PSP DBH-H model, which is not discussed here.



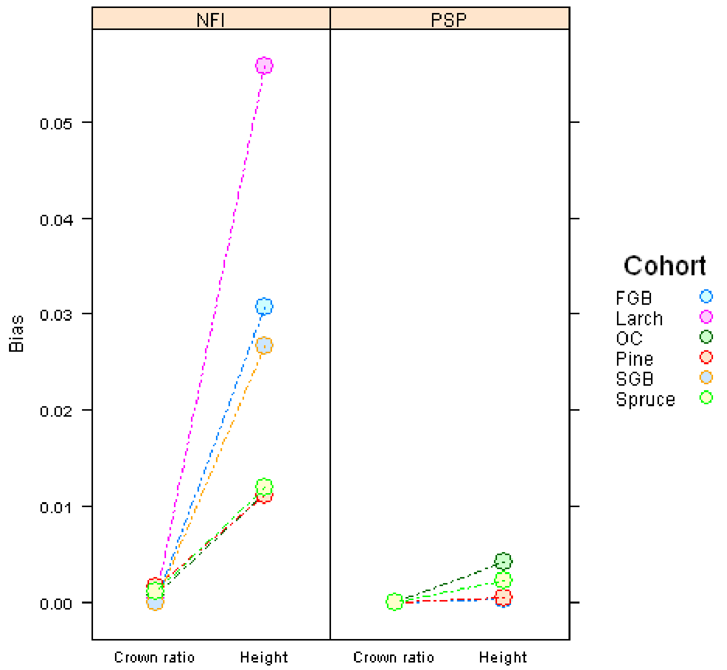


Figure 3.4.A.5.2b.. Within-sample Precision (upper panel) and Bias (lower panel) for imputation

Values are plotted for each dataset, for cohorts, and for models of Height and Crown ratio.

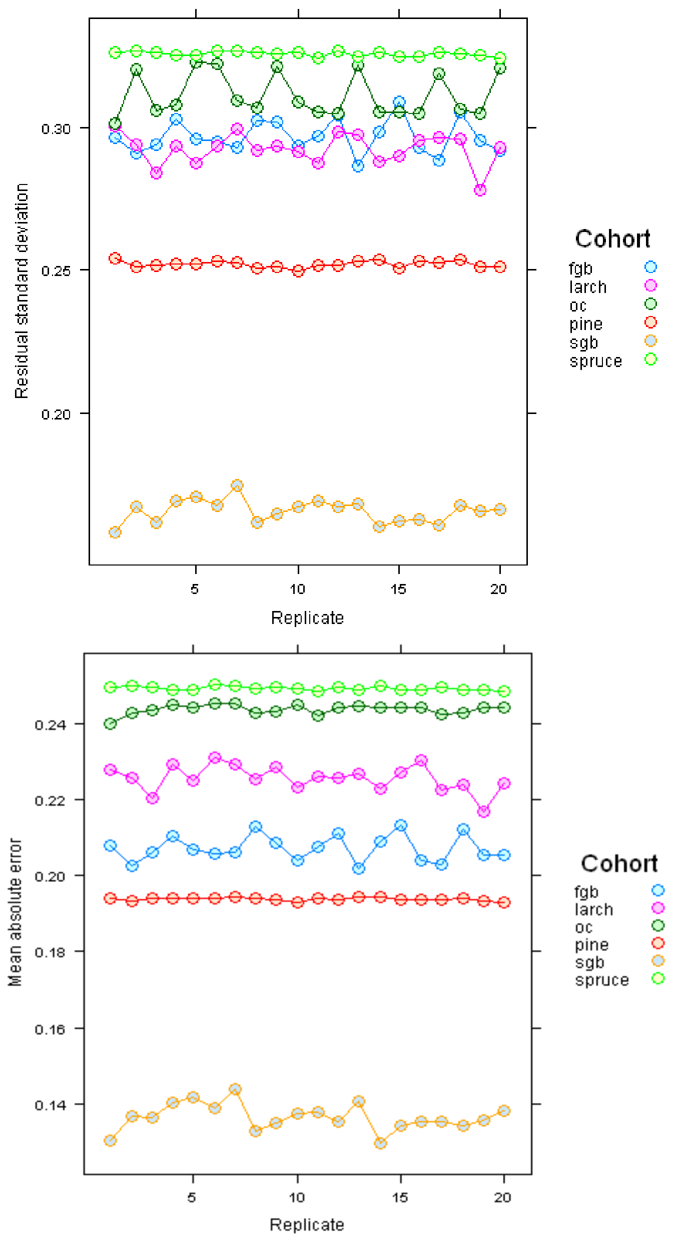


Figure 3.4.A.5.2c.. Leave k-out cross validation results, precision (top) and mean absolute error (bottom) for the Dinc model

The probability of inclusion in the validation dataset is 0.33. 20 cross-validation replicates are displayed.

Discussion and conclusions

The lines joining the points in Figure 3.4.A.5.2b. are only included to facilitate a comparison between panels. The interpolating lines in Figure 3.4.A.5.2c are indicative of variability between the different cross-validation runs. This variability is partly a function of data resources, i.e. the number of cases, and the size of the validation sample as a proportion of the number of cases. The low variability of Pine and Spruce, the cohorts with by far the most number of cases, reflects this.

In Figure 3.4.A.5.2b, the better performance of PSP versus NFI is partly a result of including such blocking effects as site and plot.

From Figure 3.4.A.5.2b, bias levels are low for both NFI and PSP. Pine and Spruce, the most important cohorts, are among the top performers. This partly reflects the better data resources for those cohorts.

(b) Modelling height increments for small trees

Introduction

Height growth for small trees is a driving developmental force as trees compete for light and vertical growing space. Because of this, the small-tree portion of CARBWARE is a height-growth driven model. Height growth is estimated first, and then diameter growth is predicted from height growth. Equations used to predict small-tree height increment vary by species, variant, silvicultural practice and site type. Most single tree based models for young growth, generally use the same predictors as described for DBH increment models. However, the NFI data set provides little or no information on predictors for young tree height. The development of a H growth model for trees less than 1.3 m to a maximum H of 2.3 to 5.1 m (i.e. the diameter at breast H, DBH) is described here. The model uses a empirical Chapman-Richards approach for different species with sub models for different height index ratios (i.e. mean H over age as proxy's for young stand productivity and site factors).

Methodology

Modelling framework

The model uses a empirical Chapman-Richards approach for different species with sub models for different height index ratios (i.e. mean H over age as proxy's for young stand productivity and site factors).

$$xHinc_{i,j}^{n+1} = \frac{a_1}{1 + \exp(-1 \times \left[\frac{age^n - a_2}{a_3}\right])}$$

where, *xH* is mean height of all trees in the NFI plot for the $_i$th species and $_j$th H index ratio at the determined age (n+1). The age of the forest (n) is obtained from the NFI stand attribute data. The partial coefficients (*a*) for each species and productivity class and goodness of f

Once the new mean tree H (xH_n+$xHinc_{n+1}$) is computed, the individual tree H is recalculated based on a scaling function:

$$H_{n+1} = \frac{H_n}{xH_n} \times H_n$$

where, H_{n+1} is the individual H of the tree in the plot in the year following the NFI , H_n is the individual H in the year the NFI was completed, and xH_n is the mean H of trees in the plot in the year the last NFI was completed.

The Productivity class (H over age) categories were defined to match conventional yield class productivity indices (YC*eq*) as described by (Christy and Edwards, 1981). This was derived by comparison of Chapman Richard outputs from each H index ratio (HI) with static age-H tables at ca. 10 to 20 year old crops.

$$YCeq = HI = \min, \{YCH_{ij} - xH_{ij}\}^2$$

where, YC *eq* is the *HI* equivalent to YC at the lowest least-squares different between the yield table H values (*YCH*) and the predicted mean height (*x*H see equation 1) for the *i*th cohort and *j*th HI.

Selection of tree for H increment model

All trees with no measurable DBH are selected for growth increment using the H model. The CARBWARE model also selects eligible trees to be grown using the H growth model based on cohort-specific threshold DBH values (Table 5.2B-B.2). These are derived from analysis of the minimum DBH ranges suitable for the DBH increment model. The transition from the H to DBH increment model is based on the threshold H value which corresponds to the minimum allowable DBH value to be used in the DBH increment model (Table 5.2b-B.2). If a tree has a larger corresponding DBH than the threshold value, it is grown using the DBH increment model.

Table 3.4.A.5.2b. Threshold minimum DBH values suitable for use din DBH increment model and corresponding cut-off H values used for H growth in small trees

Cohort	DBH threshold (cm)	Corresponding H (m)
Spruce	4	2.7
Pine	4	5.1
Larch	2	3.6
Other conifers	4	3.1
Slow growing Broadleaves (SGB)	2	4.2
Fast growing Broadleaves (FGB)	2	3.2

Datasets and measure of goodness of fit

We used both the Coillte PSP and NFI individual tree data base to develop H-age curves (range 0.1 to 12 m). Data operations were concerned with assembling datasets of the variables used in the H model, insofar as was feasible.

We looked at the performance of the various models –H-Age for different cohort for the combined datasets. Some measures such as those used by Thurig et al (2005), for example, are *accuracy, precision,* and *excess error,* and are calculated as follows.

Fitted model parameters

Table 3.4.A.5.2c shows the partial coefficients for each species and productivity class for the Chapman-Richards H-Age functions.

Table 3.4.A.5.2c Spruce cohort

HI range	YC*eq*				Precision	RMSE	Bias
		a_1	a_2	a_3			
>1.2	>24	1.02	5.59	2.04	1.8	4.69	0.32
1-1.2	24	1.05	7.05	2.32	1.42	4.23	-0.23
0.8-1	22	0.76	5.98	1.63	1.33	3.21	0.11
0.6-0.8	20	0.66	5.51	1.33	0.66	2.55	0.56
0.5-0.6	18	0.57	5.26	1.12	0.89	1.69	0.45
0.4-0.5	16	0.53	5.35	1.47	1.11	3.66	0.32
0.3-0.4	14	0.48	5.32	0.54	0.74	3.54	0.62
0.2-0.3	12	0.44	6.59	2.20	1.53	4.53	0.24
0.1-0.2	10	0.35	6.93	2.27	0.69	1.77	-0.43
<0.1	<10	0.28	8.02	0.35	1.9	4.23	-0.7

3.4.A.5.2: CARBWARE stand modification functions

The NFI permanent plots structure is modified at each growth cycle iteration to simulate the losses associated with natural mortality and harvest. This section discusses the development of the CARBWARE modification functions from that presented in International, peer reviewed Scientific Journals papers.

3.4.A.5.2.1: Mortality models

Introduction

In the general context of forest growth models, and at the most basic level, the tree mortality module's role at each iteration is to classify a particular tree in the dataset as being either dead or alive. This issue is approached in the context of an individual-tree model of mortality that is both age- and distance-independent. The specific modelling framework within which the mortality module will be applied, is a framework similar to the PrognAus framework, with the goal of estimating annual forest dynamics for Ireland.

Literature review

There are two areas of interest in the literature: *tree-mortality* modelling, and *threshold-based* classification.

1. *Mortality modelling* in Forest Succession.

Wunder et al. [2006a] compared the use of classical stress-thresholds in mortality modules of forest succession models. They conclude that logistical regression-based models are superior to stress-threshold models with regard to predicting time of tree death.

Baesens et al. [2003] reviewed threshold-based classifiers in the context of credit-scoring. They examined logistic regression, discriminant analysis, k-nearest neighbour, neural networks and decision trees, advanced kernel-based classification algorithms such as support vector machines and least-squares support vector machines (LS-SVM). They assessed performance using the classification accuracy and the area under the receiver operating characteristic curve. They found that both the LS-SVM and neural network classifiers yield a very good performance, but also simple classifiers such as logistic regression and linear discriminant analysis perform very well for credit scoring.

Bigler and Bugmann [2004] introduced a new approach to modelling tree mortality based on different growth patterns of entire tree-ring series. They were interested in predicting time of tree death. In their study, dendrochronological data from *Picea abies* (Norway spruce) in the Swiss Alps were used to calibrate mortality models using logistic regression. They introduced a mortality threshold and classified a tree as dead if its modelled mortality probability curve plotted over time went above that threshold. They ignored autocorrelation at the modelling stage, and applied a jackknife method to correct for the resulting biased variance estimates. They found that the most reliable models were those that included relative growth rate and a short-term growth trend as explanatory variables.

Focussing on the role played by life-history strategies in determining tree mortality Wunder et al. [2008] investigated whether the relationship between growth and mortality divers among tree species and site conditions. This carries on from Monserud [1976] who showed that reduced growth generally accompanies a higher mortality risk. For each of nine species, they modelled mortality probablity as a function of relative basal area increment, tree size and site. They selected the species-specific model with the highest goodness-of-fit and calculated the area under the receiver operating characteristic curve and calibration measures. The discriminatory power as measured by AUC ranged from 0.62 to 0.87. They found that most growth-mortality relationships differed among species and sites, i.e. there is no universal growth-mortality relationship.

It has been noted that a lack of long-term growth/mortality data has made it difficult to evaluate the performance of mortality models. Wunder et al. [2006b] adopt a “virtual ecology" approach to this problem, simulating forests with either of two a priori specified growth-mortality relationships. They simulate different sampling regimes in these virtual forests, thereby generating virtual tree-ring data, forest inventory data, or a combination of both. They compare eight existing or newly developed models of different structural flexibility by their ability to model the growth-mortality relationship in the simulated data, and quantify the deviation from the *a priori* specified growth-mortality relationships with the Kullback-Leibler distance. Of the models they evaluated, the highest accuracies were obtained with tree-ring based models, which required only small (approx. 60) numbers of dead trees. For larger sample sizes (approx 500 dead trees) forest inventory based models were also found to be accurate. They also showed that exible statistical approaches were superior to less flexible models only for large sample sizes (totally 2000 trees) and that the additional use of Bayesian statistics, model accuracies only when model flexibility was constrained. They also provided guidelines for sufficient sampling schemes in real forests.

In the PrognAus framework, Monserud and Sterba [1999] modelled mortality in Austrian forests for six major species based on 5-year re-measurements of the permanent plot network of the Austrian National Forest Inventory. Their general results, varying slightly between species, was that inverse of tree diameter, crown ratio and BAL were respectively the three most closely correlated factors in their model with 5-year mortality rates. They compared mortality rates across tree diameter class, thereby identifying a classic U-shape in mortality rates as diameter class increased. They modelled mortality rates rather than individual tree mortality probability, and validated the model with the chi-square statistic calculated between observed and estimated. Because the explanatory variables in their model were measured on the scale of the individual tree, they were able to calculate the classification success rate using the complement of the overall proportion of mortality (i.e., approximately 93%, although it is not clear from the text) as the threshold. On this basis, their model correctly classified between 81 and 92%, of live trees, and between 25 and 44%, of dead trees. However, their treatment of the threshold is very brief, and may not be a typical interpretation, e.g. in their interpretation, a tree is classified as dead if the threshold exceeds the modelled probability. Also, they derive a total correct classification accuracy of 86%.

Materials and Methods

Logistic regression models were fitted to the growth dataset. Model performance was investigated in the case of separate models for each cohort. (Principal issue here was the lack of data for some cohorts). The response variable was a binary indicator of mortality (arbitrarily, 1 = tree dead at time of DBH measurement, 0 = tree alive). Only trees whose cause of death was natural mortality were included, i.e. such causes as windblown, diseased, were excluded. Explanatory variables were those that were selected by Monserud and Sterba [1999] {DBH and transformations thereof, CR, BAL, CCF}, but relative growth indicators that Bigler and Bugmann [2004] were also investigated and are noted as being useful correlates. Site and plot effects were modelled as random, and consecutive observations on the same tree were modelled as being correlated. Conditional on this correlation structure the fixed effects parameters were selected by backward selection starting with the candidate set of covariates just listed.

Models were fitted by maximum likelihood and individual fixed effects were identified as non-significant on the basis of asymptotic Wald-tests. This was done for each cohort separately. Performance of candidate models was then evaluated by cross-validation and external validation (comparing fitted to observed mortality in the NFI dataset) and with threshold-based classification tools like the ROC and ROL curves and related measures and hypothesis tests. Cross-validation was done on a leave-k out basis, where the data ”left-out" was selected at random. Up to twenty independent cross-validation runs were performed, and up to 33% of the data was left-out as cross-validation data for each run.

Other performance measures were consulted, and the ROC convex hull played a role in our chosen classifier. We used threshold-averaging to investigate the performance of the classifier in cross-validation and bootstrap scenarios. We derived confidence bands for the ROC curve of the chosen classifier following the approach of Macskassy et al. [2005]. (Note, the authors have also developed techniques for point interval estimation also, the reference appearing in that paper.)

Performance measures in ROC space and their role in uncertainty analysis

The AUC of the ROC curve is the estimated probability that the classifier will give a higher score to positive cases than negative cases. (In our application, the estimated probability of mortality is higher for dead trees than live trees). It was envisaged that an uncertainty analysis of the forest growth model of which the mortality classifier is a component part could utilise this probability and its standard error in monte-carlo simulation assessments of overall uncertainty and sensitivity.

The AUC is equivalent to the Mann-Whitney U-statistic, and methods for comparing AUCs have been developed as a result, e.g. Heagerty et al. [2000]. The principal complicating factor here is the underlying correlation structure of the comparison, which can be influenced by details pertaining to the derivation of the classification forecasts, the setup of the calibration datasets, or whether the forecasts are clustered in some way, e.g. DeLong et al. [1988], Obuchowski [1997], Heagerty et al. [2000], Mason and Graham [2002].

The convex hull of a classifier, or group of classifiers, in ROC space, can be seen as the optimal attainable classification performance. Fawcett [2006] notes that candidate classifiers that do not attain the convex hull can be discarded, on the grounds that a better classifier in ROC space exists. He suggests a method for interpolating between candidate classifiers to better approach the limit of performance estimated by the convex hull based on mis-classification costs and the prior class distribution.

When comparing ROC curves, per se, a complicating factor when it is of interest to compare different classifiers crops up if the classifiers in question are of a different \class", e.g. a probabilistic classifier versus a discrete classifier, or, more generally, comparisons across model classes, whose scoring systems are incommensurate Fawcett [2006].

Datasets

Permanent Sample Plot

The mortality model is calibrated on data extracted from the PSP record system of Coillte Teoranta (the Irish Forestry Board state commercial forestry company). Broad and Lynch [2006b] provide details of the dataset in the context of modelling plot volume. The database consists of records of many silvicultural and thinning trials. These longitudinal trials were established from the 1950s onwards, and were initially established as replicated and blocked experimental designs Broad and Lynch [2006a].

Although there are several categories of disease or mortality causes in the PSP database {including, Windblown, Uprooted, Diseased, Broken and Dead}, we modelled only the binary response Dead/Alive for the initial model. In this way, after derived variables {basal area, plot density, etc. {were calculated, only data points that could be classified as Dead/Alive, were kept in the calibration dataset

National Forest Inventory Plot data

The ROC curve for the chosen model on the NFI data was validated. In the NFI sample, the probability that a tree's status as dead or alive will be recorded {more generally, the probability that any feature of the tree is measured {is a function of its diameter class at the time of survey, and its distance from the centre of the plot. The expansion factor concept is a weight that varies between each tree in the dataset that estimates the prior probability of the tree's inclusion in the dataset (see Chapter 6).

The question to address is whether one can arrive at a sensible definition of representative mortality. At issue is how to derive a binary individual-tree-level mortality rule based on information in the NFI dataset, given the fact that there is missing information due to the sampling scheme. With this in mind, Figure 3.4.A.5.2.1a classifies all dead trees in the PSP database by cohort, and describes the empirical distribution of diameter classes conditional on mortality status. (the diameter class (0,7] is included for completeness, even though there is no equivalent in the NFI dataset). Note that the left-hand column is very similar to the unconditional distribution of diameter classes, so it does not need to be displayed. On those grounds, a comparison of the columns of Figure 5.2c-A.2 shows the dramatic extent to which the chance of mortality declines if a tree does not die while in the lowest diameter class. For example, the global fraction of trees in the Spruce cohort in the lowest diameter class is very small, but this class represents 50% of dead trees in the cohort. Similarly for Pine, OC and FGB.

The right-hand column of Figure 3.4.A.5.2.1a, at least for the cohorts with enough observations, suggests a way to make the operation of a binary mortality rule more accurate in the context of the NFI sampling scheme. The basic idea is to use the column heights as weights in a finite mixture function whose components are the outcome of the mortality rule. Rather than reducing the expansion factor by one unit when death is predicted (which, can be shown, can lead to an unrealistically height global mortality rate), the actual reduction would be a function of the weight for the given diameter class. This method can be stochastic or deterministic. Other information might be used to inform the values of the weights, including a forester's rule of thumb about global mortality (i.e. 6%), or information from the NFI or a meta-analysis.

A similar approach is to mix the outcome of the mortality rule with the diameter class mortality weights. It may be possible to iteratively tune the weights and/or the rule's cut-off parameter.

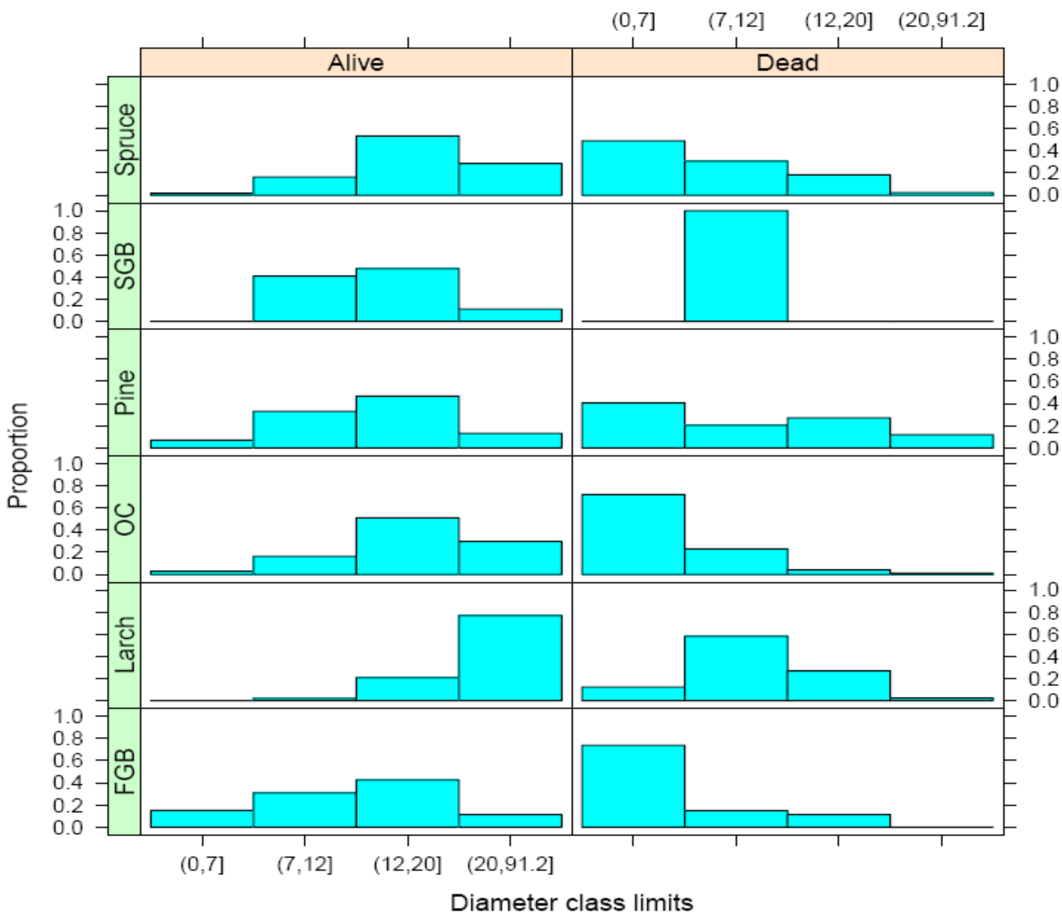


Figure 3.4.A.5.2.1a The empirical distribution in the PSP dataset of diameter classes of dead/alive trees classified by cohorts

Results

Candidate model Number 1. Candidate model 1 was a fixed effects model. A logistic GLM was fitted in Glimmix in SAS. The _fixed effects were DBH, BAL, and

RelDiamInc $\left(\dfrac{growth(t-t-1)}{DBH(t)}\right)$

Part of the reason for looking at this model was that it was not subject to additional uncertainty due to imputation of missing X data, as would have been the case with the model put forward by Monserud and Sterba [1999], which also conditioned mortality on CR, a variable that was not measured on every tree in our dataset.

There are several points of interest to the results of this model fitting:

1. The characteristics of the parameters.

2. The cross-validation exercise.

3. The out-of-sample/deployment performance. E.g. how well the model described NFI mortality.

Estimated parameters Candidate Model 1 (Used in CARBWARE models)

The fitted parameters and their standard errors are presented in Table 3.4.A.5.2.1a. Parameter estimates are shown for cohort-wise fits and the fit to the entire dataset, with no cohort-effect parameter.

Table 3.4.A.5.2.1a . Candidate model 1 parameters

Fast-growing broadleaves cohort

Parameter	Estimate	s.e.	df	Wald statistic	Wald p-value
Intercept	-2.9295	0.1510	11784	-19.41	0.0001
DBH	-0.4307	0.02508	11784	-17.17	0.0001
BAL	0.06816	0.004384	11784	15.55	0.0001
RelDiamInc	-1.6783	1.2147	11784	-1.38	0.1671

Larch cohort

Parameter	Estimate	s.e.	df	Wald statistic	Wald p-value
Intercept	3.0526	0.1691	6544	18.06	0.0001
DBH	-0.4373	0.01276	6544	-34.27	0.0001
BAL	0.05688	0.003066	6544	18.56	0.0001
RelDiamInc	-14.7793	2.5794	6544	-5.73	0.0001

Other conifers

Parameter	Estimate	s.e.	df	Wald statistic	Wald p-value
Intercept	4.3636	0.1090	21239	40.02	0.0001
DBH	-0.8384	0.01447	21239	-57.95	0.0001
BAL	0.05970	0.002078	21239	28.72	0.0001
RelDiamInc	-29.2957	1.0322	21239	-28.38	0.0001

Pine cohort

Parameter	Estimate	s.e.	df	Wald statistic	Wald p-value
Intercept	2.3952	0.04531	187E3	52.86	0.0001
DBH	-0.8127	0.007225	187E3	-112.49	0.0001
BAL	0.08083	0.000999	187E3	80.91	0.0001
RelDiamInc	-23.0015	0.3995	187E3	-57.57	0.0001

Slow growing broadleaves

Parameter	Estimate	s.e.	df	Wald statistic	Wald p-value
Intercept	29.6029	7.1305	1027	4.15	0.0001
DBH	-2.1970	0.4873	1027	-4.51	0.0001
BAL	-0.1225	0.01754	1027	-6.98	0.0001
RelDiamInc	-2199.90	521.36	1027	-4.22	0.0001

Spruce cohort

Parameter	Estimate	s.e.	df	Wald statistic	Wald p-value
Intercept	1.2286	0.02747	298E3	44.72	0.0001
DBH	-0.6640	0.003840	298E3	-172.93	0.0001
BAL	0.05051	0.000529	298E3	95.57	0.0001
RelDiamInc	-13.0524	0.2544	298E3	-51.30	0.0001

Candidate Model 2

The fixed effects in Candidate model 2 were those in Monserud and Sterba [1999], and diameter increment as a proportion of diameter (RelDiamInc).

Cross-validation and deployment performance

Plot-wise and case-wise leave k-out cross-validation of the chosen models was performed. The case-wise deletion algorithm was very slow for the Pine and Spruce cohorts, in which case we opted to use only plot-wise deletion. The algorithm selected plots for deletion from the fitting dataset using a Bernoulli mechanism with parameter p, which was sometimes changed depending on the number of plots in the cohort dataset. Details are provided with each graphical representation of the results in Figures below. Twenty “leave-outs" were performed and the variability in these twenty runs is represented by the dotted curves.

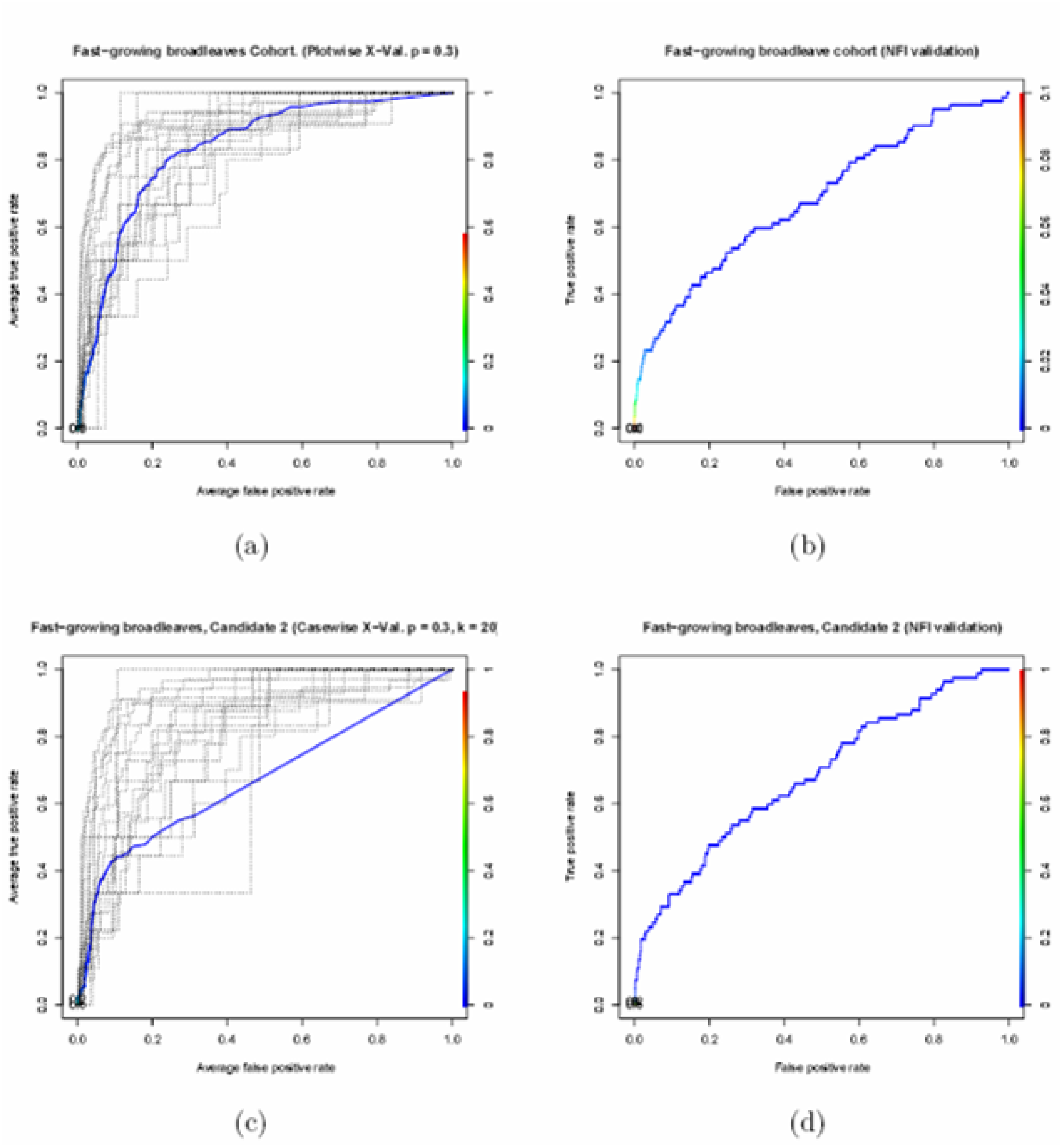


Figure 3.4.A.5.2.1b. The Receiver operating characteristic curve for Candidate model 1 (panels (a),(b)) and model 2 (panel (c),(d)) in the Fast-growing broadleaves cohort

20-fold cross-validation plotwise with average leave-out probability p = 0.3. Curves for each cross-validation run and a threshold-averaged curve are shown.

The ROC curve is estimated for each cohort model's out-of-sample performance by comparing model predictions with the actual NFI mortality data (Figure 3.4.A.5.2.1b). The cross-validation and deployment performance plots are presented pair-wise in the Figures below. In all cased model candidate outperformed candidate based on false positives and fit. For example we show the results for Fast growing cohorts in Figure 3.4.A.5.2.1c. Note that Slow-growing broadleaves cohort did not have enough data for the cross-validation to be feasible, the ROC curve for that cohort depicts in-sample performance.

Models fitted to NFI data

When fitting models to the NFI data backward elimination was used, starting with the parameters in the model developed by Monserud and Sterba (1999). Relative diameter was not used, because the dataset is cross-sectional. In Figure 3.4.A.5.2.1c we present an example of the out-of-sample performance (i.e. their performance in predicting NFI data) of the two PSP-calibrated models, and the in-sample performance of the NFI-calibrated model.

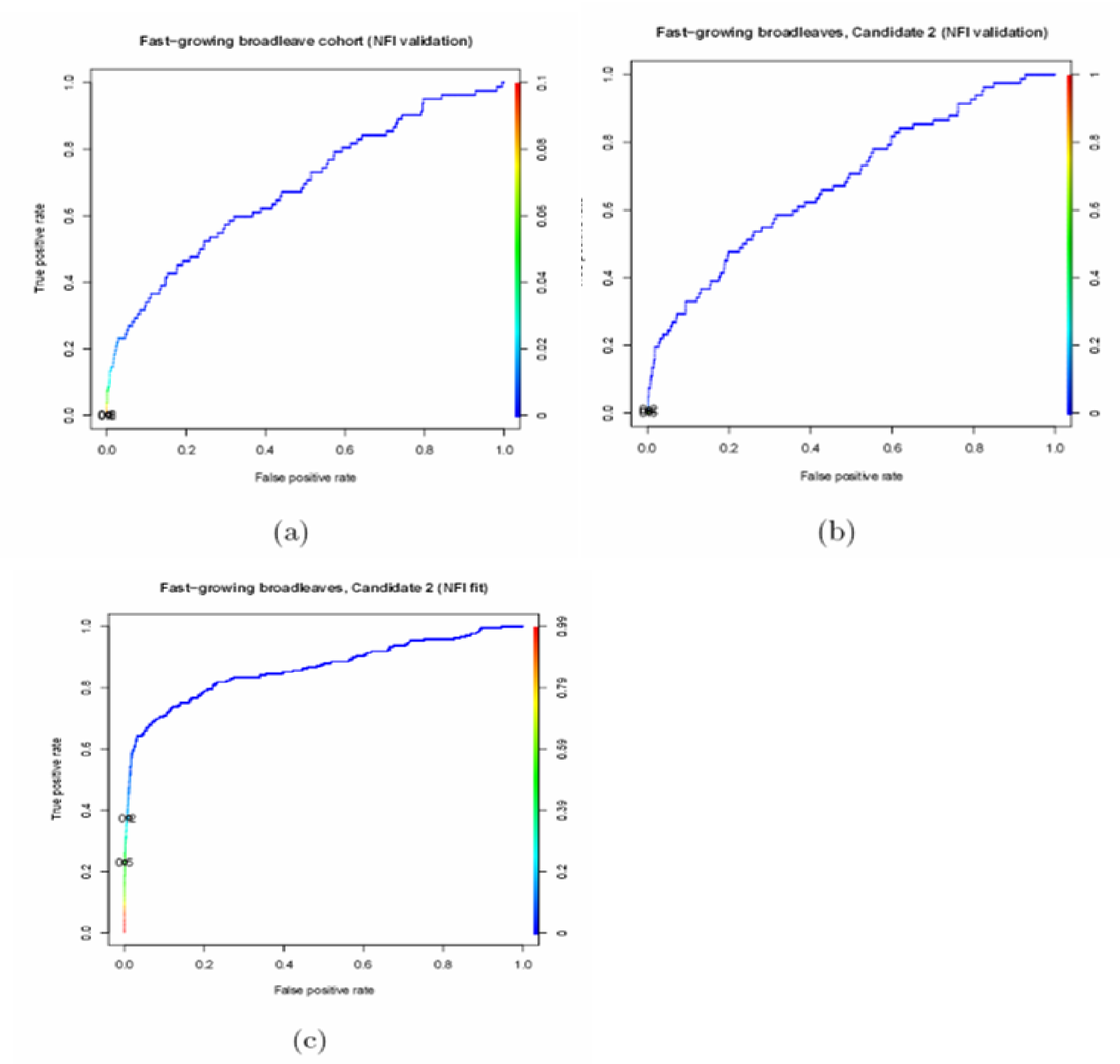


Figure 3.4.A.5.2.1c The Receiver operating characteristic curve for Fast-growing broadleaves cohort Candidate models 1 and 2 fitted on PSP, and for the NFI-fitted model.

The selected CARBWARE models based on NFI data fits

Fast-growing broadleaves cohort

$$Pmort = IL(12.93 + 0.068 \times BAL - 2.868 \times CR - 0.962 \times DBH - 72.28 \times \frac{1}{DBH} + 0.009 \times DBH^2$$

Larch cohort

$$Pmort = IL(-4.9266 + 0.04273 \times DBH)$$

Other conifers

$$Pmort = IL(-4.5226 + 0.067 \times BAL - 6.05 \times CR + 0.066 \times DBH)$$

Pine cohort

$$Pmort = IL(2.395 + 0.0408 \times BAL - 3.0036 \times CR - 0.2263 \times DBH - 24.21 \times \frac{1}{DBH})$$

Slow growing broadleaves

$$Pmort = IL(15.78 + 0.0109 \times BAL - 2.2807 \times CR - 0.771 \times DBH - 94.002 \times \frac{1}{DBH} + 0.00449 \times DBH^2$$

Spruce cohort

$$Pmort = IL(6.8976 + 0.0912 \times BAL - 21.3795 \times CR - 0.8287 \times DBH - 49.15 \times \frac{1}{DBH} + 0.008 \times DBH^2$$

Where (0 < Pmort < 1) is the probability the tree is dead. The estimated probability was mapped onto the binary (Dead, Alive) outcome using a cutoff, which may differ between cohorts. More details on this is give elsewhere. IL(.) is the inverse logit, e.g. IL(x) = exp(x)/(1+exp(x)).

Choosing the operational cut-off

To identify a cut-off level to use for the mortality probability estimate, the True positive rate (TPR) and (FPR) were plotted on the same axis versus the cut-off (e.g. Figure 3.4.A.5.2.1d). In forest mortality, the number of positive cases (dead trees) is usually greatly outnumbered by the number of negative cases. This suggests that, all mis-classification costs being equal, the cut-off should be chosen with a view to keeping as small as feasible the rate of false positives predicted by the resulting rule, even though the rate of true positives is reduced as an unavoidable consequence. When combining individual cohort results to make an aggregate prediction the issue of false positive rate is of particular importance for large cohorts, because they have a greater weight in the aggregate estimate. In Figure 3.4.A.5.2.1d an FPR of not greater than 0.001 is represented with a blue vertical line, and an FPR of not greater than 0.01 with a green vertical line, to illustrate the trade-off involved in each particular case.

Figure 3.4.A.5.2.1d illustrate some other considerations for choosing cut-off points, accuracy, rate of positive predictions and a correlation coefficient are plotted for a range of cut-offs.

The graphs illustrate why the accuracy measure should not be used in isolation when choosing a cut-off. For example, in Figure 3.4.A.5.2.1d, a high accuracy is obtained despite the correlation coefficient indicating that the correlation between correct predictions and the data is worse than random, i.e. a negative correlation coefficient.

Table 3.4.A.5.2.1b Formulae for some standard performance measures used in the text

Performance Measure	Formula
Accuracy	$\frac{TP+TN}{TP+FP+TN+FN}$
Rate of positive predictions	$\frac{TP+FP}{TP+FP+TN+FN}$
Correlation Coefficient	$\frac{(TP.TN)-(FP.FN)}{\sqrt{(TP+FN).(TN+FP).(TP+FP).(TN+FN)}}$

Note TP, TN, FP, and FN are the numbers of true positives, true negatives, false positives and false negatives, which are tallied by comparing the predictions with the data.

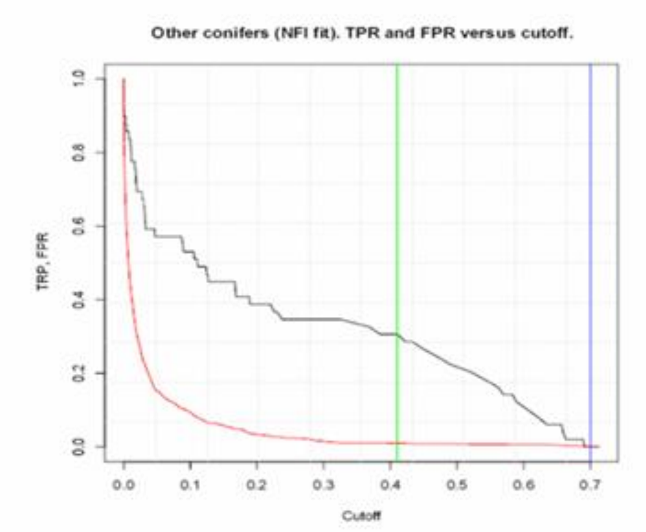


Figure 3.4.A.5.2.1d TPR (Black) and FPR (Red) versus cut-off for Fast-growing broadleaves

The vertical green line shows the cut-of where FPR < 0.01, the blue vertical line shows the cut-off where FPR< 0.001

Discussion

In binary classification, a common approach is to visualise the parameterised curve described by plotting two performance measures as a parametric curve parameterised by the threshold value. Comparing models based on classification and mis-classification rate (precision, recall, etc.) makes more sense when there is some hierarchy of misclassification errors. That is, that we can quantify the relative importance of gains from correct classification and losses from incorrect classification. Such a loss function is particularly useful when the number of objects to be classified is not equal, because then the trade-off curves are much more likely to be nonlinear and the concept of trade-off between competing performance measures is not easy to understand. The problem is how to specify losses/gains, in other words, how to quantify Trade-off, how to measure gains and losses in the same units so a net trade-off can be calculated. Otherwise, it is not always clear, even for commonly presented parameterised curves, in what sense the trade-off is occurring, particularly when a “good" classifier, e.g. one that exhibits desirable tendencies in threshold-space, can *a priori* exhibit a number of different “shapes" when presented as a “trade-off" curve.

For example, the class ROC trade-off curve has *a priori* a sense in which a classifier is good or bad. This is when the majority of the ROC curve lies below the line of equality. However, the precision-recall curve is not so easily understood. We know that the best classifier from a group is the one with the largest area between the curve and the line of equality. However, because the value of the precision at zero threshold is a function of the number of objects in each class to be classified, it is possible to have a “good" classifier for which that area is zero. However, such a classifier is probably not statistically better than the naive, 50:50 classifier. It is proposed that for a classifier to be demonstrably better than the naive classifier, it should at the minimum describe a positive region between the curve and the line of equality. It is concluded that the precision-recall curve does not describe a trade-off, and that in fact, a trade-off should have a point of equilibrium and the gains and losses should be incurred when the threshold moves from that point in either direction. In other words, the gains and losses as quantified by the two performance measures should be negatively correlated, for the parameterised graph to truly describe a trade-off. The precision-recall performance measures, for example, are positively correlated (both have TP in the numerator), and so their parameterised curve representation does not describe a true trade-off situation in every region of threshold space. If we overlay the two graphs with precision and recall on the y and y' axes, and threshold on the x axis, we can see more clearly where a true trade-off may occur. It is likely that should a true trade-off occur, that the region between the parameterised curve and the line of equality will have to be positive. As external corroboration, DeLong et al. [1988] note that the cost or loss function is essential to deciding the optimal cutpoint/threshold for a ROC curve. In summary, there are therefore two issues: comparing classifiers and, given a classifier, choosing a cut-off point.

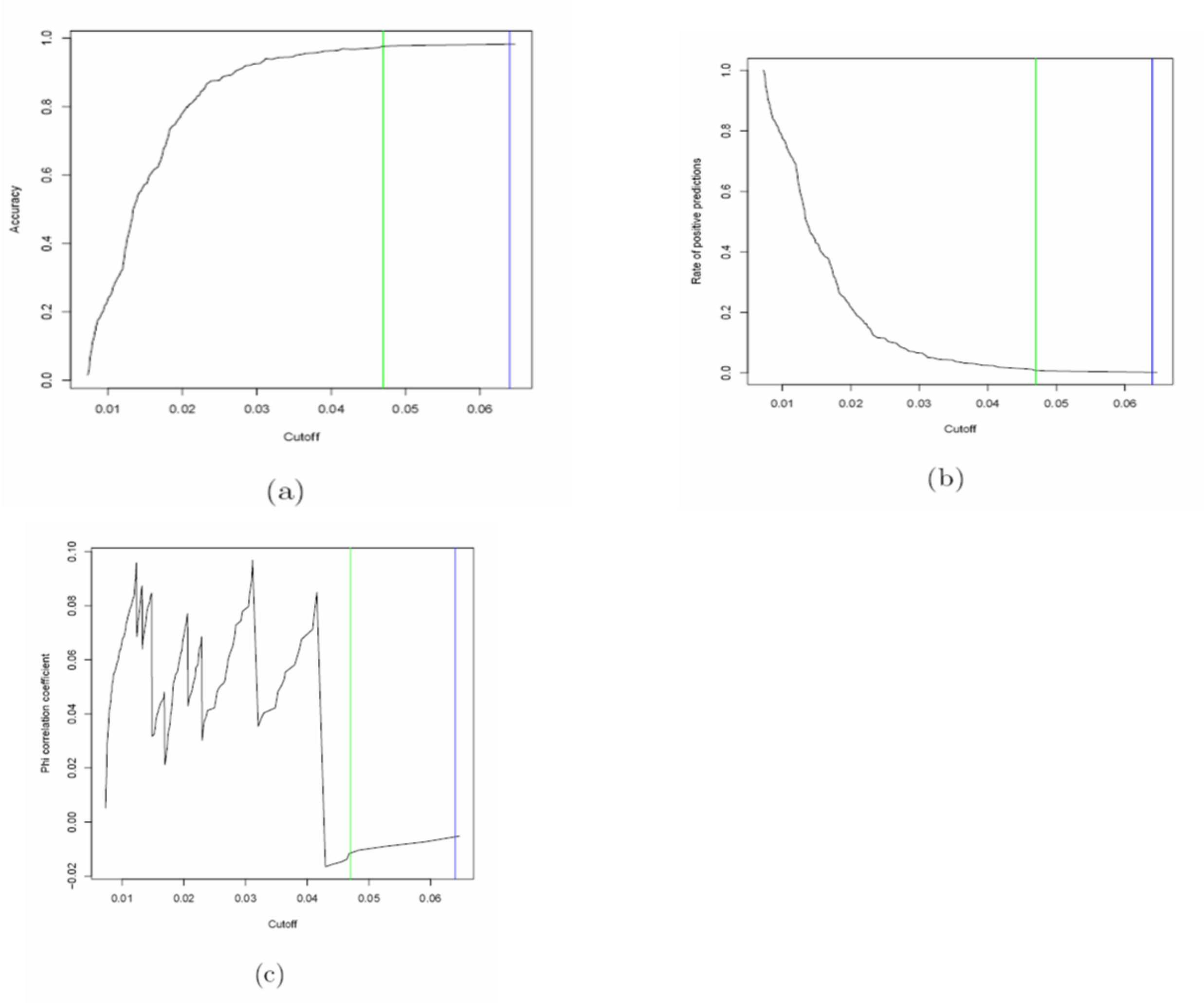


Figure 3.4.A.5.2.1e llustrating some other performance measures of the NFI-calibrated model for the Larch cohort across the cut-off range and in particular the 0.01 (green vertical) and 0.001(blue vertical) cut-off points

This latter can only be done in conjunction with some kind of loss function describing costs of the different types of classification error. The kind of classifier used, based on multiple correlation/regression, and therefore wholly empirical, is easier to select than other types of classifier. Model selection criteria can be used based on correlation/regression, or minimization of errors, or some other abstract modelling concepts. Then, with the classifier selected, a cut-off can be chosen. In what we call mechanistic classifiers, such as described in Martin-Davila et al. [2005], where the classifier is predicated first and foremost on an understood pathway, not naive correlation, the threshold has a physical dimension, and the choice of cut-off has a defined purpose in a physical system. Note that a logistic regression with a single explanatory variable can be made to fit such a schema. In fact, it may be possible to define a convex hull of the multiple explanatory variables to take the place of single-variable classifier in that schema. Also, some variables might be better at defining the threshold than others and this can also be examined. A convex hull defined by cut-off points in each explanatory variable might be envisaged to play the role of a kind of “syncretized" cut-off point. In such an instance, it would be relevant to assess the cross-correlations among the explanatory variables.

Conclusions

The aim of this paper was to determine a logistic regression model of mortality that could be used to describe mortality in the NFI data. This was the ultimate goal of the model. The possibility of calibrating this model was investigated on the permanent sample plot longitudinal data but it was found that the result could not be improved by simply calibrating the parameters on the NFI data alone. In the absence of a mis-classification cost function cut-off was chosen for transforming predictions on the logit scale to the binary (dead, alive) scale based on the false positive rate (the rate at which the model predicted mortality incorrectly). Specifically, a cut-off was chosen to keep this as small as reasonably possible.

3.4.A.5.2.2: Other modifications in the growth simulator

Thinning/Harvest

It is assumed that all thinning occur randomly. Random thinning can be implemented on an individual plot level. The CARBWARE model user sets a basal area (BA) to be removed as stipulated in the harvest activity data (in the ‘**Eventstable**’) so thinning of trees are selected at random from the plot until this target BA is achieved. The thinned or harvested trees in a given plot are removed from the growth database and populated in a modifier table within the CarwKP_xx database. These data are then called up in the allocation module (see Fig 6.3.8 Chapter 6).

Although it is common practice that clear felled stands are replanted within 2 years, the CARBWARE model does not re-populate clear felled plots due to uncertainty of re-establishment success and species choice. This is a conservative approach and is consistent with the rules applied, which differentiate between deforestation and clear fell with re-establishment.

3.4.B Detailed Non-Forest Land Use Change Matrices

This annex provides detailed tables for annual estimates of area for the non-Forest Land, land use categories. Shown are estimates of gains and losses related to each land use type on an annual basis, the subsequent annual net change in area and the resultant cumulative total area under each category.

Also shown in the tables are the summary values for Remaining Land and In Transition which appear in the Common Reporting Format submission.

Table 3.4.B-1 Cropland Matrix ('000 ha)

	Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Initial Area	Cropland Remaining Cropland	700.66	699.05	697.11	695.41	693.78	691.80	689.39	687.25	686.05	684.70	683.37	681.75	680.23
	Cropland in Transition Cummulative	0	0	0	0	0	0	0	0	0	0	0	0	0
	Forest to Cropland	0	0	0	0	0	0	0	0	0	0	0	0	0
	Grassland to Cropland	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wetland to Cropland	0	0	0	0	0	0	0	0	0	0	0	0	0
	Settlement to Cropland	0	0	0	0	0	0	0	0	0	0	0	0	0
	Other land to Cropland	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total Gain in Cropland	0	0	0	0	0	0	0	0	0	0	0	0	0
	Cropland to Forest	1.58	1.91	1.67	1.60	1.95	2.37	2.10	1.14	1.29	1.27	1.57	1.46	1.33
	Cropland to Grassland	0	0	0	0	0	0	0	0	0	0	0	0	0
	Cropland to Wetland	0	0	0	0	0	0	0	0	0	0	0	0	0
	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
	Cropland to Other land	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total Loss from Cropland	1.61	1.94	1.70	1.62	1.98	2.41	2.14	1.19	1.35	1.33	1.62	1.52	1.39
	Net Change Forest/Cropland	-1.58	-1.91	-1.67	-1.60	-1.95	-2.37	-2.10	-1.14	-1.29	-1.27	-1.57	-1.46	-1.33
	Net Change Grassland/Cropland	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
	Net Change Wetland/Cropland	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
	Net Change Settlement/Cropland	-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
	Net Change Otherland/Cropland	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
	Total Annual net Change	-1.61	-1.94	-1.70	-1.62	-1.98	-2.41	-2.14	-1.19	-1.35	-1.33	-1.62	-1.52	-1.39
Final Area	Total Cropland	699.05	697.11	695.41	693.78	691.80	689.39	687.25	686.05	684.70	683.37	681.75	680.23	678.84

Table 3.4.B-1 Cropland Matrix ('000 ha) (continued)

	Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Initial area	Cropland Remaining Cropland	678.84	678.01	677.17	676.36	676.02	675.76	675.57	675.30	674.97	674.75	674.55	674.35	674.15	673.95
	Cropland in Transition Cummulative	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Forest to Cropland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Grassland to Cropland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wetland to Cropland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Settlement to Cropland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Other land to Cropland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total Gain in Cropland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Cropland to Forest	0.75	0.75	0.72	0.24	0.22	0.19	0.20	0.25	0.20	0.18	0.18	0.18	0.18	0.19
	Cropland to Grassland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Cropland to Wetland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Cropland to Settlement	0.08	0.09	0.10	0.10	0.04	0.00	0.08	0.08	0.02	0.02	0.02	0.02	0.02	0.03
	Cropland to Other land	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total Loss from Cropland	0.83	0.84	0.81	0.34	0.25	0.19	0.28	0.33	0.22	0.19	0.20	0.20	0.20	0.22
	Net Change Forest/Cropland	-0.75	-0.75	-0.72	-0.24	-0.22	-0.19	-0.20	-0.25	-0.20	-0.18	-0.18	-0.18	-0.18	-0.19
	Net Change Grassland/Cropland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Net Change Wetland/Cropland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Net Change Settlement/Cropland	-0.08	-0.09	-0.10	-0.10	-0.04	0.00	-0.08	-0.08	-0.02	-0.02	-0.02	-0.02	-0.02	-0.03
	Net Change Otherland/Cropland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total Annual net Change	-0.83	-0.84	-0.81	-0.34	-0.25	-0.19	-0.28	-0.33	-0.22	-0.19	-0.20	-0.20	-0.20	-0.22
Final area	Total Cropland	678.01	677.17	676.36	676.02	675.76	675.57	675.30	674.97	674.75	674.55	674.35	674.15	673.95	673.73

Table 3.4.B-2 Grassland Matrix ('000 ha)

	Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Initial area	Grassland Remaining Grassland	4452.55	4447.50	4441.49	4436.17	4431.10	4424.87	4417.57	4411.04	4407.31	4403.07	4398.84	4393.99	4388.81
	Grassland in Transition	0.01	0.02	0.02	0.03	0.04	0.31	0.57	0.84	1.11	1.37	1.77	2.17	2.58
	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
	Cropland to Grassland	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wetland to Grassland	0	0	0	0	0	0	0	0	0	0	0	0	0
	Settlement to Grassland	0	0	0	0	0	0	0	0	0	0	0	0	0
	Other land to Grassland	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total Gain in 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
	Grassland to Forest	4.75	5.74	5.01	4.80	5.84	7.11	6.29	3.43	3.88	3.80	4.71	4.83	4.89
	Grassland to Cropland	0	0	0	0	0	0	0	0	0	0	0	0	0
	Grassland to Wetland	0	0	0	0	0	0	0	0	0	0	0	0	0
	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
	Grassland to Other land	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total Loss from Grassland	5.06	6.02	5.33	5.07	6.24	7.56	6.80	4.00	4.51	4.49	5.25	5.59	5.59
	Net Change Forest/Grassland	-4.74	-5.74	-5.00	-4.79	-5.83	-6.85	-6.03	-3.16	-3.61	-3.53	-4.31	-4.43	-4.49
	Net Change Grassland/Cropland	0	0	0	0	0	0	0	0	0	0	0	0	0
	Net Change Wetland/Grassland	0	0	0	0	0	0	0	0	0	0	0	0	0
	Net Change Settlement/Grassland	-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
	Net Change Other land/Grassland	0	0	0	0	0	0	0	0	0	0	0	0	0
Matrix Increment	Total Annual net Change	-5.05	-6.01	-5.33	-5.07	-6.24	-7.29	-6.54	-3.73	-4.24	-4.22	-4.85	-5.19	-5.19
Final area	Total Grassland Input	4447.50	4441.49	4436.17	4431.10	4424.87	4417.57	4411.04	4407.31	4403.07	4398.84	4393.99	4388.81	4383.62

Table 3.4.B-2 Grassland Matrix ('000 ha) (continued)

	Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Initial area	Grassland Remaining Grassland	4383.62	4380.04	4376.02	4371.68	4366.96	4363.31	4360.84	4357.41	4353.58	4351.56	4348.72	4345.81	4342.89	4340.59
	Grassland in Transition	2.98	3.38	3.78	3.78	3.78	4.18	4.58	5.38	6.58	6.58	6.64	6.68	6.78	6.93
	Forest to Grassland	0.40	0.40	0.40	0.00	0.00	0.40	0.40	0.80	1.20	0.00	0.06	0.04	0.10	0.15
	Cropland to Grassland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wetland to Grassland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Settlement to Grassland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Other land to Grassland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total Gain in Grassland	0.40	0.40	0.40	0.00	0.00	0.40	0.40	0.80	1.20	0.00	0.06	0.04	0.10	0.15
	Grassland to Forest	3.07	3.41	3.66	3.62	3.23	2.81	2.99	3.74	2.99	2.63	2.77	2.74	2.20	2.70
	Grassland to Cropland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Grassland to Wetland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Grassland to Settlement	0.91	1.01	1.08	1.10	0.43	0.05	0.84	0.89	0.23	0.21	0.20	0.22	0.20	0.29
	Grassland to Other land	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total Loss from Grassland	3.98	4.41	4.74	4.72	3.66	2.86	3.83	4.63	3.22	2.84	2.97	2.96	2.40	2.99
	Net Change Forest/Grassland	-2.67	-3.01	-3.26	-3.62	-3.23	-2.41	-2.59	-2.94	-1.79	-2.63	-2.71	-2.70	-2.11	-2.55
	Net Change Grassland/Cropland	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
	Net Change Wetland/Grassland	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
	Net Change Settlement/Grassland	-0.91	-1.01	-1.08	-1.10	-0.43	-0.05	-0.84	-0.89	-0.23	-0.21	-0.20	-0.22	-0.20	-0.29
	Net Change Other land/Grassland	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
Matrix Increment	Total Annual net Change	-3.58	-4.01	-4.34	-4.72	-3.66	-2.46	-3.43	-3.83	-2.02	-2.84	-2.91	-2.92	-2.31	-2.84
Final area	Total Grassland Input	4380.04	4376.02	4371.68	4366.96	4363.31	4360.84	4357.41	4353.58	4351.56	4348.72	4345.81	4342.89	4340.59	4337.75

Table 3.4.B-3Wetland Matrix ('000 ha)

	Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Initial area	Wetland Remaining Wetland	1,308.43	1,298.77	1,287.85	1,278.33	1,269.22	1,258.12	1,244.61	1,232.65	1,226.13	1,218.76	1,211.54	1,202.77	1,194.28
	Wetland in Transition	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.34	0.51
	Forest to Wetland	0	0	0	0	0	0	0	0	0	0	0.17	0.17	0.17
	Cropland to Wetland	0	0	0	0	0	0	0	0	0	0	0	0	0
	Grassland to Wetland	0	0	0	0	0	0	0	0	0	0	0	0	0
	Settlement to Wetland	0	0	0	0	0	0	0	0	0	0	0	0	0
	Other land to Wetland	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total Gain in Wetland	0	0	0	0	0	0	0	0	0	0	0.17	0.17	0.17
	Wetland to Forest	9.02	10.91	9.52	9.12	11.09	13.51	11.96	6.52	7.37	7.22	8.95	8.66	8.28
	Wetland to Cropland	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wetland to Grassland	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wetland to Settlement	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wetland to Other land	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total Loss from Wetland	9.02	10.91	9.52	9.12	11.09	13.51	11.96	6.52	7.37	7.22	8.95	8.66	8.28
	Net Change Forest/Wetland	-9.02	-10.91	-9.52	-9.12	-11.09	-13.51	-11.96	-6.52	-7.37	-7.22	-8.78	-8.49	-8.11
	Net Change Wetland/Cropland	0	0	0	0	0	0	0	0	0	0	0	0	0
	Net Change Wetland/Grassland	0	0	0	0	0	0	0	0	0	0	0	0	0
	Net Change Settlement/Wetland	0	0	0	0	0	0	0	0	0	0	0	0	0
	Net Change Otherland/Wetland	0	0	0	0	0	0	0	0	0	0	0	0	0
Matrix Increment	Total Annual net Change	-9.02	-10.91	-9.52	-9.12	-11.09	-13.51	-11.96	-6.52	-7.37	-7.22	-8.78	-8.49	-8.11
Final area	Matrix Total Wetland Annual	1,299.41	1,287.85	1,278.33	1,269.22	1,258.12	1,244.61	1,232.65	1,226.13	1,218.76	1,211.54	1,202.77	1,194.28	1,186.17

Table 3.4.B-3 Wetland Matrix ('000 ha) (continued)

	Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Initial area	Wetland Remaining Wetland	1,186.17	1,181.43	1,176.44	1,171.36	1,167.74	1,164.91	1,162.10	1,159.51	1,155.77	1,153.17	1,150.54	1,147.77	1,144.54	1,141.97
	Wetland in Transition	0.68	0.85	1.02	1.02	1.42	1.42	1.82	1.82	2.22	2.22	2.22	2.22	2.22	2.23
	Forest to Wetland	0.17	0.17	0.17	0.00	0.40	0.00	0.40	0.00	0.40	0.00	0.00	0.00	0.00	0.01
	Cropland to Wetland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Grassland to Wetland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Settlement to Wetland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Other land to Wetland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total Gain in Wetland	0.17	0.17	0.17	0.00	0.40	0.00	0.40	0.00	0.40	0.00	0.00	0.00	0.00	0.01
	Wetland to Forest	4.91	5.16	5.25	3.62	3.23	2.81	2.99	3.74	2.99	2.63	2.77	3.23	2.56	2.43
	Wetland to Cropland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wetland to Grassland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wetland to Settlement	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wetland to Other land	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total Loss from Wetland	4.91	5.16	5.25	3.62	3.23	2.81	2.99	3.74	2.99	2.63	2.77	3.23	2.56	2.43
	Net Change Forest/Wetland	-4.74	-4.99	-5.08	-3.62	-2.83	-2.81	-2.59	-3.74	-2.59	-2.63	-2.77	-3.23	-2.56	-2.43
	Net Change Wetland/Cropland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Net Change Wetland/Grassland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Net Change Settlement/Wetland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Net Change Otherland/Wetland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Matrix Increment	Total Annual net Change	-4.74	-4.99	-5.08	-3.62	-2.83	-2.81	-2.59	-3.74	-2.59	-2.63	-2.77	-3.23	-2.56	-2.43
Final area	Matrix Total Wetland Annual	1,181.43	1,176.44	1,171.36	1,167.74	1,164.91	1,162.10	1,159.51	1,155.77	1,153.17	1,150.54	1,147.77	1,144.54	1,141.97	1,139.55

Table 3.4.B-4 Settlement Matrix ('000 ha)

	Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Initial area	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
	Settlement in Transition	0.37	0.69	1.07	1.40	1.88	2.39	2.98	3.63	4.35	5.14	5.93	6.97	7.94
	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
	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
	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
	Wetland to Settlement													
	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
	Total Gain in Settlement	0.37	0.32	0.38	0.33	0.48	0.51	0.59	0.65	0.72	0.79	0.79	1.04	0.97
	Settlement to Forest	0	0	0	0	0	0	0	0	0	0	0	0	0
	Settlement to Cropland	0	0	0	0	0	0	0	0	0	0	0	0	0
	Settlement to Grassland	0	0	0	0	0	0	0	0	0	0	0	0	0
	Settlement to Wetland	0	0	0	0	0	0	0	0	0	0	0	0	0
	Settlement to Other land	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total Loss from Settlement	0	0	0	0	0	0	0	0	0	0	0	0	0
	Net Change Forest/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
	Net Change Settlement/Cropland	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
	Net Change Settlement/Grassland	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
	Net Change Settlement/Wetland	0	0	0	0	0	0	0	0	0	0	0	0	0
	Net Change Other land/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
Matrix Increment	Total Annual net Change	0.37	0.32	0.38	0.33	0.48	0.51	0.59	0.65	0.72	0.79	0.79	1.04	0.97
Final area	Total Settlement Input	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

Table 3.4.B-4 Settlement Matrix ('000 ha) (continued)

	Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
CRF	Settlement Remaining Settlement	111.31	112.53	113.86	115.27	116.94	118.63	119.89	120.85	121.88	122.14	123.18	123.47	123.75	124.09
CRF	Settlement in Transition	9.16	10.49	11.90	13.57	15.26	16.52	17.48	18.51	18.77	19.81	20.11	20.38	20.72	21.07
	Forest to Settlement	0.17	0.17	0.17	0.40	1.20	1.20	0.00	0.00	0.00	0.80	0.06	0.02	0.11	0.02
	Cropland to Settlement	0.08	0.09	0.10	0.10	0.04	0.00	0.08	0.08	0.02	0.02	0.02	0.02	0.02	0.03
	Grassland to Settlement	0.91	1.01	1.08	1.10	0.43	0.05	0.84	0.89	0.23	0.21	0.20	0.22	0.20	0.29
	Wetland to Settlement														
	Other land to Settlement	0.05	0.06	0.06	0.07	0.03	0.00	0.05	0.05	0.01	0.01	0.01	0.01	0.01	0.02
	Total Gain in Settlement	1.22	1.33	1.41	1.67	1.69	1.26	0.97	1.02	0.26	1.04	0.30	0.27	0.34	0.35
	Settlement to Forest	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Settlement to Cropland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Settlement to Grassland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Settlement to Wetland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Settlement to Other land	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total Loss from Settlement	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Net Change Forest/Settlement	0.17	0.17	0.17	0.40	1.20	1.20	0.00	0.00	0.00	0.80	0.06	0.02	0.11	0.02
	Net Change Settlement/Cropland	0.08	0.09	0.10	0.10	0.04	0.00	0.08	0.08	0.02	0.02	0.02	0.02	0.02	0.03
	Net Change Settlement/Grassland	0.91	1.01	1.08	1.10	0.43	0.05	0.84	0.89	0.23	0.21	0.20	0.22	0.20	0.29
	Net Change Settlement/Wetland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Net Change Otherland/Settlement	0.05	0.06	0.06	0.07	0.03	0.00	0.05	0.05	0.01	0.01	0.01	0.01	0.01	0.02
Matrix Increment	Total Annual net Change	1.22	1.33	1.41	1.67	1.69	1.26	0.97	1.02	0.26	1.04	0.30	0.27	0.34	0.35
Annual Matrix	Total Settlement Input	112.53	113.86	115.27	116.94	118.63	119.89	120.85	121.88	122.14	123.18	123.47	123.75	124.09	124.44

Table 3.4.B-5 Other Land Matrix ('000 ha)

	Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Initial area	Other Land Remaining Other Land	81.51	81.66	81.07	80.55	80.06	79.45	78.78	78.19	77.88	77.52	77.17	76.78	76.33
	Other Land in Transition	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
	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
	Cropland to Other Land	0	0	0	0	0	0	0	0	0	0	0	0	0
	Grassland to Other Land	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wetland to Other Land	0	0	0	0	0	0	0	0	0	0	0	0	0
	Settlement to Other Land	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total Gain in Other Land	0.00	0	0	0	0	0	0	0	0	0	0	0	0
	Other Land to Forest	0.47	0.57	0.50	0.48	0.58	0.71	0.63	0.34	0.39	0.38	0.47	0.52	0.55
	Other Land to Cropland	0	0	0	0	0	0	0	0	0	0	0	0	0
	Other Land to Grassland	0	0	0	0	0	0	0	0	0	0	0	0	0
	Other Land to Wetland	0	0	0	0	0	0	0	0	0	0	0	0	0
	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
	Total Loss from Other Land	0.49	0.49	1.49	2.49	3.49	4.49	5.49	6.49	7.49	8.49	9.49	10.49	11.49
	Net Change Forest/Other Land	-0.47	-0.57	-0.50	-0.48	-0.58	-0.64	-0.56	-0.28	-0.32	-0.31	-0.36	-0.40	-0.44
	Net Change Other Land/Cropland	0	0	0	0	0	0	0	0	0	0	0	0	0
	Net Change Other Land/Grassland	0	0	0	0	0	0	0	0	0	0	0	0	0
	Net Change Other land/Wetland	0	0	0	0	0	0	0	0	0	0	0	0	0
	Net Change Other land/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
Matrix Increment	Total Annual net Change	-0.49	-0.59	-0.52	-0.49	-0.61	-0.67	-0.59	-0.31	-0.36	-0.35	-0.39	-0.45	-0.48
Final area	Total Other Land	81.02	81.07	80.55	80.06	79.45	78.78	78.19	77.88	77.52	77.17	76.78	76.33	75.86

Table 3.4.B-5 Other Land Matrix ('000 ha) (continued)

	Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Initial area	Other Land Remaining Other Land	75.86	75.55	75.19	74.77	75.74	75.21	75.17	74.65	74.02	73.54	72.32	71.78	71.90	71.61
	Other Land in Transition	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
	Forest to Other Land	0.11	0.11	0.11	1.60	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.13	0.38	0.03
	Cropland to Other Land	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Grassland to Other Land	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wetland to Other Land	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Settlement to Other Land	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total Gain in Other Land	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Other Land to Forest	0.36	0.42	0.47	0.56	0.50	0.44	0.47	0.58	0.47	0.41	0.43	0.00	1.03	1.02
	Other Land to Cropland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Other Land to Grassland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Other Land to Wetland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Other Land to Settlement	0.05	0.06	0.06	0.07	0.03	0.00	0.05	0.05	0.01	0.01	0.01	0.01	0.01	0.02
	Total Loss from Other Land	12.49	13.49	14.49	15.49	16.49	17.49	18.49	19.49	20.49	21.49	22.49	23.49	24.49	25.49
	Net Change Forest/Other Land	-0.25	-0.31	-0.36	1.04	-0.50	-0.04	-0.47	-0.58	-0.47	-0.41	-0.43	0.13	-0.65	-0.99
	Net Change Other Land/Cropland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Net Change Other Land/Grassland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Net Change Other land/Wetland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Net Change Other land/Settlement	-0.05	-0.06	-0.06	-0.07	-0.03	0.00	-0.05	-0.05	-0.01	-0.01	-0.01	-0.01	-0.01	-0.02
Matrix Increment	Total Annual net Change	-0.30	-0.37	-0.42	0.97	-0.53	-0.04	-0.52	-0.63	-0.48	-0.42	-0.44	0.12	-0.66	-1.01
Final area	Total Other Land	75.55	75.19	74.77	75.74	75.21	75.17	74.65	74.02	73.54	73.12	71.88	71.90	71.24	70.61

Annex 3.5

Waste (IPCC Sector 5)

3.5.A Time Series of Solid Waste Disposal and Composition 1990-2016

3.5.B Methane Correction Factor (MCF) 1990-2016

3.5.C Parameters, EFs for Clinical Waste Incineration 1990-2016

3.5.D Parameters, EFs for Solvent (Liquid/Vapour destruction) Waste Incineration 1990-2016

Table 3.5.A Time Series of Solid Waste Disposal and Composition 1990-2016

Year	*Pop*	*MSW Prod Rate kg/cap/day*	*MSW Managed tonnes*	*MSW to SWDS %*	*MSW to SWDS tonnes*	*Sewage Sludge tonnes*	*MSW Food %*	*MSW Garden %*	*MSW Paper %*	*MSW Wood %*	*MSW Textiles %*	*MSW Nappies %*	*MSW Other %*	*MSW Organic tonnes*	*MSW Garden tonnes*	*MSW Paper tonnes*	*MSW Wood tonnes*	*MSW Textiles tonnes*	*MSW Nappies[a] tonnes*	*MSW Other tonnes*
1990	3,505,800	1.79	2,088,927	0.92	1,925,317	11,987	39.3%	0.0%	29.5%	5.2%	9.8%	0.0%	16.3%	756,805		567,893	99,436	187,836		313,348
1991	3,525,700	1.75	2,070,927	0.92	1,908,727	11,987	37.7%	0.0%	29.6%	5.2%	8.0%	0.0%	19.5%	720,201		565,619	98,579	152,700		371,628
1992	3,554,500	1.75	2,050,701	0.92	1,890,085	11,987	36.2%	0.0%	29.8%	5.2%	6.2%	0.0%	22.7%	683,379		562,688	97,616	118,019		428,384
1993	3,574,100	1.74	2,077,579	0.92	1,914,858	11,987	34.6%	0.0%	29.9%	5.2%	4.5%	0.0%	25.9%	662,157		572,689	98,895	85,941		495,175
1994	3,585,900	1.74	2,190,130	0.92	2,018,594	11,987	33.0%	0.0%	30.0%	5.2%	2.7%	0.0%	29.1%	666,215		606,484	104,253	55,151		586,491
1995	3,601,300	1.72	2,117,873	0.92	1,951,997	11,987	31.4%	0.0%	30.2%	4.5%	1.0%	1.0%	31.9%	613,637		589,328	88,157	19,063	19,063	622,750
1996	3,626,100	1.79	2,533,294	0.92	2,325,036	14,828	28.8%	0.0%	27.9%	3.9%	0.9%	0.9%	37.6%	669,951		648,655	90,924	21,594	20,209	873,702
1997	3,664,300	1.86	2,614,595	0.91	2,389,493	14,828	27.3%	0.0%	28.4%	3.4%	1.0%	0.9%	39.1%	653,010		678,856	80,368	23,365	20,522	933,372
1998	3,703,100	1.93	2,412,700	0.91	2,195,604	16,753	25.7%	0.0%	28.5%	2.9%	1.0%	0.8%	41.1%	564,568		625,733	63,028	22,164	18,318	901,793
1999	3,741,600	1.93	2,128,686	0.90	1,906,630	16,753	25.8%	0.0%	27.8%	2.4%	1.1%	0.9%	42.1%	491,491		529,532	45,562	21,303	16,564	802,178
2000	3,789,500	1.93	2,485,546	0.88	2,190,632	18,052	26.2%	0.0%	28.2%	1.7%	1.3%	0.9%	41.6%	574,850		618,655	37,818	28,065	20,740	910,503
2001	3,847,200	1.93	2,649,231	0.87	2,296,916	18,052	26.6%	0.0%	28.3%	1.1%	1.4%	1.0%	41.6%	610,331		649,966	25,648	32,799	23,215	954,957
2002	3,917,200	1.90	2,767,020	0.79	2,193,832	14,909	27.3%	0.0%	27.2%	0.9%	1.5%	1.1%	42.1%	599,860		596,423	18,701	31,836	24,188	922,824
2003	3,979,900	2.01	2,817,984	0.72	2,017,791	14,909	28.0%	0.0%	28.6%	0.8%	1.5%	1.1%	40.0%	564,426		576,416	15,439	30,580	23,008	807,922
2004	4,045,200	2.03	2,862,830	0.66	1,901,772	10,651	32.0%	4.1%	23.7%	0.9%	4.2%	3.5%	31.5%	608,809	77,988	450,322	17,664	80,332	66,674	599,983
2005	4,133,800	2.02	2,911,896	0.65	1,904,830	8,536	31.9%	4.0%	23.7%	0.9%	4.2%	3.4%	31.9%	607,042	76,545	450,915	17,219	80,717	65,348	607,043
2006	4,232,900	2.19	3,249,854	0.64	2,076,154	4,554	31.6%	4.3%	23.1%	0.9%	4.4%	3.7%	32.1%	656,464	88,537	479,024	19,001	90,765	75,904	666,460
2007	4,375,800	2.13	3,427,196	0.63	2,175,134	4,554	37.2%	3.5%	18.6%	1.5%	6.6%	4.3%	28.2%	809,914	77,093	403,998	32,505	143,743	94,446	613,435
2008	4,485,100	1.96	3,222,023	0.62	2,012,544	61	31.3%	3.7%	21.0%	1.5%	6.2%	4.8%	31.6%	629,023	74,772	421,863	29,942	124,669	96,643	635,632
2009	4,533,400	1.78	2,939,700	0.61	1,793,705	63	30.9%	3.8%	20.7%	1.5%	6.2%	4.9%	31.9%	554,441	68,657	371,664	26,630	111,654	88,772	571,887
2010	4,554,800	1.71	2,580,436	0.58	1,495,565	188	31.8%	3.7%	21.7%	0.9%	6.2%	4.7%	31.0%	475,492	54,714	323,869	13,951	92,553	70,724	464,263
2011	4,574,900	1.69	2,553,782	0.53	1,347,811	304	19.4%	3.5%	21.8%	2.1%	19.7%	6.6%	26.9%	261,805	47,280	293,291	28,309	266,114	88,782	362,230
2012	4,585,400	1.60	2,875,976	0.38	1,097,584	4	18.4%	3.8%	20.3%	2.2%	20.4%	6.0%	28.8%	201,933	42,191	222,986	24,093	224,356	65,600	316,424
2013	4,593,100	1.61	2,015,862	0.38	769,331	2,866	16.1%	4.0%	18.7%	3.0%	21.9%	5.7%	30.6%	124,174	30,538	143,659	23,266	168,788	43,501	235,405
2014	4,609,600	1.60	1,613,759	0.38	615,873	361	15.4%	4.2%	18.8%	4.8%	22.9%	4.6%	29.4%	94,783	25,729	115,597	29,283	141,154	28,493	180,835
2015	4,635,400	1.59	1,673,107	0.38	638,523	94	15.6%	4.1%	19.0%	4.2%	22.8%	5.1%	29.1%	99,536	26,417	121,354	27,095	145,388	32,723	186,010
2016	4,761,865	1.54	2,100,159	0.38	801,502	102	16.4%	4.3%	19.1%	3.4%	22.6%	6.1%	28.1%	131,506	34,277	153,347	26,958	181,172	48,803	225,440

[a] Nappies are assumed to be included in the textiles proportion during the period 1990-1995 inclusive.

Table 3.5.B Methane Correction Factor (MCF) 1990-2016

Year	Waste disposals (by mass) in per cent			Weighted average MCF for MSW
	Un-managed, shallow	Un-managed, deep	Managed	
1956-1963	100%	0%	0%	0.40
1964	90%	10%	0%	0.44
1965	91%	9%	0%	0.44
1966	92%	8%	0%	0.43
1967	92%	8%	0%	0.43
1968	95%	5%	0%	0.42
1969	95%	5%	0%	0.42
1970	95%	5%	0%	0.42
1971	91%	9%	0%	0.43
1972	85%	15%	0%	0.46
1973	85%	15%	0%	0.46
1974	84%	16%	0%	0.46
1975	77%	23%	0%	0.49
1976	56%	44%	0%	0.57
1977	58%	42%	0%	0.57
1978	59%	41%	0%	0.56
1979	59%	41%	0%	0.57
1980	57%	43%	0%	0.57
1981	55%	45%	0%	0.58
1982	56%	44%	0%	0.58
1983	54%	46%	0%	0.59
1984	53%	47%	0%	0.59
1985	52%	48%	0%	0.59
1986	52%	48%	0%	0.59
1987	49%	51%	0%	0.61
1988	45%	55%	0%	0.62
1989	41%	59%	0%	0.63
1990	39%	61%	0%	0.64
1991	37%	63%	0%	0.65
1992	39%	61%	0%	0.64
1993	38%	62%	0%	0.65
1994	37%	63%	0%	0.65
1995	38%	62%	0%	0.65
1996	31%	69%	0%	0.68
1997	29%	71%	0%	0.69
1998	29%	71%	0%	0.68
1999-2016	0%	0%	100%	1.00

Table 3.5.C Parameters, EFs for Clinical Waste Incineration 1990-2016

	Quantity of Clinical Waste (SW_{CW})	Dry Matter content of Clinical Waste (dm_{CW})	Fraction of Carbon in the dry matter as % (CF_{CW})	Fraction of fossil carbon in total carbon as % (FCF_{CW})	Oxidation Factor (OF_{CW})	Emissions CO_2 (Fossil)
	kt					kt CO_2
	A	B	C	D	E	= A * B * C * D * E * 44/12
1990	4.0	NA	60.00	40.00	1.000	3.52
1991	4.0	NA	60.00	40.00	1.000	3.52
1992	4.0	NA	60.00	40.00	1.000	3.52
1993	4.0	NA	60.00	40.00	1.000	3.52
1994	4.0	NA	60.00	40.00	1.000	3.52
1995	4.0	NA	60.00	40.00	1.000	3.52
1996	4.0	NA	60.00	40.00	1.000	3.52
1997	4.0	NA	60.00	40.00	1.000	3.52
1998	NO	NA	60.00	40.00	1.000	NO
1999	NO	NA	60.00	40.00	1.000	NO
2000	NO	NA	60.00	40.00	1.000	NO
2001	NO	NA	60.00	40.00	1.000	NO
2002	NO	NA	60.00	40.00	1.000	NO
2003	NO	NA	60.00	40.00	1.000	NO
2004	NO	NA	60.00	40.00	1.000	NO
2005	NO	NA	60.00	40.00	1.000	NO
2006	NO	NA	60.00	40.00	1.000	NO
2007	NO	NA	60.00	40.00	1.000	NO
2008	NO	NA	60.00	40.00	1.000	NO
2009	NO	NA	60.00	40.00	1.000	NO
2010	NO	NA	60.00	40.00	1.000	NO
2011	NO	NA	60.00	40.00	1.000	NO
2012	NO	NA	60.00	40.00	1.000	NO
2013	NO	NA	60.00	40.00	1.000	NO
2014	NO	NA	60.00	40.00	1.000	NO
2015	NO	NA	60.00	40.00	1.000	NO
2016	NO	NA	60.00	40.00	1.000	NO

Equation 5.1, 2006 IPCC Guidelines: CO_2 emissions = $\sum i \; (SW_i * dm_i * CF_i * FCF_i * OF_i) * \frac{44}{12}$

i, type of waste incinerated (CW: Clinical Waste)

Table 3.5.D Parameters, EFs for Solvent (Liquid/Vapour destruction) Waste Incineration 1990-2016

	Quantity of Fossil Liquid Waste (SW_i)	Dry Matter content of Fossil Liquid Waste (dm_i)	Fraction of Carbon in the dry matter as % (CF_i)	Fraction of fossil carbon in total carbon as % (FCF_i)	Oxidation Factor (OF_i)	Emissions CO_2
	kt					kt CO_2
	A	B	C	D	E	= A * B * C * D * E * 44/12
1990	27.084	NA	80.00	100.00	1.000	79.446
1991	27.084	NA	80.00	100.00	1.000	79.446
1992	27.084	NA	80.00	100.00	1.000	79.446
1993	27.084	NA	80.00	100.00	1.000	79.446
1994	27.084	NA	80.00	100.00	1.000	79.446
1995	27.084	NA	80.00	100.00	1.000	79.446
1996	27.084	NA	80.00	100.00	1.000	79.446
1997	22.482	NA	80.00	100.00	1.000	65.947
1998	17.880	NA	80.00	100.00	1.000	52.448
1999	18.940	NA	80.00	100.00	1.000	55.557
2000	20.000	NA	80.00	100.00	1.000	58.667
2001	21.491	NA	80.00	100.00	1.000	63.040
2002	21.830	NA	80.00	100.00	1.000	64.035
2003	32.821	NA	80.00	100.00	1.000	96.275
2004	37.415	NA	80.00	100.00	1.000	109.751
2005	36.229	NA	80.00	100.00	1.000	106.270
2006	35.042	NA	80.00	100.00	1.000	102.790
2007	27.970	NA	80.00	100.00	1.000	82.045
2008	20.898	NA	80.00	100.00	1.000	61.301
2009	21.378	NA	80.00	100.00	1.000	62.709
2010	18.237	NA	80.00	100.00	1.000	53.495
2011	12.615	NA	80.00	100.00	1.000	37.004
2012	15.129	NA	80.00	100.00	1.000	44.378
2013	15.129	NA	80.00	100.00	1.000	44.378
2014	13.121	NA	80.00	100.00	1.000	38.488
2015	13.292	NA	80.00	100.00	1.000	38.990
2016	7.488	NA	80.00	100.00	1.000	21.965

Equation 5.1, 2006 IPCC Guidelines: CO_2 emissions = $\sum i \, (SW_i * dm_i * CF_i * FCF_i * OF_i) * \frac{44}{12}$

Annex 4

Ireland’s Energy Balance 1990-2016

4.A Ireland’s Energy Balance - Stakeholders, Surveys and Sources

4.B Expanded Energy Balance sheets for 2016

4.C Country specific carbon emission factors – fossil fuels

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

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 DCENR). 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

Department of Communications, Climate Action & Environment (DCCAE) - 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

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 Communications, Climate Action and Environment (DCCAE). Oil companies are required to report to DCCAE 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 DCCAE 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, DCCAE 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 DCCAE 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 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.

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 Communications, Climate Action and Environment
  - 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 Bord Gáis Networks. Bord Gáis Networks 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.

Table 4.B Expanded Energy Balance Sheet 2016

2016 Units = ktoe	Coal	Bituminous Coal	Anthracite + Manufactured Ovoids	Coke	Lignite \ Brown Coal Briquettes	Peat	Milled Peat	Sod Peat	Briquettes	Oil	Crude	Refinery Gas	Gasoline	Kerosene	Jet Kerosene	Fueloil	LPG	Gasoil / Diesel /DERV	Petroleum Coke
Indigenous Production	-	-	-	-	-	679.1	551.4	127.7	-	-	-	-	-	-	-	-	-	-	-
Imports	1,154.8	1,083.8	61.5	-	9.6	-	-	-	-	9,009.2	3,270.2	-	794.7	520.4	1,122.1	59.8	136.3	2,684.1	149.4
Exports	9.2	-	7.6	-	1.6	4.7	-	-	4.7	1,642.7	-	-	371.0	12.8	-	1,038.9	16.7	117.2	0.1
Mar. Bunkers	-	-	-	-	-	-	-	-	-	159.7	-	-	-	-	-	10.6	-	149.1	-
Stock Change	227.7	235.0	-6.8	-	-0.5	59.4	67.5	-	-8.1	-33.7	2.0	-	-6.3	4.0	-2.2	-4.4	-0.3	-25.7	1.2
Primary Energy Supply (incl non-energy)	**1,373.3**	**1,318.8**	**47.0**	**-**	**7.5**	**733.9**	**618.9**	**127.7**	**-12.7**	**7,173.1**	**3,272.2**	**-**	**417.4**	**511.7**	**1,119.9**	**-994.2**	**119.3**	**2,392.1**	**150.5**
Primary Energy Requirement (excl. non-energy)	**1,373.3**	**1,318.8**	**47.0**	**-**	**7.5**	**733.9**	**618.9**	**127.7**	**-12.7**	**6,911.2**	**3,272.2**	**-**	**417.4**	**511.7**	**1,119.9**	**-994.2**	**119.3**	**2,392.1**	**150.5**
Transformation Input	1,101.2	1,101.2	-	-	-	607.0	607.0	-	-	3,340.2	3,272.2	4.6	-	-	-	52.3	0.3	10.9	-
Public Thermal Power Plants	1,101.2	1,101.2	-	-	-	512.9	512.9	-	-	63.2	-	-	-	-	-	52.3	-	10.9	-
Combined Heat and Power Plants	-	-	-	-	-	9.0	9.0	-	-	4.9	-	4.6	-	-	-	-	0.3	-	-
Pumped Storage Consumption	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Briquetting Plants	-	-	-	-	-	85.1	85.1	-	-	-	-	-	-	-	-	-	-	-	-
Oil Refineries & other energy sector	-	-	-	-	-	-	-	-	-	3,272.2	3,272.2	-	-	-	-	-	-	-	-
Transformation Output	-	-	-	-	-	81.1	-	-	81.1	3,318.5	-	92.1	589.7	184.7	-	1,046.5	47.9	1,277.7	-
Public Thermal Power Plants	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Combined Heat and Power Plants - Electricity	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Combined Heat and Power Plants - Heat	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumped Storage Generation	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Briquetting Plants	-	-	-	-	-	81.1	-	-	81.1	-	-	-	-	-	-	-	-	-	-
Oil Refineries	-	-	-	-	-	-	-	-	-	3,318.5	-	92.1	589.7	184.7	-	1,046.5	47.9	1,277.7	-
Exchanges and transfers	11.7	-6.6	18.4	-	-	-	-	-	-	-15.0	-	-	-0.1	198.5	-198.0	1.1	-	-4.6	-11.7
Electricity	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	11.7	-6.6	18.4	-	-	-	-	-	-	-15.0	-	-	-0.1	198.5	-198.0	1.1	-	-4.6	-11.7
Own Use and Distribution Losses	**-**	**-**	**-**	**-**	**-**	**11.5**	**11.5**	**-**	**-**	**87.6**	**-**	**87.5**	**-**	**-**	**-**	**-**	**0.0**	**0.2**	**-**
Available Final Energy Consumption	**283.8**	**210.9**	**65.4**	**-**	**7.5**	**196.5**	**0.4**	**127.7**	**68.4**	**7,048.9**	**0.0**	**-**	**1,007.0**	**894.8**	**921.8**	**1.2**	**166.9**	**3,654.0**	**138.8**

2016 Units = ktoe	Coal	Bituminous Coal	Anthracite + Manufactured Ovoids	Coke	Lignite \ Brown Coal Briquettes	Peat	Milled Peat	Sod Peat	Briquettes	Oil	Crude	Refinery Gas	Gasoline	Kerosene	Jet Kerosene	Fueloil	LPG	Gasoil / Diesel /DERV	Petroleum Coke
Non-Energy Consumption	-	-	-	-	-	-	-	-	-	261.9	-	-	-	-	-	-	-	-	-
Final non-Energy Consumption (Feedstocks)	-	-	-	-	-	-	-	-	-	261.9	-	-	-	-	-	-	-	-	-
Total Final Energy Consumption	**288.9**	**210.9**	**68.6**	**-**	**9.5**	**197.7**	**0.8**	**127.7**	**69.2**	**6,740.2**	**-**	**-**	**1,002.8**	**905.8**	**868.4**	**44.4**	**163.5**	**3,616.4**	**138.9**
Industry*	110.2	110.2	0.0	-	-	0.8	0.8	-	-	484.5	-	-	-	90.6	-	34.6	113.4	112.6	133.4
Non-Energy Mining	-	-	-	-	-	-	-	-	-	30.9	-	-	-	2.9	-	1.1	0.2	26.8	-
Food & beverages	20.7	20.7	-	-	-	0.8	0.8	-	-	130.9	-	-	-	53.2	-	19.8	32.3	25.5	-
Textiles and textile products	-	-	-	-	-	-	-	-	-	2.4	-	-	-	1.2	-	0.4	0.0	0.8	-
Wood and wood products	-	-	-	-	-	-	-	-	-	2.5	-	-	-	0.4	-	0.2	0.3	1.7	-
Pulp, paper, publishing and printing	-	-	-	-	-	-	-	-	-	2.8	-	-	-	1.0	-	0.4	0.2	1.2	-
Chemicals & man-made fibres	-	-	-	-	-	-	-	-	-	27.5	-	-	-	12.7	-	4.7	2.9	7.2	-
Rubber and plastic products	-	-	-	-	-	-	-	-	-	9.1	-	-	-	0.1	-	0.0	5.8	3.1	-
Other non-metallic mineral products	89.5	89.5	-	-	-	-	-	-	-	181.9	-	-	-	8.6	-	3.2	1.3	35.5	133.4
Basic metals and fabricated metal products	-	-	-	-	-	-	-	-	-	8.5	-	-	-	-	-	0.8	5.4	2.3	-
Machinery and equipment n.e.c.	-	-	-	-	-	-	-	-	-	5.2	-	-	-	0.4	-	0.2	2.2	2.4	-
Electrical and optical equipment	-	-	-	-	-	-	-	-	-	40.9	-	-	-	0.4	-	0.1	39.0	1.4	-
Transport equipment manufacture	-	-	-	-	-	-	-	-	-	4.5	-	-	-	0.3	-	0.1	3.5	0.6	-
Other manufacturing	-	-	-	-	-	-	-	-	-	37.3	-	-	-	9.5	-	3.6	20.0	4.2	0.0
Transport	-	-	-	-	-	-	-	-	-	4,825.1	-	-	1,002.8	-	868.4	-	2.5	2,951.3	-
Road Freight	-	-	-	-	-	-	-	-	-	713.2	-	-	-	-	-	-	-	713.2	-
Road Light Goods Vehicle	-	-	-	-	-	-	-	-	-	308.9	-	-	-	-	-	-	-	308.9	-
Road Private Car	-	-	-	-	-	-	-	-	-	2,076.1	-	-	831.2	-	-	-	2.5	1,242.3	-
Public Passenger Services	-	-	-	-	-	-	-	-	-	130.5	-	-	13.4	-	-	-	-	117.1	-
Rail	-	-	-	-	-	-	-	-	-	36.5	-	-	-	-	-	-	-	36.5	-
Domestic Aviation	-	-	-	-	-	-	-	-	-	3.6	-	-	0.8	-	2.8	-	-	-	-
International Aviation	-	-	-	-	-	-	-	-	-	865.6	-	-	-	-	865.6	-	-	-	-
Fuel Tourism	-	-	-	-	-	-	-	-	-	372.5	-	-	9.5	-	-	-	-	362.9	-
Navigation	-	-	-	-	-	-	-	-	-	85.9	-	-	-	-	-	-	-	85.9	-
Unspecified	-	-	-	-	-	-	-	-	-	232.3	-	-	147.8	-	-	-	-	84.5	-
Residential	178.8	100.7	68.6	-	9.5	196.9	-	127.7	69.2	1,005.0	-	-	-	815.3	-	-	39.1	145.2	5.5

2016 Units = ktoe	Coal	Bituminous Coal	Anthracite + Manufactured Ovoids	Coke	Lignite \ Brown Coal Briquettes	Peat	Milled Peat	Sod Peat	Briquettes	Oil	Crude	Refinery Gas	Gasoline	Kerosene	Jet Kerosene	Fueloil	LPG	Gasoil / Diesel /DERV	Petroleum Coke
Commercial/Public Services	-	-	-	-	-	-	-	-	-	247.1	-	-	-	-	-	9.8	8.4	228.8	0.0
Commercial Services	-	-	-	-	-	-	-	-	-	158.4	-	-	-	-	-	1.0	6.3	151.2	0.0
Public Services	-	-	-	-	-	-	-	-	-	88.7	-	-	-	-	-	8.9	2.2	77.7	-
Agricultural	-	-	-	-	-	-	-	-	-	159.2	-	-	-	-	-	-	-	159.2	-
Fisheries	-	-	-	-	-	-	-	-	-	19.3	-	-	-	-	-	-	-	19.3	-
Statistical Difference	**-5.1**	**0.0**	**-3.2**	**-**	**-2.0**	**-1.2**	**-0.5**	**-**	**-0.8**	**46.8**	**0.0**	**-**	**4.1**	**-11.0**	**53.5**	**-43.2**	**3.4**	**37.7**	**-0.1**

Table 4.B Expanded Energy Balance Sheet 2016 (continued)

2016 Units = ktoe	Naphta	Bitumen	White Spirit	Lubricants	Natural Gas	Renewables	Hydro	Wind	Biomass & Renewable Waste	Landfill Gas	Biogas	Liquid Biofuel	Solar	Geothermal	Non-Renewable Waste	Electricity	Heat	TOTAL
Indigenous Production	-	-	-	-	2,492.8	1,026.4	58.6	528.8	290.9	38.9	15.9	24.4	14.3	54.7	66.2	-	-	4,264.5
Imports	-	230.4	1.6	40.2	1,704.4	139.0	-	-	45.8	-	-	93.2	-	-	-	74.9	-	12,082.4
Exports	75.7	2.8	0.0	7.5	-	0.2	-	-	0.2	-	-	-	-	-	-	136.1	-	1,792.9
Mar. Bunkers	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	159.7
Stock Change	-1.9	-	-	-	53.9	-7.9	-	-	-1.1	-	-	-6.8	-	-	-	-	-	299.3
Primary Energy Supply (incl non-energy)	**-77.7**	**227.6**	**1.6**	**32.7**	**4,251.0**	**1,157.2**	**58.6**	**528.8**	**335.4**	**38.9**	**15.9**	**110.8**	**14.3**	**54.7**	**66.2**	**-61.2**	**-**	**14,693.6**
Primary Energy Requirement (excl. non-energy)	**-77.7**	**-**	**-**	**-**	**4,251.0**	**1,157.2**	**58.6**	**528.8**	**335.4**	**38.9**	**15.9**	**110.8**	**14.3**	**54.7**	**66.2**	**-61.2**	**-**	**14,431.7**
Transformation Input	-	-	-	-	2,395.5	159.6	-	-	114.2	38.9	6.6	-	-	-	24.5	55.7	-	7,683.8
Public Thermal Power Plants	-	-	-	-	2,068.3	150.1	-	-	111.3	38.9	-	-	-	-	24.5	-	-	3,920.3
Combined Heat and Power Plants	-	-	-	-	273.3	9.5	-	-	2.9	-	6.6	-	-	-	-	-	-	296.6
Pumped Storage Consumption	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	45.8	-	45.8
Briquetting Plants	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	85.1
Oil Refineries & other energy sector	-	-	-	-	53.9	-	-	-	-	-	-	-	-	-	-	10.0	-	3,336.1
Transformation Output	80.0	-	-	-	-	58.3	-	-	40.6	13.8	3.8	-	-	-	6.1	2,036.1	-	5,500.2
Public Thermal Power Plants	-	-	-	-	-	53.1	-	-	39.3	13.8	-	-	-	-	6.1	1,821.9	-	1,821.9
Combined Heat and Power Plants - Electricity	-	-	-	-	-	5.2	-	-	1.4	-	3.8	-	-	-	-	189.1	-	189.1
Combined Heat and Power Plants - Heat	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumped Storage Generation	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	25.1	-	25.1
Briquetting Plants	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	81.1
Oil Refineries	80.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3,318.5
Exchanges and transfers	-	-	-	-	-	-587.7	-58.6	-528.8	-	-	-	-	-0.4	-	-	587.7	-	-3.2
Electricity	-	-	-	-	-	-587.7	-58.6	-528.8	-	-	-	-	-0.4	-	-	587.7	-	-
Heat	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-3.2
Own Use and Distribution Losses	**-**	**-**	**-**	**-**	**51.3**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**254.2**	**-**	**404.7**
Available Final Energy Consumption	**2.4**	**227.6**	**1.6**	**32.7**	**1,804.2**	**409.9**	**-**	**-**	**221.2**	**-**	**9.3**	**110.8**	**13.9**	**54.7**	**41.7**	**2,252.6**	**-**	**12,037.6**
Non-Energy Consumption	-	227.6	1.6	32.7	-	-	-	-	-	-	-	-	-	-	-	-	-	261.9
Final non-Energy Consumption (Feedstocks)	-	227.6	1.6	32.7	-	-	-	-	-	-	-	-	-	-	-	-	-	261.9
Total Final Energy Consumption	**-**	**-**	**-**	**-**	**1,793.8**	**426.0**	**-**	**-**	**229.6**	**-**	**9.3**	**118.5**	**13.9**	**54.7**	**41.7**	**2,199.3**	**-**	**11,687.7**

2016 Units = ktoe	Naphta	Bitumen	White Spirit	Lubricants	Natural Gas	Renewables	Hydro	Wind	Biomass & Renewable Waste	Landfill Gas	Biogas	Liquid Biofuel	Solar	Geothermal	Non-Renewable Waste	Electricity	Heat	TOTAL
Industry*	-	-	-	-	754.6	174.1	-	-	171.7	-	2.4	-	-	-	41.7	872.3	-	2,438.2
Non-Energy Mining	-	-	-	-	11.6	-	-	-	-	-	-	-	-	-	-	62.7	-	105.2
Food & beverages	-	-	-	-	102.3	21.6	-	-	19.3	-	2.4	-	-	-	-	186.3	-	462.7
Textiles and textile products	-	-	-	-	1.1	-	-	-	-	-	-	-	-	-	-	11.2	-	14.7
Wood and wood products	-	-	-	-	2.0	113.1	-	-	113.1	-	-	-	-	-	-	37.5	-	155.1
Pulp, paper, publishing and printing	-	-	-	-	3.3	-	-	-	-	-	-	-	-	-	-	20.5	-	26.5
Chemicals & man-made fibres	-	-	-	-	63.2	-	-	-	-	-	-	-	-	-	-	158.8	-	249.4
Rubber and plastic products	-	-	-	-	4.4	-	-	-	-	-	-	-	-	-	-	38.4	-	51.9
Other non-metallic mineral products	-	-	-	-	16.5	39.4	-	-	39.4	-	-	-	-	-	41.7	55.6	-	424.6
Basic metals and fabricated metal products	-	-	-	-	416.6	-	-	-	-	-	-	-	-	-	-	67.9	-	493.0
Machinery and equipment n.e.c.	-	-	-	-	5.3	-	-	-	-	-	-	-	-	-	-	22.3	-	32.8
Electrical and optical equipment	-	-	-	-	120.1	-	-	-	-	-	-	-	-	-	-	107.9	-	269.0
Transport equipment manufacture	-	-	-	-	1.8	-	-	-	-	-	-	-	-	-	-	18.5	-	24.8
Other manufacturing	-	-	-	-	6.3	-	-	-	-	-	-	-	-	-	-	84.9	-	128.5
Transport	-	-	-	-	21.3	118.5	-	-	-	-	-	118.5	-	-	-	4.2	-	4,969.0
Road Freight	-	-	-	-	-	21.6	-	-	-	-	-	21.6	-	-	-	-	-	734.8
Road Light Goods Vehicle	-	-	-	-	0.0	9.4	-	-	-	-	-	9.4	-	-	-	-	-	318.3
Road Private Car	-	-	-	-	-	64.8	-	-	-	-	-	64.8	-	-	-	0.3	-	2,141.3
Public Passenger Services	-	-	-	-	-	4.0	-	-	-	-	-	4.0	-	-	-	-	-	134.5
Rail	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.8	-	40.3
Domestic Aviation	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.6
International Aviation	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	865.6
Fuel Tourism	-	-	-	-	-	11.3	-	-	-	-	-	11.3	-	-	-	-	-	383.8
Navigation	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	85.9
Unspecified	-	-	-	-	21.3	7.4	-	-	-	-	-	7.4	-	-	-	-	-	261.0
Residential	-	-	-	-	563.0	82.4	-	-	31.9	-	-	-	13.8	36.7	-	677.1	-	2,703.1
Commercial/Public Services	-	-	-	-	455.0	51.0	-	-	25.9	-	6.9	-	0.2	18.0	-	597.8	-	1,350.9
Commercial Services	-	-	-	-	199.4	44.1	-	-	25.9	-	-	-	0.2	18.0	-	428.6	-	830.5
Public Services	-	-	-	-	255.6	6.9	-	-	-	-	6.9	-	-	-	-	169.2	-	520.5
Agricultural	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	48.0	-	207.2
Fisheries	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	19.3
Statistical Difference	**2.4**	**-**	**-**	**-**	**10.4**	**-16.1**	**-**	**-**	**-8.4**	**-**	**-**	**-7.7**	**-**	**-**	**-**	**53.3**	**-**	**88.0**

Table 4.C Country specific carbon emission factors – fossil fuels

Liquid fuels	NCV (toe/t)	NCV (MJ kg^{-1})	CO_2 (t/TJ)	Density (kg l^{-1})
Crude Oil	1.0226	42.814	73.333	
Refinery Gas	1.1970	50.118	53.914	
LPG	1.1263	47.156	63.690	
Naphtha	1.0510	44.003	73.333	
Motor Gasoline	1.0650	44.589	69.960	0.7550
Aviation Gasoline	1.0650	44.589	70.033	0.7550
Jet Kerosene	1.0533	44.100	71.390	0.8000
Other Kerosene	1.0556	44.196	71.390	0.8000
DERV (Road Gasoil)	1.0344	43.308	73.297	0.8450
Heating and Other Gasoil	1.0344	43.308	73.297	0.8450
Residual Fuel Oil	0.9849	41.236	76.010	0.9416
Residual Fuel Oil (Electricity Generation)	0.9653	40.416	78.698	
Fuel Oil – Low Sulphur content	0.9849	41.236	76.010	0.9416
Fuel Oil – High Sulphur content	0.9849	41.236	76.010	0.9416
White Spirits	1.0510	44.003	73.333	
Lubricants	1.0100	42.287	73.333	
Petroleum Coke	0.7642	31.996	94.446	
Bitumen (including Orimulsion)	0.9004	37.698	80.667	
Solid Fuels	**NCV (toe/t)**	**NCV (MJ kg^{-1})**	**CO_2 (t/TJ)**	**Density (kg l^{-1})**
Coal (electricity generation)	0.5890	24.890	92.869	
Other Bituminous Coal (imports)	0.6649	29.098	94.600	
Other Bituminous Coal (default)	0.6650	25.333	94.600	
Anthracite	0.6650	27.842		
Lignite/Brown Coal	0.4733	19.816		
Patent Fuels (Manufactured Ovoids)	0.7643	32.000	98.300	
Milled Peat	0.1812	7.585	116.640	
Sod Peat	0.3130	13.105		
BKB/Peat Briquettes	0.4430	18.548		

Gaseous fuels	NCV (MJ m^{-3})	NCV (MJ kg^{-1})	CO_2 (t/TJ)	Density (kg m^{-3})
Natural Gas-Indigeneous 1	34.2208	47.520	55.942	0.7201
Natural Gas-Indigeneous 2	33.9475	47.229	55.191	0.7188
Natural Gas-Imported	35.6567	46.537	56.754	0.7662
Natural Gas- weighted average		46.957	55.849	

Annex 5.1

Ireland's Response to the Recommendations in the UNFCCC Annual Review Reports

5.1a for Submission 2013

5.1b for Submission 2014

Table 5.1a Ireland's Response to the recommendations in the UNFCCC Annual Review Report for Submission 2014

Sector	Issue	ARR Paragraph	Recommendation	Party response	NIR Section
Cross-cutting	General	4	Include the information on the key drivers of emission/removal trends on cropland, grassland, wetlands, settlements and other land in the next NIR	More discussion on trends included in NIR 2015.	Chapter 2, Chapter 6, Chapter 11, Annex 3.4
Cross-cutting	General	77	Include a paragraph explaining the assessment of key categories for the KP-LULUCF activities in chapter 11 in its NIR in order to enhance the transparency of its NIR		
Energy	Reference approach	21, 22	Further investigate the difference between reference approach and sectoral approach, and report accordingly in the next NIR	Resolved, no difference between two approaches in 2015 submission.	Chapter 3, Annex 3.1.A
Energy	Feedstocks and non-energy use of fuels	25	Investigate the emissions related to the non-energy use of lubricants, other than road transportation, and report accordingly in the next submission	Lubricants (and Paraffin wax) emissions are reported for the first time in 2015 submission.	Chapter 4
Energy	Stationary combustion: liquid and gaseous fuels – CO2	26	Improve the transparency of the reporting of emission estimates of this category by providing more information in relation to the use of EU ETS data in the NIR	Additional information provided.	Chapter 3, Annex 3.1.A, MMR IR Article 10
Energy	Stationary combustion: liquid and gaseous fuels – CO2	27	Provide information on AD and CO2 EFs for the different types of fuel and industrial activities reported under other (manufacturing industries and construction)		Chapter 3, Annex 3.1.A
Energy	Stationary combustion: liquid and gaseous fuels – CO2	28	Investigate further the issue on high IEF for gaseous fuels in petroleum refining and report accordingly in the next NIR	Ireland uses both national statistics fuel data and EU ETS emissions data for reporting of CO2 emissions from energy combustion in refinery. Unusual IEFs are a result of refinery gases/natural gas proportion that is reported in Energy Balance where activity data is derived from and different mix reported in EU ETS. Ireland is working closely with Energy Balance	Chapter 3, Annex 3.1.A, Annex 4

Sector	Issue	ARR Paragraph	Recommendation	Party response	NIR Section
				provider on harmonising the fuel mix with that reported in EU ETS.	
Energy	Other transportation: liquid fuels – CO_2	30	Reviews the notation key used to report liquid fuels and, as appropriate, change the notation key from “NO” to “IE”, and provide a transparent description on the basis for dividing fuel consumption between road and non-road traffic	Notation key IE in sector 1A5 Other applies to all other types of transportation i.e. non-road traffic that could not be further disaggregated and separated from stationary sources. The energy balance provider does not offer separate statistics for road and non-road transport.	Chapter 3
Energy	Oil and natural gas: gaseous fuels – CO_2, CH_4	31	Provide the explanation on where fugitive emissions of CH_4 and CO_2 from natural gas exploration and transmission are reported both in the CRF tables and in the NIR, and provide a detailed description of how the emissions from each activity are estimated in the NIR	Fugitive emissions of CH_4 from natural gas for all activities are reported in two categories: category 1B2b2 Production and 1B2b5 Distribution. Other activities CH_4 emissions from natural gas are reported as IE. CO_2 emissions from natural gas are reported in pipeline compressors sector 1A3e other transportation.	
Energy	Oil and natural gas: gaseous fuels – CO_2, CH_4	32	Explain where fugitive CO_2 emissions from natural gas and fugitive CH_4 emissions from venting and flaring are allocated in the CRF tables	Fugitive CO_2 emissions from natural gas are included together with combustion CO_2 emissions in sector 1A3e other (pipeline compressors). Gas venting CH_4 emissions could not be separated and are included in two fugitive categories gas is reported under: 1B2b2 Production and 1B2b5 Distribution. Gas flaring did not take place in Ireland apart from two instances in two years (1999 and 2001) and CO_2 emissions were reported accordingly for those years in category 1B2c2ii gas flaring.	
Energy	Oil and natural gas: gaseous fuels – CO_2, CH_4	32	Use notation keys consistently between the NIR and the CRF tables	Notation keys have been applied consistently in CRF and NIR in 2015 submission.	

Sector	Issue	ARR Paragraph	Recommendation	Party response	NIR Section
Energy	Oil and natural gas: gaseous fuels – CO2, CH4	33	Use the appropriate notation keys and provide a detailed description of how the emissions from each activity are estimated in the NIR. Change fugitive emissions from other leakages from natural gas to IE (from NO).	Category 1B2b6 Other (i.e. leakages from natural gas) is not occurring NO as potential leakages from natural gas are considered negligible.	
Energy	Oil and natural gas: gaseous fuels – CO2, CH4	34	Include the information on a mobile drilling unit in the Kinsale field in 2001 in the next NIR	Note added to NIR.	Chapter 3
Industrial processes and solvent and other product use	Consumption of halocarbons and SF6 – HFCs and SF6	40	Provide additional information of how the potential sources (e.g. from imported products) are considered in the emission estimates from this category to ensure a complete and accurate inventory	Potential sources are not estimated in 2015 submission (according to the 2006 IPCC Guidelines).	
Industrial processes and solvent and other product use	Limestone and dolomite use – CO2	41	Ensure consistency within the NIR and between the NIR and CRF tables in future submissions re stoichiometric ratio of CO2 to calcium carbonate (CaCO3) used as an EF. It fluctuates instead of being constant as stated in NIR (0.44 t CO2/t limestone).	NIR text corrected.	Chapter 4
Agriculture	Manure management – CH4 and N2O	50	Develop dynamic N excretion rates for non-dairy cattle and use the related data in the inventory, when the data become available	Inventory agency continues to engage with the agricultural research community to develop dynamic N excretion rates for non-dairy cattle.	
Agriculture	Agricultural soils – N2O	51	Replace the default FracGASM data with country- specific data when they become available	The default FracGASM value will replaced when country specific data is available.	
LULUCF	General	54	Follow the structure of NIR shown in the annex to decision 24/CP.19	Completed	
LULUCF	General	55	Include the information on key drivers of emission/removal trends on cropland, grassland, wetlands, settlements and other land in its NIR	Discussion of the key drivers of change in these categories is provided in the text in relevant sections of the NIR for Cropland and Grasslands. Discussion of	6.4.1, 6.4.5, 6.4.9, 6.5.1. 6.5.4, 6.5.7,

Sector	Issue	ARR Paragraph	Recommendation	Party response	NIR Section
				drivers fo changes in wetlands is restricted to Peat extraction activities. Further analysis is required to assess the underlying drivers of changes in settlements, due to the very complex economic and social interactions which influence behaviour in this sector.	6.6.3, 6.6.6. 6.6.7, 6.9
LULUCF	Forest land – CO2	56	Correct this typographical error on value of country-specific EF for organic forest soils	Completed	6.3.3.1.2
LULUCF	Forest land – CO2	57	Report the removals for the pool or report the pool as “NE” instead of “NO” or report the carbon stock changes as “NA” if the carbon stock changes in the pool are assumed to be zero because losses are balanced out by gains	Clarification in text, do not agree. Any notation can be used as long as it is clarified in text	6.3.3.1.2
LULUCF	Forest land – CO2	58	Delete the sentence “emissions from soils due to biomass burning resulting from forest wildfires are assumed to be negligible and do not occur (NO)” from its NIR in order to avoid confusion	Completed	6.3.4.4
LULUCF	Forest land – N2O	59	Use the same tier to estimate the carbon stock changes in and the N2O emissions from soils in the same category	Not valid there is new methodology under AFOLU 2006	
LULUCF	Wetlands remaining wetlands – CO2	60	Include the information on the carbon losses in DOM removed from managed wetlands in its NIR and the documentation box in CRF table in order to enhance transparency	Text has been added in the NIR. Will consider options for inclusion of information in CRF.	6.6.1
LULUCF	Land converted to wetlands – CO2	61	Include the information on mineral soils in wetlands in the next annual submission in order to clarify what kind of soils are included in wetland areas	To be considered in 2015 submission	
LULUCF	Settlements remaining settlements – CO2	62	Report the carbon stock changes in this category as “NA” instead of as “NO” and include an explanation on the use of the notation key to its NIR	To be considered in 2015 submission	

Sector	Issue	ARR Paragraph	Recommendation	Party response	NIR Section
Waste	General	65	Correct inconsistencies between NIR table 8.6 and table I.2 in annex I to the NIR	Completed	
Waste	General	66	Fully document the sector-specific QA activities in the NIR.		
Waste	General	67	Expand the discussion of uncertainty in the waste chapter to include the uncertainty estimates for wastewater and incineration	Revised and more detailed uncertainty analysis has been developed and it includes estimates for wastewater and waste incineration and open burning.	Annex 2, NIR 2015
Waste	Solid waste disposal on land – CH_4	68	Disaggregate the AD for the years up to 2003 in order to ensure time-series consistency		
Waste	Solid waste disposal on land – CH_4	69	Update the information on MSW generation in the NIR and the CRF tables (error due to the non-inclusion of town dumps and the landfill site W047 in the national waste reports and information on waste composition in annex I to the NIR)		
Waste	Solid waste disposal on land – CH_4	70	Include a discussion of these model parameters in FOD model in its next NIR, including the values used and justification for their use		
Waste	Wastewater handling – CH_4 and N_2O	71	Provide a discussion of the methodology used in the NIR in order to increase the transparency of its reporting		
Waste	Wastewater handling – CH_4 and N_2O	72	Describe the source and derivation of AD and the industrial sectors contributing to the BOD load		
Waste	Waste incineration – CO_2, CH_4 and N_2O	73	Include a discussion in the NIR on the applicability of the EFs from the 2006 IPCC Guidelines to the incinerator units.		
Waste	Waste incineration – CO_2, CH_4 and N_2O	74	Correct this double counting of AD in the quantity of clinical waste incinerated in the CRF tables by disaggregating the AD into biogenic and non- biogenic components	Waste incineration has been estimated separately for biogenic and non-biogenic components in 2015 submission.	

Sector	Issue	ARR Paragraph	Recommendation	Party response	NIR Section
KP-LULUCF	General	77	Include a paragraph explaining the assessment of the key category analysis for the KP-LULUCF activities in chapter 11 of its NIR.		
KP-LULUCF	Afforestation and reforestation – CO2, CH4 and N2O	79	Include this information on implied carbon stock change factors for organic soils in afforestation and reforestation in its NIR	Completed	Reported in ch 6
KP-LULUCF	Deforestation – CO2, CH4 and N2O	80	Include this information on implied carbon stock change factors for organic soils under deforestation in its NIR	Completed	reported in Ch 6 and cross reference in ch 11
KP-LULUCF	Deforestation – CO2, CH4 and N2O	81	Include this information that the sampling plot for measuring carbon stocks in above- and belowground biomass contained regenerating young broadleaf forest/scrub, and that stump and root biomass is greater than stems and branch biomass in the regenerating young broadleaf forest/scrub in its NIR in order to enhance transparency		

Annex 5.2

Standard Electronic Format (SEF) 2017

Commitment Period 2

Commitment Period 2

Party	Ireland
Submission Year	2018
Reported Year	2017
Commitment Period	2

Table 1. Total quantities of Kyoto Protocol units by account type at beginning of reported year

	Account type	Unit type					
		AAUs	ERUs	RMUs	CERs	tCERs	lCERs
1	Party holding accounts	NO	NO	NO	NO	NO	NO
2	Entity holding accounts	NO	74,964	NO	5,255,000	NO	NO
3	Retirement account	NO	NO	NO	NO	NO	NO
4	Previous period surplus reserve account	NO					
5	Article 3.3/3.4 net source cancellation accounts	NO	NO	NO	NO		
6	Non-compliance cancellation account	NO	NO	NO	NO		
7	Voluntary cancellation account	NO	NO	NO	NO	NO	NO
8	Cancellation account for remaining units after carry-over	NO	NO	NO	NO	NO	NO
9	Article 3.1 ter and quater ambition increase cancellation account	NO					
10	Article 3.7 ter cancellation account	NO					
11	tCER cancellation account for expiry					NO	
12	lCER cancellation account for expiry						NO
13	lCER cancellation account for reversal of storage						NO
14	lCER cancellation account for non-submission of certification report						NO
15	tCER replacement account for expiry	NO	NO	NO	NO	NO	
16	lCER replacement account for expiry	NO	NO	NO	NO		
17	lCER replacement account for reversal of storage	NO	NO	NO	NO		NO
18	lCER replacement account for non-submission of certification report	NO	NO	NO	NO		NO
19	Total	NO	74,964	NO	5,255,000	NO	NO

Party	Ireland
Submission Year	2018
Reported Year	2017
Commitment Period	2

Table 2a. Annual internal transactions

	Transaction type	Additions						Subtractions					
		AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
	Art6 issuance and conversion												
1	**Party verified projects**		NO					NO		NO			
2	**Independently verified projects**		NO					NO		NO			
	Art3.3 and 3.4 issuance or cancellation												
3	**3.3 Afforestation reforestation**			NO				NO	NO	NO	NO		
4	**3.3 Deforestation**			NO				NO	NO	NO	NO		
5	**3.4 Forest management**			NO				NO	NO	NO	NO		
6	**3.4 Cropland management**			NO				NO	NO	NO	NO		
7	**3.4 Grazing land management**			NO				NO	NO	NO	NO		
8	**3.4 Revegetation**			NO				NO	NO	NO	NO		
9	**3.4 Wetland drainage and rewetting**			NO				NO	NO	NO	NO		
	Art 12 afforestation and reforestation												
10	**Replacement of expired tCERs**							NO	NO	NO	NO	NO	
11	**Replacement of expired lCERs**							NO	NO	NO	NO		
12	**Replacement for reversal of storage**							NO	NO	NO	NO		NO
13	**Cancellation for reversal of storage**												NO
14	**Replacement for non-submission of certification report**							NO	NO	NO	NO		NO
15	**Cancellation for non submission of certification report**												NO
	Other cancelation												
16	**Voluntary cancellation**							NO	NO	NO	NO	NO	NO
17	**Article 3.1 ter and quater ambition increase cancellation**							NO					
18	**Subtotal**		NO	NO				NO	NO	NO	NO	NO	NO

Party	Ireland
Submission Year	2018
Reported Year	2017
Commitment Period	2

Table 2b. Annual external transactions

		Additions						Subtractions					
	Total transfers and acquisitions	AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
1	EU	NO	NO	NO	115,965	NO	NO	NO	NO	NO	115,965	NO	NO
2	Subtotal	NO	NO	NO	115,965	NO	NO	NO	NO	NO	115,965	NO	NO

Table 2c. Annual transactions between PPSR accounts

		AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
1	Subtotal	NO						NO					

Table 2d. Share of proceeds transactions under decision 1/CMP.8, paragraph 21 - Adaptation Fund

		AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
1	First international transfers of AAUs	NO						NO					
2	Issuance of ERU from Party-verified projects		NO						NO				
3	Issuance of independently verified ERUs		NO						NO				

Table 2e. Total annual transactions

		AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
1	Total (Sum of sub-totals in table 2a and table 2b)	NO	NO	NO	115,965	NO	NO	NO	NO	NO	115,965	NO	NO

Party	Ireland
Submission Year	2018
Reported Year	2017
Commitment Period	2

Table 3. Expiry, cancellation and replacement

	Transaction or event type	Requirement to replace or cancel			Replacement						Cancellation					
	Transaction or event type	tCERs	lCERs	CERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
	Temporary CERs															
1	Expired in retirement and replacement accounts	NO			NO	NO	NO	NO	NO							
2	Expired in holding accounts	NO													NO	
	Long-term CERs															
3	Expired in retirement and replacement accounts		NO		NO	NO	NO	NO								
4	Expired in holding accounts		NO													NO
5	Subject to reversal of Storage		NO		NO	NO	NO	NO		NO						NO
6	Subject to non submission of certification Report		NO		NO	NO	NO	NO		NO						NO
	Carbon Capture and Storage CERs															
7	Subject to net reversal of storage			NO							NO	NO	NO	NO		
8	Subject to non submission of certification report			NO							NO	NO	NO	NO		
9	Total	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

Party	Ireland

Submission Year	2018
Reported Year	2017
Commitment Period	2

Table 4. Total quantities of Kyoto Protocol units by account type at end of reported year

	Account type	Unit type					
		AAUs	ERUs	RMUs	CERs	tCERs	lCERs
1	Party holding accounts	NO	NO	NO	NO	NO	NO
2	Entity holding accounts	NO	74,964	NO	5,255,000	NO	NO
3	Retirement account	NO	NO	NO	NO	NO	NO
4	Previous period surplus reserve account	NO					
5	Article 3.3/3.4 net source cancellation accounts	NO	NO	NO	NO		
6	Non-compliance cancellation account	NO	NO	NO	NO		
7	Voluntary cancellation account	NO	NO	NO	NO	NO	NO
8	Cancellation account for remaining units after carry-over	NO	NO	NO	NO	NO	NO
9	Article 3.1 ter and quater ambition increase cancellation account	NO					
10	Article 3.7 ter cancellation account	NO					
11	tCER cancellation account for expiry					NO	
12	lCER cancellation account for expiry						NO
13	lCER cancellation account for reversal of storage						NO
14	lCER cancellation account for non-submission of certification report						NO
15	tCER replacement account for expiry	NO	NO	NO	NO	NO	
16	lCER replacement account for expiry	NO	NO	NO	NO		
17	lCER replacement account for reversal of storage	NO	NO	NO	NO		NO
18	lCER replacement account for non-submission of certification report	NO	NO	NO	NO		NO
19	Total	NO	74,964	NO	5,255,000	NO	NO

Party	Ireland

Submission Year	2018
Reported Year	2017
Commitment Period	2

Table 5a. Summary information on additions and subtractions

		Additions						Subtractions					
		AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
1	Assigned amount units issued	NO											
2	Article 3 Paragraph 7 ter cancellations							NO					
3	Cancellation following increase in ambition							NO					
4	Cancellation of remaining units after carry over							NO	NO	NO	NO	NO	NO
5	Non-compliance cancellation							NO	NO	NO	NO		
6	Carry-over		74,964		5,255,000				NO		NO		
7	Carry-over to PPSR	NO						NO					
8	Total	NO	74,964		5,255,000			NO	NO	NO	NO	NO	NO

Table 5b. Summary information on annual transactions

		Additions						Subtractions					
		AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
1	Year 1 (2013)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2	Year 2 (2014)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
3	Year 3 (2015)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
4	Year 4 (2016)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5	Year 5 (2017)	NO	NO	NO	115,965	NO	NO	NO	NO	NO	115,965	NO	NO
6	Year 6 (2018)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
7	Year 7 (2019)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
8	Year 8 (2020)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
9	Year 2021	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
10	Year 2022	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
11	Year 2023	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
12	Total	NO	NO	NO	115,965	NO	NO	NO	NO	NO	115,965	NO	NO

Table 5c. Summary information on annual transactions between PPSR accounts

Additions		Subtractions

		AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
1	**Year 1 (2013)**	NO						NO					
2	**Year 2 (2014)**	NO						NO					
3	**Year 3 (2015)**	NO						NO					
4	**Year 4 (2016)**	NO						NO					
5	**Year 5 (2017)**	NO						NO					
6	**Year 6 (2018)**	NO						NO					
7	**Year 7 (2019)**	NO						NO					
8	**Year 8 (2020)**	NO						NO					
9	**Year 2021**	NO						NO					
10	**Year 2022**	NO						NO					
11	**Year 2023**	NO						NO					
12	**Total**	NO						NO					

Table 5d. Summary information on expiry, cancellation and replacement

		Requirement to replace or cancel			Replacement						Cancellation					
		tCERs	lCERs	CERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
1	**Year 1 (2013)**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2	**Year 2 (2014)**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
3	**Year 3 (2015)**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
4	**Year 4 (2016)**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5	**Year 5 (2017)**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
6	**Year 6 (2018)**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
7	**Year 7 (2019)**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
8	**Year 8 (2020)**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
9	**Year 2021**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
10	**Year 2022**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
11	**Year 2023**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
12	**Total**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

Table 5e. Summary information on retirement

		AAUs	ERUs	RMUs	CERs	tCERs	lCERs
1	**Year 1 (2013)**	NO	NO	NO	NO	NO	NO
2	**Year 2 (2014)**	NO	NO	NO	NO	NO	NO
3	**Year 3 (2015)**	NO	NO	NO	NO	NO	NO
4	**Year 4 (2016)**	NO	NO	NO	NO	NO	NO
5	**Year 5 (2017)**	NO	NO	NO	NO	NO	NO
6	**Year 6 (2018)**	NO	NO	NO	NO	NO	NO
7	**Year 7 (2019)**	NO	NO	NO	NO	NO	NO
8	**Year 8 (2020)**	NO	NO	NO	NO	NO	NO
9	**Year 2021**	NO	NO	NO	NO	NO	NO
10	**Year 2022**	NO	NO	NO	NO	NO	NO
11	**Year 2023**	NO	NO	NO	NO	NO	NO
12	**Total**	NO	NO	NO	NO	NO	NO

Party	Ireland
Submission Year	2018
Reported Year	2017
Commitment Period	2

Table 6a. Memo item: corrective transactions relating to additions and subtractions

Additions						Subtractions					
AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs

Table 6b. Memo item: corrective transactions relating to replacement

Expiry, cancellation and requirement to replace		Replacement					
tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs

Table 6c. Memo item: corrective transactions relating to retirement

Retirement					
AAUs	ERUs	RMUs	CERs	tCERs	lCERs

Annex 5.3

Greenhouse Gases GWP and IPCC Reporting Format

Table 5.3.1 Greenhouse Gases and GWP Values

Table 5.3.2 IPCC Reporting Format (Level 1 and Level 2)

Table 5.3.1 Greenhouse Gases and GWP Values

Greenhouse Gas	Chemical Formula	IPCC GWP (100-yr horizon)[a]
Carbon Dioxide	CO_2	1
Methane	CH_4	25
Nitrous Oxide	N_2O	298
Hydrofluorocarbons (HFCs)		
HFC-23	CHF_3	14800
HFC-32	CH_2F_2	675
HFC-41	CH_3F	92
HFC-43-10mee	$CF_3CHFCHFCF_2CF_3$	1640
HFC-125	CHF_2CF_3	3500
HFC-134	CHF_2CHF_2	1100
HFC-134a	CH_2FCF_3	1430
HFC-143	CH_2FCHF_2	353
HFC-143a	CH_3CF_3	4470
HFC-152	CH_2FCH_2F	53
HFC-152a	CH_3CHF_2	124
HFC-161	CH_3CH_2F	12
HFC-227ea	CF_3CHFCF_3	3220
HFC-236cb	$CH_2FCF_2CF_3$	1340
HFC-236ea	CHF_2CHFCF_3	1370
HFC-236fa	$CF_3CH_2CF_3$	9810
HFC-245ca	$CH_2FCF_2CHF_2$	693
HFC-245fa	$CHF_2CH_2CF_3$	1030
HFC-365mfc	$CH_3CF_2CH_2CF_3$	794
Perfluorocarbons		
PFC-14	CF_4	7,390
PFC-116	C_2F_6	12,200
PFC-218	C_3F_8	8,830
PFC-3-1-10	C_4F_{10}	8,860
PFC-318	$c\text{-}C_4F_8$	10,300
PFC-4-1-12	C_5F_{12}	9,160
PFC-5-1-14	C_6F_{14}	9,300
PFC-9-1-18	$C_{10}F_{18}$	>7,500
Perfluorocyclopropane	$c\text{-}C_3F_6$	>17,340
Sulphur Hexafluoride	SF_6	22,800
Nitrogen trifluoride	NF_3	17,200

(a) GWP (global warming potential) as provided by the IPCC in its Fourth Assessment Report (WG1 errata to Table 2.14)

Table 5.3.2 IPCC Reporting Format (Level 1 and Level 2)

IPCC SOURCE and SINK CATEGORIES	CO_2	CH_4	N_2O	HFC	PFC	SF_6	NF_3
1. Energy							
A. Fuel Combustion (Sectoral Approach)							
1. Energy Industries							
2. Manufacturing Industries and Construction							
3. Transport							
4. Other Sectors							
5. Other							
B. Fugitive Emissions from Fuels							
1. Solid Fuels							
2. Oil and Natural Gas							
C. Carbon Dioxide Transport and Storage							
2. Industrial Processes and Product Use							
A. Mineral Industry							
B. Chemical Industry							
C. Metal Production							
D. Non-Energy Products from Fuels and Solvent Use							
E. Electronic Industry							
F. Product Uses as Substitutes for ODS							
G. Other Product Manufacture and Use							
H. Other							
3. Agriculture							
A. Enteric Fermentation							
B. Manure Management							
C. Rice Cultivation							
D. Agricultural Soils							
E. Prescribed Burning of Savannas							
F. Field Burning of Agricultural Residues							
G. Liming							
H. Urea Application							
I. Other							
4. Land-Use Land-Use Change and Forestry							
A. Forest Land							
B. Cropland							
C. Grassland							
D. Wetland							
E. Settlements							
F. Other Land							
G. Harvested Wood Products							
H. Other							
5. Waste							
A. Solid Waste Disposal							
B. Biological Treatment of Solid Waste							
C. Waste Incineration and Open Burning of Waste							
D. Wastewater Treatment and Discharge							

E. Other							
6. Other							
Memo Items:							
International Bunkers							
Aviation							
Navigation							
Multilateral Operations							
CO_2 Emissions from Biomass							
CO_2 captured							
Long-term storage of C in waste disposal sites							
Indirect N_2O							
Indirect CO_2							

The grey cells indicate sources/sinks where no emissions/removals of the various gases are expected

Appendix 1
Standard Independent Assessment Report
(Electronic Appendix)

AN GHNÍOMHAIREACHT UM CHAOMHNÚ COMHSHAOIL
Tá an Ghníomhaireacht um Chaomhnú Comhshaoil (GCC) freagrach as an gcomhshaol a chaomhnú agus a fheabhsú mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaol 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 maithe comhshaoil a sholáthar agus chun díriú orthu siúd nach gcloíonn leis na córais sin.*

Eolas: *Soláthraímid sonraí, faisnéis agus measúnú comhshaoil atá ar ardchaighdeán, spriocdhírithe agus tráthúil chun bonn eolais a chur faoin gcinnteoireacht ar gach leibhéal.*

Tacaíocht: *Bímid ag saothrú i gcomhar le grúpaí eile chun tacú le comhshaol atá glan, táirgiúil agus cosanta go maith, agus le hiompar a chuirfidh le comhshaol inbhuanaithe.*

Ár bhFreagrachtaí

Ceadúnú

Déanaimid na gníomhaíochtaí seo a leanas a rialú ionas nach ndéanann siad dochar do shláinte an phobail ná don chomhshaol:

- saoráidí dramhaíola *(m.sh. láithreáin líonta talún, loisceoirí, stáisiúin aistrithe dramhaíola)*;
- gníomhaíochtaí tionsclaíocha ar scála mór *(m.sh. déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta)*;
- an diantalmhaíocht *(m.sh. muca, éanlaith)*;
- úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaithe *(OGM)*;
- foinsí radaíochta ianúcháin *(m.sh. trealamh x-gha agus radaiteiripe, foinsí tionsclaíocha)*;
- áiseanna móra stórála peitril;
- scardadh dramhuisce;
- gníomhaíochtaí dumpála ar farraige.

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 dhíriú 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 chomhshaol.

Bainistíocht Uisce

- Monatóireacht agus tuairisciú a dhéanamh ar cháilíocht aibhneacha, lochanna, uiscí idirchriosacha agus cósta na hÉireann, agus screamhuiscí; leibhéil 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 gComhshaol

- 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 tréimhsiúil ar staid Chomhshaol na hÉireann agus Tuarascálacha ar Tháscairí)*.

Rialú Astaíochtaí na nGás Ceaptha Teasa in Éirinn

- Fardail agus réamh-mheastacháin na hÉireann maidir le gáis cheaptha 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 shainaithint, 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 gcomhshaol in Éirinn *(m.sh. mórphleananna forbartha)*.

Cosaint Raideolaíoch

- Monatóireacht a dhéanamh ar leibhéil 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 gcomhshaol ar a bhfuil fáil éasca a chur ar fáil chun rannpháirtíocht an phobail a spreagadh sa chinnteoireacht i ndáil leis an gcomhshaol *(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 chosc agus a bhainistiú.

Múscailt Feasachta agus Athrú Iompraíochta

- Feasacht chomhshaoil 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 lánaimseartha, 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 imní agus le comhairle a chur ar an mBord.

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An Ghníomhaireacht um Chaomhnú Comhshaoil

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