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Air and energy accounts for Scotland

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1 Executive summary

This report details a study to produce a set of 'air and energy accounts' for Scotland for all years from 1998 to 2018, equivalent to ONS UK Environmental Accounts[1] tables on Emissions and Energy. The study has been commissioned by ClimateXChange (CXC) on behalf of the Scottish Government in support of its implementation of the policies and proposals within the current Climate Change Plan[2] published in 2018.

Purpose of the study

The Scottish Greenhouse Gas Inventory[3] is the key data source for understanding the origins and magnitudes of Scotland's emissions. The inventory is compiled in line with international guidance from the Intergovernmental Panel on Climate Change (IPCC). Data are reported by source sector and by greenhouse gas.

In the UK, businesses and industry are classified according to the nature of their economic activity. This Standard Industrial Classification[4] (SIC) provides a framework for the collection, presentation and analysis of economic data in a uniform manner.

A set of air and energy accounts provides the Scottish Government with information to more accurately monitor changes in emissions and energy use of sectors in relation to their economic output and employment. This will support the Scottish Government in the implementation of Scotland's Climate Change Plan. In particular, the outputs are intended to:

- Improve the Scottish Government's knowledge and understanding of how emissions and energy use have changed over time, by sector.
- Allow direct comparison of emissions and energy use with economic variables such as Gross Value Added (GVA), employment and turnover, by sector.

[1] https://www.ons.gov.uk/economy/environmentalaccounts/bulletins/ukenvironmentalaccounts/latest
[2] https://www.gov.scot/publications/scottish-governments-climate-change-plan-third-report-proposals-policies-2018/
[3] Latest statistics available for 1990-2018: https://www.gov.scot/publications/scottish-greenhouse-gas-emissions-2018/pages/2/
[4] https://www.ons.gov.uk/methodology/classificationsandstandards/ukstandardindustrialclassificationofeconomicactivities

- Enable more accurate tracking of targets and metrics such as industrial emissions intensity (ratio between emissions and economic output) and energy productivity (ratio between energy use and economic output), by sector.
- Improve estimation of environmental impacts of economic events – enabling improvements in environmental input-output analysis and understanding of the environmental impact of public-sector expenditure.

The accounts are presented in line with the Office of National Statistics Environmental Accounts which are produced annually.

Methodology

The key source for this study is the National Atmospheric Emissions Inventory (NAEI)[5], maintained by Ricardo Energy & Environment (Ricardo), which includes the Scottish Greenhouse Gas Inventory. For the purposes of Environmental Accounts, these data are adjusted to align with the residence principle, such that emissions are assigned to the country where the economic operator causing the emissions is resident (rather than being assigned to the country where the emissions take place). Emissions are then apportioned according to the SIC07 industrial classifications.

In many cases mapping the NAEI to industrial classifications is simple. However, in other cases NAEI sources relate to activity in several SIC codes, and the emissions must be split across the relevant industries.

The methodologies applied in air and energy accounts for Scotland largely parallel the UK Environmental Accounts. However, for some sectors with particular significance in Scotland improved methodologies have been developed:

- Better tracking of aviation and shipping sources related to the oil and gas industry has led to a higher estimate of emissions than if the UK Environmental Accounts methodology had been used.
- Emissions per unit of GVA for the Scottish crude petroleum, natural gas and metal ores industry is substantially higher than published figures[6] for the same industry in the UK. However, this is mostly due to the inclusion of 'Extra-Regio' GVA in the analysis of UK emission intensity, whereby economic activity that cannot be assigned to regions is assigned to this additional category and included in the total for the UK.
- To endeavour to match this scope, offshore rig emissions have been excluded from the Scottish Air & Energy Accounts, based on Environmental and Emissions Monitoring System (EEMS)[7] classifications. However, it is likely that the scope of these Accounts still does not fully align with ONS Scottish GVA statistics, and emissions and energy intensities are therefore not comparable with published UK Environmental Accounts tables. Comparing emissions and energy intensity on a like-by-like basis (i.e. excluding extra-regio GVA for the UK) reveals no significant difference between emission intensity in Scotland and the rest of the UK for this industry.
- Emissions from fishing vessels have been further disaggregated to distinguish between 'Fishing' and 'Aquaculture' based on Scottish fishing and marine statistics.

[5] https://naei.beis.gov.uk/
[6] https://www.ons.gov.uk/economy/environmentalaccounts/datasets/ukenvironmentalaccountsatmosphericemissionsgreenhousegasemissionsintensitybyeconomicsectorunitedkingdom
[7] https://www.gov.uk/guidance/oil-and-gas-eems-database

- Producers of spirits, wines and cider were distinguished from producers of beer and malt using site-specific data and judgements of the main economic activity of the business.
- Silviculture and Logging were also separated using models that are a part of the NAEI.

Results and conclusions

Significant differences in emissions per unit of GVA between Scotland and the UK were found in the crude petroleum, natural gas and metal ores sector. The measure has reduced from a 2009 high, but the industry has been around 1.5 and 2 times more emissions intensive in Scotland than the UK as a whole since 2012. Around 20% of the difference is expected to be due to improvements in methodology.

The coke, refined petroleum products and petrochemicals sector in Scotland has increased emissions per unit of GVA since 2006 while the same measure continued to decrease in the UK. The divergence is likely to be in part due to the closure of emissions intensive facilities in England and Wales resulting in Grangemouth in Scotland having a greater share of the UK's refining capacity.

Emissions intensity in the agriculture, hunting and related services sector has increased since 2007, and has been consistently higher than in the rest of the UK from then on. Since the closure of Scotland's coal-fired power stations, this has been the highest emitting sector by a significant margin.

Consumer expenditure travel and non-travel are the second and third highest emitting sectors, mostly due to cars, and domestic heating and hot water systems. Emissions per capita in Scotland do not differ significantly from the rest of the UK, and since 2016 have been lower in Scotland for both sectors.

In contrast to increases in these major sectors, the emissions intensity of the beverages and tobacco manufacturing industry has fallen dramatically from 2000, and is now lower than in the UK as a whole.

Further details on the results and conclusions of this study are set out in Sections 5 and 6 of this report.

Contents

2 Introduction

Air and energy accounts for Scotland have been produced covering the period 1998 to 2018. The emissions estimated are for the 7 major greenhouse gases, carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3). The energy accounts estimate the emission-relevant use of energy by combustion of renewable, waste and fossil fuels.

These accounts have been compiled and reported on a 'by source' basis whereby spatial and sectoral allocation is based on the location and SIC sector of the source of emission. The Scottish Greenhouse Gas Inventory is used as the basis of this work, however, there are also many emission sources that require additional information to link them to an industrial classification.

The data produced by this study provides an estimate of how emissions and energy use in Scotland have evolved over time, by economic sector. The emissions intensity, or 'emissions per unit of GVA', of each sector has been calculated in order to identify areas where economic output is strongly linked with emissions and where this differs from the same measures of the UK economy. The intention of this is to inform policy makers on the sustainable routes to decarbonisation.

This document sets out the principles and key findings of these air and energy accounts in context, and outlines the methodology developed for their creation. There are four Appendices which provide supplementary information and definitions to support the main text of the document.

3 Standards, concepts and definitions

3.1 UN System of Environmental Economic Accounts

The UN System of Environmental Economic Accounts[8] (SEEA) was adopted by the UN Statistical Commission as the first international standard for environmental-economic accounting in 2012, following a comprehensive global consultation process. The SEEA sits alongside the UN System of National Accounts (SNA) to provide a framework for producing internationally comparable statistics on the environment and its relationship with the economy.

The SEEA framework follows a similar accounting structure to the SNA and uses consistent concepts, definitions and classifications in order to facilitate the integration of environmental and economic statistics.

The SEEA says that:

'The intent in physical flow accounting is to record the physical flows underpinning the transactions recorded in the monetary supply and use tables, primarily with respect to goods, and to then extend the monetary supply and use table to record physical flows from the environment to the economy (such as flows of natural resources) and physical flows from the economy to the environment (such as emissions to air and water).'

UN SEEA 2012 Central Framework, Chapter 3

The air emissions accounts are concerned with the physical flows of emissions from the economy to air. These flows from the economy to the environment are termed residuals.

[8] https://seea.un.org/content/air-emissions-accounts

Air emissions are defined in the SEEA as 'gaseous and particulate substances released to the atmosphere by establishments and households as a result of production, consumption and accumulation processes'. The aim of the account is to record 'the generation of air emissions by resident economic units, by type of substance' in line with 'the scope and boundaries used in the compilation of the economic accounts'.

3.2 European Environmental Economic Accounts Regulation

The UK has been recording air emissions accounts and submitting them to Eurostat[9] for a number of years, initially on a voluntary basis, and more recently under the mandatory requirements. During 2011, a European Regulation on Environmental Economic Accounts was adopted by the European Parliament and European Council. The Regulation includes a module on Air Emissions Accounts, mandating delivery to Eurostat (European Statistical Agency) annually from September 2013.

The concepts and definitions in the Regulation are exactly in line with SEEA, and the breakdown of emissions is very similar, although there is not the requirement for the distinction between those emissions released direct to the environment and those captured and transferred to other economic units or stored. Neither is the separate identification of emissions from landfill sites.

However, in addition there is a requirement for 'bridging items' to be reported. These are the items which make transparent the differences between the environmental accounts measure and the United Nations Framework Convention on Climate Change (UNFCCC) and Convention on Long Range Transboundary Air Pollution (CLRTAP) measures.

3.3 Economic boundary with respect to air emissions - the Residence Principle

The residence principle is applied to the accounts in accordance with SEEA, in order to align as closely as possible with the scope of Scottish National Accounts. In theory, estimates compiled on a residency basis include only data relating to Scottish residents and Scotland-registered businesses, regardless of whether they are in the Scotland or overseas. Data relating to foreign visitors and foreign businesses in Scotland would be excluded.

However, in practice, data limitations mean that residence principle adjustments for many sources of emissions are not possible or too uncertain to be worthwhile. In these air and energy accounts, it was possible to adjust for two of the largest cross-boundary sources and the methodology for this is detailed in Section 1.

3.3.1 Other boundary issues

Inclusions and exclusions of specific sources are applied in line with SEEA, for example:

Exclusions

- Emissions which are released in one country and travel through the atmosphere to another – flow within the environment
- Emissions from land use, land use change and forestry (LULUCF), for example CO_2 captured by the environment in forests
- Respiratory emissions made by humans and animals, and from cultivated plants to the atmosphere

Included:

[9] https://ec.europa.eu/eurostat/web/environment/air-emissions

- CH_4 emissions from cultivated livestock due to digestion
- Flaring and venting from oil and gas extraction
- Emissions from manure collected and spread on agricultural land

3.4 Greenhouse gas emissions

Greenhouse gases are gaseous constituents of the atmosphere, both natural and produced by human activity, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere and clouds. This property causes the greenhouse effect. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the earth's atmosphere. Moreover, there are a number of entirely human-made greenhouse gases in the atmosphere, such as halocarbons and other chlorine and bromine-containing substances, covered by the Montreal Protocol[10]. Besides carbon dioxide, nitrous oxide and methane, the Kyoto Protocol[11] deals with the greenhouse gases sulphur hexafluoride, hydrofluorocarbons, and perfluorocarbons.

Global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years. There is growing consensus that this rise in greenhouse gas emissions has led to changes in the global atmosphere which have resulted in global warming.

The greenhouse gases included in the atmospheric emissions accounts are those covered by the Kyoto Protocol. These are carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3).

Further information on Greenhouse Gases can be found in Appendix 2 of this report and the glossary of the IPCC 4th Assessment Report[12].

4 Methodologies

4.1 Sources

Ricardo Energy & Environment (Ricardo) maintains the National Atmospheric Emissions Inventory (NAEI) on behalf of the Department for Business, Energy and Industrial Strategy (BEIS). As a part of this work, Ricardo also compiles an inventory for each of the devolved administrations including the Scottish Greenhouse Gas Inventory. The NAEI uses many data sources to estimate the activity data and emission factors of all relevant sources in the UK, which is then used to calculate the air emissions. This is the starting point for generating the air and energy accounts for Scotland.

The residence principle is then applied to these datasets thereby apportioning the emissions to an industrial classification based on SIC07. This complex industrial classification mapping methodology is outlined later in this document and the key data sources for this process identified in Appendix 4.

[10] https://www.unenvironment.org/ozonaction/who-we-are/about-montreal-protocol
[11] https://unfccc.int/kyoto_protocol
[12] https://www.ipcc.ch/site/assets/uploads/2018/02/AR5_SYR_FINAL_Annexes.pdf

4.2 Classifications

The industrial classification system used is the UK Standard Industrial Classification of Economic Activities 2007 (SIC07), however as detailed in the terms of reference for this project the results of the study are presented using the Input-Output Classification (IOC) used in the Supply, Use and Input-Output Tables of Scotland's economic statistics. This classification is used to create statistics consistent with the Scottish National Accounts.

The IOC maps directly to SIC07 and the two are identical at section level but differ at subsection level, where the IOC combines some SIC07 groups. Details of the groupings can be found in Appendix 3.

4.3 Geography

The geographical coverage of the air emissions accounts is Scotland. There is no regional or spatial breakdown.

4.4 Allocating emissions to industries and households

Emissions estimates for pollutant releases from sources in the UK are estimated by combining an activity statistic with an emission factor, and the NAEI compiles estimates of emissions from a wide range of sources in this way. The same activity data is commonly used to calculate emissions of many pollutants for a specific source. This is done by applying different emission factors to the activity statistic, and this approach can be used to estimate emissions for relevant air quality pollutants and greenhouse gases using the same activity metric.

A source is defined as a process, equipment or substance that leads to air emissions. These NAEI sources are chiefly defined according to framework set out by the IPCC and UNECE, as well as by:

- Other requirements for output data and inventory guidance such as that produced by European air quality inventory guidelines;
- The structure of national energy statistics (largely BEIS's annual publication of the Digest of UK Energy Statistics[13], DUKES);
- The classifications of industrial activities used for regulatory regimes such as Integrated Pollution Prevention & Control (IPPC) and Local Authority Pollution Control (LAPC);
- The structure of industrial sectors as perceived by industry representatives (e.g. through the provision of data by industry for defined subsectors which must then be replicated in the NAEI).
- The structure of other data sets, such as UK production statistics etc.

The sources can also be representative of the limits of the raw data upon which the inventory compilation is based.

These NAEI source categories are not based on a coding structure such as the Standard Industrial Classification (SIC), and a mapping procedure is thus required to make a link between source category and SIC, with the final step being to combine SIC groups to produce results in IOC format.

The definitions are such that many of the NAEI sources can be mapped directly to a SIC07 classification through a one-to-one relationship, where a single NAEI source is judged as being equivalent to a single SIC07 classification. An example of this is the

[13] https://www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes

source activity combination that relates to gas oil used in freight trains, which can be fully attributed to the SIC07 code corresponding to the rail transport industry.

In some other cases NAEI sources can be linked to several SIC classifications through one-to-many relationships. Here, the 'activity' and consequent emissions from that source must be split to each of the relevant SIC07 codes either directly, according to their proportionate level of activity, or indirectly. A significant part of the air emissions and energy accounts work carried out by Ricardo is in determining what proportions the emissions and fuel use by these sources should be split across the SIC divisions that span the economy. The methodology to do this is sometimes necessarily complex, and varies depending on the source category.

In principle, estimates for the emissions of each industry are made on the basis of which industry is the primary emitter and which industry owns the unit creating the emissions. For example, if a retailer owns a fleet of trucks that deliver stock to its stores, the emissions from those trucks would go to the retail industry. However, if the retailer hires a separate freight company to deliver its goods, the emissions would go to the road freight industry. The full list of industries that data is published for are listed in Appendix 3.

4.4.1 Point source emissions

For many sources, site-specific emissions data are compiled for the UK inventory from various datasets such as the Scottish Pollutant Release Inventory[14] (SPRI), EU Emissions Trading Scheme[15] (EU ETS) and Environmental and Emissions Monitoring System[16] (EEMS). The compiled point source emissions dataset includes emissions for 226 sites in Scotland from 2005 onwards.

These installations have been individually allocated to SIC07 categories consistent with the IOC98 classification, based on the primary economic activity of each installation, to NAEI source/activity combinations consistent with the structure of the Scottish GHGI, and to LAD19 Local Authority boundaries.

Where emissions from point sources do not comprise the total emissions at source/activity level in the Scottish GHGI, the residual non-points emissions are calculated and allocated to SIC07 using the source-specific 'area source' methodology as outlined below.

4.4.2 Road transport - cars

Road transport is a common activity throughout the economy, and the emissions calculated for this source are thus split over all the SIC07 sectors that represent industry, commerce and public administration, as well as to households. The levels of activity, and therefore emissions the activity is responsible for, vary significantly between these SIC07 sectors and so data is required to estimate the proportion that should be attributed to each sector.

In order to split these emissions the Scottish Household Survey is first used to indicate the proportion of car use that is for domestic purposes, which is allocated to supplementary subsection 101 'Consumer expenditure – travel'.

The proportion of activity in subsection 49.32 'Taxi operation' is then estimated based on numbers of licenced taxis & PHVs from Scottish Transport Statistics, and average annual mileage for Taxis across the UK as a whole from the UK Department for Transport. The remaining activity is split between all other SIC07 sectors using data from

[14] https://www.sepa.org.uk/environment/environmental-data/spri/
[15] https://www.eea.europa.eu/data-and-maps/data/european-union-emissions-trading-scheme-14
[16] https://www.gov.uk/guidance/oil-and-gas-eems-database

the UK Environmental Accounts methodology for road transport. This is then adjusted to better reflect the Scottish economy using relative levels of employment by SIC07 sector from ONS employment surveys. For example across the UK as a whole in 2018 APS indicates around 0.35% of industry petrol purchases are by business classed under SIC07 as 'Manufacture of alcoholic beverages'. UK employment in this sector represents 0.07% of total employment in 2018, however in Scotland this sector accounts for 0.47%. The APS proportion for the UK is therefore scaled up to represent the increased significance of this sector in Scotland. Following renormalisation across all sectors, this industry is calculated to account for 1.56% of petrol purchases by business in Scotland.

4.4.3 Coastal shipping

Data from the UK Inventory shipping emissions model[17], disaggregated by country and vessel type, has been used to estimate emissions from fishing vessels, and vessels operated by or for the oil and gas industry. Vessels types are allocated to SIC07 as follows:

SIC07 Subsection	Vessel type
03: Fishing and aquaculture	Miscellaneous – fishing
06: Extraction of crude petroleum and natural gas	Liquefied gas tanker
	Offshore
	Oil tanker
50: Water transport	Bulk carrier
	Chemical tanker
	Container
	Cruise
	Ferry-pax only
	General cargo
	Miscellaneous – other
	Refrigerated bulk
	Ro-Ro
	Service - other
	Service - tug

4.4.4 Fishing

Emissions from fishing vessels have further been disaggregated to subsections 03.1 'Fishing' and 03.2 'Aquaculture' based on production and landings data from Scottish Sea Fisheries Statistics, Aquaculture Scotland and Marine Economic Statistics from Scottish Government.

No data was identified to establish the relative fuel consumption per unit of production in each sector, for example average trip lengths by aquaculture vessels, so it has been approximated that this is equal in both sectors.

4.4.5 Power stations

Point source emissions comprise over 99% of emissions from power stations in Scotland. Installations are allocated based on their primary fuel to one of 5 subcategories of SIC07 subsection 35.1.

Subsection	Name
35.1/1	Electricity production – gas
35.1/2	Electricity production – coal
35.1/3	Electricity production – nuclear
35.1/4	Electricity production – oil
35.1/5	Electricity production – other

[17] https://naei.beis.gov.uk/reports/reports?report_id=950

Residual emissions are allocated based on the 'other sources' methodology outlined in Section 4.4.9 below.

4.4.6 Public sector combustion

Fuel use in this sector is for heating, hot water and catering for the public sector. Emissions from coal and natural gas combustion are split between the relevant subsections 84-88 based on data from the Scottish Government Input-Output 'combined use' table[18]. Supply from subsections 05 'Coal' and 35.2-3 'Gas etc' are assumed to be good proxies for the relative levels of coal/coke and natural gas consumption respectively in public sector combustion.

4.4.7 Autogeneration using biogas from anaerobic digestion

This source represents the generation of electricity by combustion of gas produced from anaerobic digestion plants, for which a directory of installations is available from The Official Information Portal on Anaerobic Digestion (www.biogas-info.co.uk). These installations have been classified by SIC07 subsection for the purpose of this split, and emissions apportioned on the basis of plant capacity.

4.4.8 Railways stationary combustion

This source includes fuel use by rail companies, other than for office buildings or fuelling trains. Emissions are split between subsection group 49.1-2 'Rail transport services' and 49.3-5 which includes tubes and trams subsections 49.31/9/2 and 49.39.

The proportion of emissions allocated to each sector is based on the relative number of station buildings operated for the overground and underground rail networks in Scotland.

4.4.9 Other sources

For all remaining sources, a hybrid approach is followed whereby emissions at local authority level, sourced from the NAEI emission maps[19], are split to SIC07 sectors using proportions from the UK Environmental Accounts, and then adjusted by employment at the local authority level to best represent the local economy. Emissions for all sectors from all local authorities are then recombined and reconciled to Scottish GHGI totals for Scotland at source, activity and pollutant level.

For example CO_2 emissions from gas oil use in off-road machinery in the forestry sector (SIC07 subsection 02) in Dumfries and Galloway are calculated as follows:

- NAEI maps indicate 124 kilotonnes (kt) CO_2 from gas oil use in off-road machinery in all sectors in Dumfries and Galloway.
- Across the UK as whole 0.2% of this source is allocated to the forestry sector.
- Employment in the forestry sector is 0.05% of total employment in the UK
- In Dumfries and Galloway this sector accounts for 0.7% of total employment.
- The 0.2% UK split for this source is therefore scaled up by the ratio of employment (i.e. 0.7÷0.05) to be more representative of the local economy in Dumfries and Galloway.
- This approach is carried out for all sectors across all Scottish local authorities, and then reconciled to the Scottish GHGI total CO_2 emissions from gas oil use in off-road machinery.

CO_2 emissions in the forestry sector from this source in Dumfries and Galloway are therefore calculated to be 1.7 kt, as opposed to the 0.5 kt suggested by the UK split.

[18] https://www.gov.scot/publications/input-output-latest/
[19] https://naei.beis.gov.uk/emissionsapp/

Total CO_2 emissions across Scotland in the forestry sector from this source are calculated to be 5.2 kt, as opposed to 2.8 kt suggested by the UK split.

This approach assumes that average fuel consumption per employee is similar across the UK in each SIC07 sector. That is, that the best guide to expected fuel activity of an employee is provided by fuel consumption of employees in the same sector in other local authorities, rather than by fuel consumption of employees in other sectors in the same local authorities.

4.5 Cross-boundary emissions

As already discussed, the air and energy accounts are prepared on a residence basis.

In principle Environmental Accounts would include all emissions caused by residents travelling abroad and exclude any emissions caused by foreign residents travelling in Scotland. In practice this is not always possible with available data, therefore adjustments for residents and non-residents are made for cross-border travel by cars, coaches and lorries and foreign and domestic international air, shipping and fishing activity.

Adjustments are not made for emissions that non-residents make within the territory or residents make outside the territory, from public transport use, electricity use or that are from cars that do not cross the border such as those that are rented at their destination. Emissions embedded in the import and export of goods are also not accounted for. This follows the methodology approach set out in UNSEEA guidelines.

For most sources, data is not available to estimate cross-boundary adjustments for Scotland with the rest of the UK, in these cases the cross-boundary adjustments for the UK are apportioned to Scotland based on the relative significance of the relevant emissions sources in Scotland. The exceptions to this are aviation, for which flights by airlines economically resident in Scotland have been separately estimated, and heavy goods vehicles (HGVs), for which fuel consumption by Scottish registered vehicles has been estimated.

4.5.1 Aviation

Emissions from flights to and from all Scottish airports have been estimated from NAEI and CAA data, disaggregated by NAEI source classification (i.e. fuel and territorial classification of destination) and airline operator, for all years from 1998-2018.

For UK airlines, publicly available data for UK airports was used to assign airlines to airport pairs. Routes operated by non-UK airlines were assigned to non-UK. In some cases it was not possible to assign all routes to a single UK airline or entirely to non-UK airlines, for example if more than one UK airline operated the same route or if both UK and non-UK airlines operated the same route. In these cases the types of aircraft used on the routes were first assessed in order to match them to those operated by UK airlines. If this was not possible, the assumption was made that the flights are shared evenly between airlines that operate the route. Finally, a renormalisation was applied to ensure that the number of flight by UK airlines tally with the published CAA statistics of UK airline data.

For the purposes of these air and energy Accounts for Scotland, it has been assumed that the following airlines are economically resident in Scotland:

- Loganair Ltd
- Hebridean Air Services
- Caledonian Airways
- Highland Airways Ltd

In addition, flights to and from offshore oil and gas rigs have been separately identified. These have been assumed to be entirely by Scottish resident economic units, and allocated to SIC07 subsection 06 'Extraction of crude petroleum and natural gas'.

This approach reduces aviation emissions allocated to Scotland by around 95% across all years, with the greatest impact on SIC07 subsection 51 'Air transport'. The methodology does not include emissions from these airlines on routes where neither the origin nor destination airport are in Scotland, and is therefore likely to underestimate emissions. However, it is considered that this is unlikely to substantively affect the nature or general magnitude of the net result.

4.5.2 Heavy Goods Vehicles

UK emissions from Heavy Goods vehicles have been spatially distributed using number of vehicles licenced, rather than by traffic counts as for other road transport sources. This is based on the understanding that due to the much longer average trip length of HGVs, the location of registration is likely to be a better guide to residence basis emissions than the emissions from vehicles at any particular location.

No information was identified to assess differences in activity per licenced vehicle between UK and Scotland, so this estimate necessarily makes the approximation that average activity per vehicle is equal in Scotland and the rest of the UK. For this reason, this approach is not deemed suitable for other vehicle types, for which the location of emissions is expected to be a better guide to residence basis emissions, due to much lower average trip lengths.

This difference in approach for HGVs results in estimates of HGV emissions for Scotland which are around 20% lower across the time series, primarily impacting on SIC07 subsection 49.3-5 'Land transport services and transport services via pipelines, excluding rail transport'.

4.6 Energy

Energy estimates are derived from the activity data underlying the emission estimates, converting from mass to energy units where necessary based on year-dependant gross calorific values, primarily sourced from BEIS DUKES table A.2. These estimates therefore include only emission-relevant energy use, and exclude for example electricity consumption. Estimates are presented in units of kilotonnes oil equivalent (ktoe) consistent with UK Environmental Accounts, and gigawatt-hours (GWh) consistent with Energy Balance for Scotland. Energy intensity is presented in units of GWh per million pounds GVA chained volume measures in 2016 money value.

5 Results

5.1 Greenhouse gas emissions

Figure 1 shows the 10 sectors with the highest total greenhouse gas emissions over the time period. The emissions of different gases are made comparable by calculating their global warming potential, expressed in 'kilotonnes of carbon dioxide equivalent' (more information about the global warming potential of a gas compared to its weight can be found in Appendix 2). The legend is arranged in descending order from left to right.

Electricity generation from coal has seen by far the largest fall in emissions of any of the sectors since 1998. Electricity generation from gas declined by 89% between 1998 and 2015, but emissions have more than tripled since then and coincide with the closure of

coal power stations. Electricity production from other fuels has seen the largest increase in emissions of any sector over the time series, highlighting that not all fuel switching away from coal has been to emissions free sources.

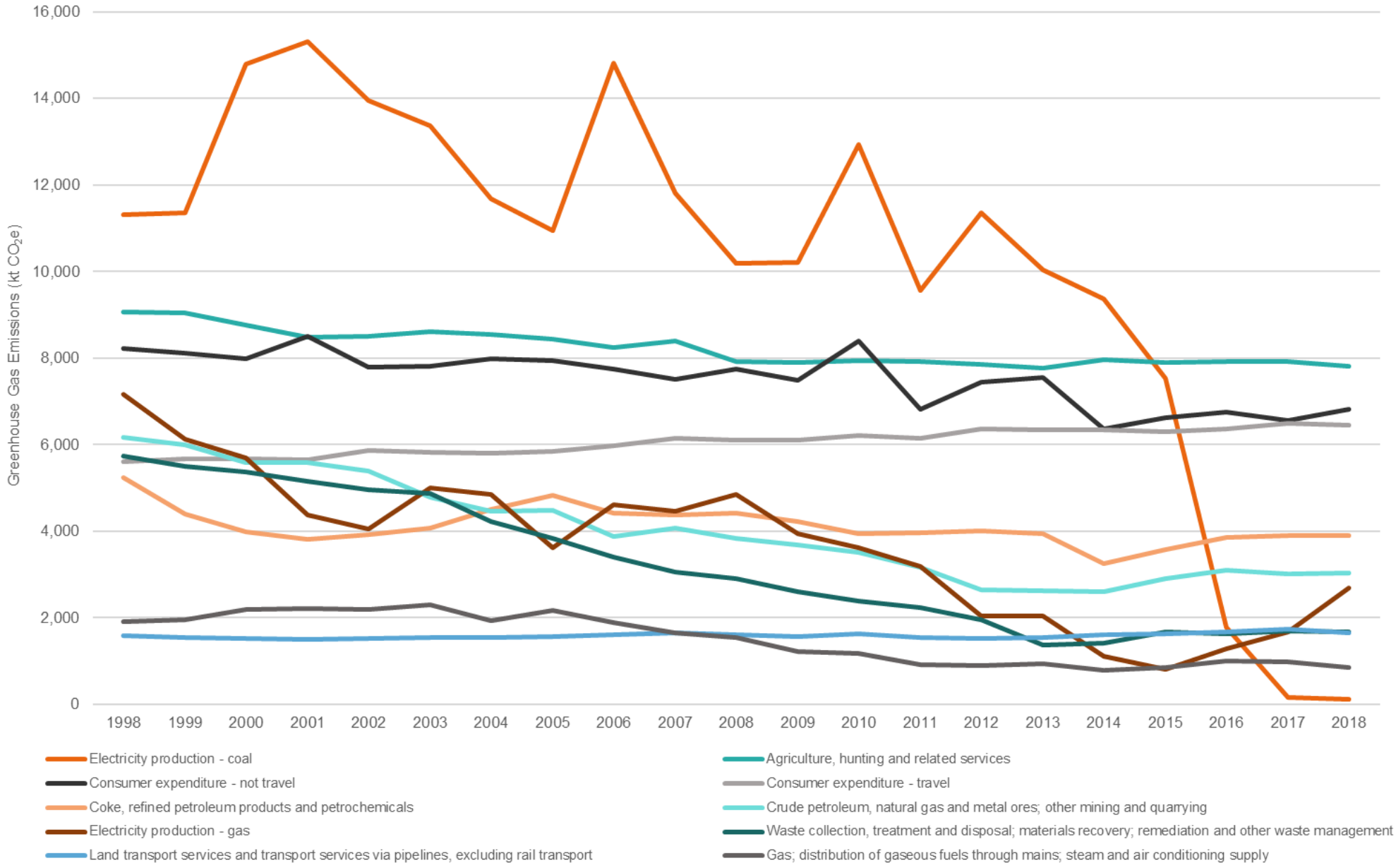
Agriculture, hunting and related services emissions declined slowly until 2008 but have remained stable since. The sector dominates Scotland's emissions of nitrous oxide, a highly potent greenhouse gas. The sector has also come to dominate Scotland's methane emissions, as the waste management sector has reduced its methane emissions by 76% between 1998 and 2018.

'Consumer expenditure – travel' recorded the second largest increase of any sector since 1998, likely due to the increase in the number and size of cars. 'Consumer expenditure - not-travel' declined by the fifth largest quantity over the same period, likely due to improvements in the efficiency of domestic combustion activities and home insulation.

Emissions from the coke, refined petroleum products and petrochemicals sector have followed multi-year trends of increases and decreases until reaching a plateau in 2010. Excluding a low in 2014 and recovery in 2015, emissions have remained relatively stable between 2010 and 2018.

The sector combining crude petroleum, natural gas, metal ores and other mining and quarrying reduced emissions by 58% between 1998 and 2014. Emissions increased 18% in the following two years but have remained stable since 2016.

Figure 1: Top 10 Highest emitting sector



5.2 Emissions intensity

Emissions intensity is the quantity of emissions produced per unit of a specific activity. In this study, emissions intensity refers to the quantity of greenhouse gas emitted per million pounds of gross value added (GVA). The statistic has been calculated annually and Figure 2 shows the 8 sectors with the highest mean emissions intensity between 1998 and 2018.

GVA was chosen as the measure of economic output in order to be comparable to the UK Environmental Accounts. However, SICs in the GVA data are grouped into a smaller number of categories than in the emission data. This has led to less detail and different names of sectors in this section of the report as compared to Section 135 above.

‘Mining and quarrying, excluding support activities’ is dominated by crude petroleum, natural gas, metal ores and other mining and quarrying. Emissions from this sector decreased steadily between 1998 and 2012, meaning the extreme fluctuations in emissions intensity are due to changes in GVA. This sector appears as the most emission intensive sector, however, this is largely due to the exclusion of Extra-Regio GVA, which comprises the vast majority of GVA in this sector. Emission intensity in this sector is not therefore directly comparable with other sectors.

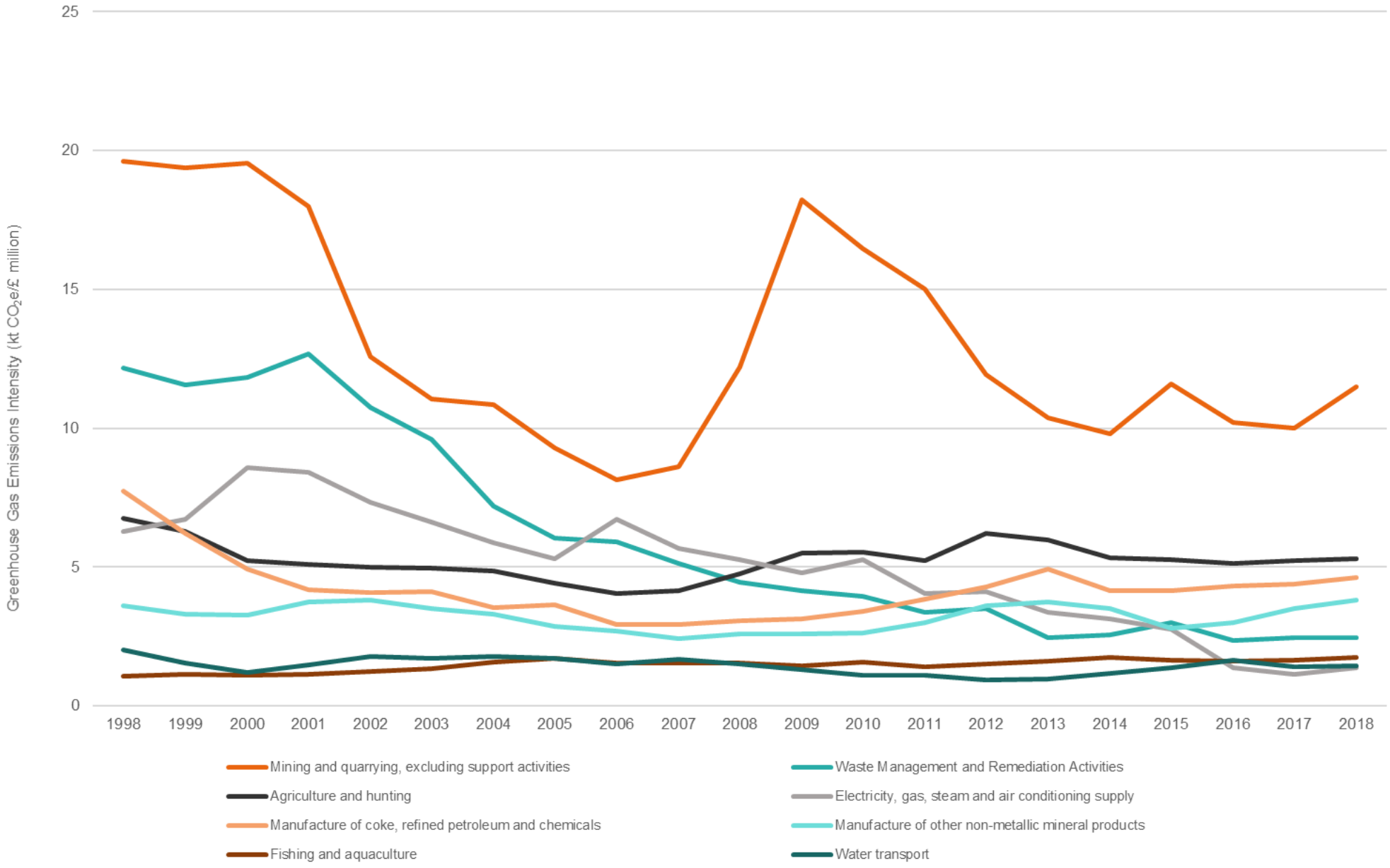
Waste and remediation activities are 80% less emissions intensive in 2018 compared to 1998, driven by reducing emissions. Similarly, the closure of coal fired power stations has caused the emissions intensity of electricity, gas, steam and air conditioning supply to fall by 84% from its peak in 2000.

The emissions intensity of the agriculture and hunting sector has increased from a low in 2006 due to a decrease in GVA. Though emissions have remained stable since 2008, this sector now has the highest emissions and second highest emissions intensity of any sector.

Manufacture of coke, refined petroleum and chemicals is another large sector that follows a similar pattern. Emissions have remained relatively stable while GVA declined between 2010 and 2018, causing emissions intensity to increase by 36%.

Sectors dependent on boat movements appear to be more emissions intensive than most. The emissions intensity of water transport services has not changed dramatically between 1998 and 2018 while emissions have decreased 58%. Fishing and aquaculture emissions have remained stable while emissions intensity has increased 65%.

Figure 2: Top 8 Most emissions intensive sectors



6 Conclusion

Electricity production from coal was the largest emitting sector for all years before 2015 but has fallen to negligible levels since the closure of Longannet in 2016. Generation has since switched to lower emitting sources, particularly non-thermal renewables; around 60% of the UK's electricity from onshore wind is generated in Scotland[20]. However, generation from primarily gas fired power stations has increased from the 2015 low to be the sixth largest emitting sector in 2018.

The rapid decrease in emissions from coal fired power stations caused 'Agriculture, hunting and related services' to become the highest emitting sector from 2015 onwards, despite a slow decline in emissions over the time series. Agriculture has also come to dominate Scotland's methane emissions as waste management services have been increasingly successful in capturing methane at landfills. The emissions intensity of the agriculture industry in Scotland has been markedly higher than in the rest of the UK since the significant decline in GVA from this sector in 2008.

Consumer expenditure travel and non-travel have been interchangeable as the second and third highest emitting sectors in the recent years of this analysis, mostly due to cars and domestic combustion respectively. Emissions per capita in Scotland do not differ significantly from the rest of the UK, and since 2016 have been lower in Scotland for both sectors.

The coke, refined petroleum products and petrochemicals sector reduced emissions between 1998 and 2010 but, excluding lows in 2014 and 2015, has remained stable since. The sector is therefore responsible for an increasing proportion of Scotland's total emissions which contrasts with the UK as whole, where the sector's share is decreasing. The trend corresponds with the closure of a number of large refineries in England and Wales resulting in Grangemouth in Scotland accounting for an increasing share of the UK's refining capacity. However, this does not explain changes in emissions intensity, where emissions per unit of GVA have reduced elsewhere in the UK but have been increasing in Scotland since 2006.

The emissions from Scottish crude petroleum, natural gas and metal ores industries halved between 1998 and 2012 but subsequently increased to be the fifth highest emitting sector in 2018. The change is partly due to new methodologies for estimating aviation and shipping contributions for Scotland which have not been employed for the UK Environmental Accounts, as outlined above.

Production of spirits, wines and ciders makes up a higher proportion of total emissions in Scotland than it does in the UK. Whisky distilleries dominate the GVA from the beverage and tobacco manufacturing sector in Scotland, while the manufacture of beer and soft drinks plays a greater role in the UK as a whole[21]. This difference in balance, combined with the greater value of whisky products, may be a driver behind the lower emissions intensity of this sector in Scotland compared with the UK.

[20] Regional Renewable Statistics: www.gov.uk/government/statistics/regional-renewable-statistics
[21] Non-financial business economy, UK (Annual Business Survey): https://www.ons.gov.uk/businessindustryandtrade/business/businessservices/bulletins/uknonfinancialbusinesseconomy/2017provisionalresults/relateddata

7 Appendices

Appendix 1: Glossary of terms and acronyms

Appendix 2: Description of greenhouse gases

Appendix 3: Classification of the 98 input-output industry/product groups by SIC07

Appendix 4: List of key data sources

Appendix 1: Glossary of terms and acronyms

Term	Definition
Activity	A quantitative representation of the variable which explains the emissions in a source category. For example, measures such as the energy content in GJ of fuels used in combustion processes, kilotonnes of solvents used in painting or other coating processes, or the distance in km driven by cars.
BEIS	Department for Business, Energy and Industrial Strategy
COICOP	Classifications of Individual Consumption According to Purpose
DECC	Department for Energy and Climate Change
Defra	Department of Environment, Food and Rural Affairs
Emissions intensity	Emissions per unit of economic output i.e. GDP
Kyoto Protocol	International agreement regarding reductions in greenhouse gas emissions
NAEI	National Atmospheric Emissions Inventory – Estimates of emissions to the atmosphere from anthropogenic and natural sources in the UK and Gibraltar
GHGI	Greenhouse Gas Inventory – Emission estimates for the 6 greenhouse gases and 10 UK territories specified under the UNFCCC and Kyoto Protocol
SEEA	System of Environmental Economic Accounts – Internationally agreed system of measuring air emissions on a national accounts basis
SIC	Standard Industrial Classification. A full listing is in Appendix 3
SNA	System of National Accounts
Source	Processes, equipment or substances that lead to emissions to the atmosphere
UNECE	United Nations Economic Convention for Europe
UNFCCC	United Nations Framework Convention on Climate Change

Appendix 2: Description of greenhouse gases

'Changes in the atmospheric abundance of greenhouse gases and aerosols, in solar radiation and in land surface properties alter the energy balance of the climate system. […] Global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years.'

IPCC Fourth Assessment Report

The greenhouse gases included in the atmospheric emissions accounts are those covered by the Kyoto Protocol: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3).

Definitions can be found in the glossary of the Synthesis Report of the IPCC Fourth Assessment Report

Carbon dioxide (CO_2) emissions come from a wide variety of natural and anthropogenic sources, however the global increases in carbon dioxide concentration are due primarily to fossil fuel use and land use change. It is also produced in some industrial processes such as the manufacture of cement. Carbon dioxide is a long-lived gas remaining in the atmosphere for between 50 and 200 years. It is the most important anthropogenic greenhouse gas.

Methane (CH_4) is mainly produced when organic matter is broken down in the absence of oxygen. Large quantities are produced by enteric fermentation in cattle and sheep, by the spreading of animal manure and from organic waste deposited in landfill sites. Methane is also emitted in coal mining, oil and gas extraction and gas distribution activities. Methane is a significant greenhouse gas.

Nitrous oxide (N_2O) is released in a few industrial processes and from the soil when nitrogenous fertilisers are applied in agriculture and horticulture. These are the main anthropogenic sources. It is a long-lived pollutant, lasting about 120 years in the atmosphere and is a potent greenhouse gas.

Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6) are artificial fluids that contain chlorine and/or fluorine. Because of their low reactivity and non-toxicity, they were widely used as refrigerants, foam blowing agents, aerosol propellants and solvents.

Nitrogen trifluoride (NF_3) is the most recent addition to GHGs which are reported under the Kyoto protocol. It is most readily released through the production of LCDs and solar cells.

To aggregate the greenhouse gases covered in the accounts, a weighting based on the relative global warming potential (GWP) of each of the gases is applied, using the effect of CO_2 over a 100 year period as a reference. This gives methane a weight of 25 relative to CO_2 and nitrous oxide a weight of 298 relative to CO_2. SF6 has a GWP of 23,900 relative to CO_2. The GWP of the other fluorinated compounds varies according to the individual gas.

Greenhouse gas emissions are sometimes shown in terms of carbon equivalent rather than CO_2 equivalent. To convert from CO_2 equivalent to carbon equivalent it is necessary to multiply by 12/44.

Appendix 3: Classification of the 98 input-output industry/product groups by SIC07

SIC07 Section		Input-Output Classification (SIC2007)		Std. Industrial Classification of Economic Activities 2007					
Agriculture, forestry and fishing	**A**	01	Agriculture, hunting and related services	01					
		02.1, 02.4	Silviculture and other forestry activities and support services	02.1	02.4				
		02.2-3	Logging and gathering	02.2	02.3				
		03.1	Marine and freshwater fishing	03.1					
		03.2	Marine and freshwater aquaculture	03.2					
Mining and quarrying	**B**	05	Coal and lignite	05					
		06-08	Crude petroleum, natural gas and metal ores; other mining and quarrying	06	07	08			
		09	Mining support services	09					
Manufacturing	**C**	10.1	Preserved meat and meat products	10.1					
		10.2-3	Processed and preserved fish, crustaceans, molluscs, fruit and vegetables	10.2	10.3				
		10.4-5	Dairy products, vegetable and animal oils and fats	10.4	10.5				
		10.6	Grain mill products, starches and starch products	10.6					
		10.7	Bakery and farinaceous products	10.7					
		10.8	Other food products	10.8					
		10.9	Prepared animal feeds	10.9					
		11.01-04	Alcoholic beverages - spirits, wines and cider	11.01	11.02	11.03	11.04		
		11.05-06	Alcoholic beverages - beer and malt	11.05	11.06				
		11.07	Soft drinks	11.07					
		12	Tobacco products	12					
		13	Textiles	13					
		14	Wearing apparel	14					
		15	Leather and related products	15					
		16	Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials	16					
		17	Paper and paper products	17					
		18	Printing and recording services	18					
		19, 20B	Coke, refined petroleum products and petrochemicals	19	20.14	20.16	20.17	20.6	
		20.3	Paints, varnishes and similar coatings, printing ink and mastics	20.3					
		20.4	Soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations	20.4					
		20.5	Other chemical products	20.5					
		20AC	Industrial gases, inorganic chemicals, fertilisers, dyestuffs and agrochemicals	20.11	20.12	20.13	20.15	20.2	
		21	Basic pharmaceutical products and pharmaceutical preparations	21					
		22	Rubber and plastic products	22					
		23.5-6	Manufacture of cement, lime, plaster and articles of concrete, cement and plaster	23.5	23.6				
		23OTHER	Glass, refractory, clay, other porcelain and ceramic, stone and abrasive products	23.1	23.2	23.3	23.4	23.7	23.9
		24.1-3	Basic iron and steel	24.1	24.2	24.3			
		24.4-5	Other basic metals and casting	24.4	24.5				
		25	Fabricated metal products, including weapons and ammunition	25					
		26	Computer, electronic and optical products	26					
		27	Electrical equipment	27					
		28	Machinery and equipment not elsewhere classified	28					
		29	Motor vehicles, trailers and semi-trailers	29					
		30	Other transport equipment	30					
		31	Furniture	31					
		32	Other manufactured goods	32					
		33	Repair and installation of machinery and equipment	33					
Electricity, Gas, Steam and Air Conditioning supply	**D**	35.1	Electricity; generation, transmission, distribution and trade	35.1					
		35.2-3	Gas; distribution of gaseous fuels through mains; steam and air conditioning supply	35.2	35.3				
Water Supply, Sewerage, Waste Management and Remediation	**E**	36, 37	Natural water treatment and supply services, sewerage services	36	37				
		38, 39	Waste collection, treatment and disposal; materials recovery; remediation and other waste management	38	39				
Construction	**F**	41-43	Construction	41	42	43			
Wholesale and Retail Trade; Repair of Motor Vehicles and Motorcycles	**G**	45	Wholesale and retail trade and repair services of motor vehicles and motorcycles	45					
		46	Wholesale trade services, except of motor vehicles and motorcycles	46					
		47	Retail trade services, except of motor vehicles and motorcycles	47					
Transportation and Storage	**H**	49.1-2	Rail transport services	49.1	49.2				
		49.3-5	Land transport services and transport services via pipelines, excluding rail transport	49.3	49.4	49.5			
		50	Water transport services	50					
		51	Air transport services	51					
		52	Warehousing and support services for transportation	52					
		53	Postal and courier services	53					
Accommodation and Food Service activities	**I**	55	Accommodation services	55					
		56	Food and beverage serving services	56					
Information and Communication	**J**	58	Publishing services	58					
		59 & 60	Motion picture, video and TV programme production services, sound recording & music publishing; Programming	59	60				
		61	Telecommunications services	61					
		62	Computer programming, consultancy and related services	62					
		63	Information services	63					
Financial and Insurance activities	**K**	64	Financial services, except insurance and pension funding	64					
		65	Insurance, reinsurance and pension funding services, except compulsory social security and pension funding	65					
		66	Services auxiliary to financial services and insurance services	66					
Real Estate activities	**L**	68.1-2	Real estate services, excluding on a fee or contract basis and imputed rent	68.1	68.2				
		68.2IMP	Imputed rent services	-					
		68.3	Real estate activities on a fee or contract basis	68.3					
Professional, Scientific and Technical activities	**M**	69.1	Legal services	69.1					
		69.2	Accounting, bookkeeping and auditing services; tax consulting services	69.2					
		70	Services of head offices; management consulting services	70					
		71	Architectural and engineering services; technical testing and analysis services	71					
		72	Scientific research and development services	72					
		73	Advertising and market research services	73					
		74	Other professional, scientific and technical services	74					
		75	Veterinary services	75					
Administrative and Support Service activities	**N**	77	Rental and leasing services	77					
		78	Employment services	78					
		79	Travel agency, tour operator and other reservation services and related services	79					
		80	Security and investigation services	80					
		81	Services to buildings and landscape	81					
		82	Office administrative, office support and other business support services	82					
Public Administration and Defence	**O**	84	Public administration and defence services; compulsory social security services	84					
Education	**P**	85	Education services	85					
Human Health and Social Work activities	**Q**	86	Human health services	86					
		87, 88	Residential care services; Social work services without accommodation	87	88				
Arts, Entertainment and Recreation	**R**	90	Creative, arts and entertainment services	90					
		91	Libraries, archives, museums and other cultural services	91					
		92	Gambling and betting services	92					
		93	Sports services and amusement and recreation services	93					
Other Service activities	**S**	94	Services furnished by membership organisations	94					
		95	Repair services of computers and personal and household goods	95					
		96	Other personal services	96					
Activities of Households	**T**	97	Services of households as employers of domestic personnel	97					

Appendix 4: List of key data sources

Data Source	Purpose
Business Register and Employment Survey/Annual Business Inquiry	Number of employees used to indicate the size of industrial sectors within each local authority
Civil Aviation Authority	Air mileage used to apportion air travel emissions to industries
Digest of UK Energy Statistics	Fuel consumption statistics used to apportion emission associated with energy production to industries
Maritime and Coastguard Agency	Ship movement and identification data used to apportion shipping emissions to industries
Office for National Statistics	UK Environmental Accounts – Air Emissions and Energy Accounts Regional gross value added (balanced) by industry used to calculate emissions and energy intensities Population estimates
Transport Scotland	Scottish Transport Statistics used in calculation of mileage and goods lifted for a variety of vehicles Collation of Scottish Household Survey data used to indicate the proportion of car distance travelled for business and domestic purposes

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