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Energy & Environment

# 2019 Greenhouse Gas Inventory Improvement Programme: Wastewater modelling refinement

## Workstream 2

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# Executive summary

This is the project report for the wastewater modelling refinement, conducted as part of the National Atmospheric Emission Inventory (NAEI) improvement programme for the UK's Greenhouse Gas Inventory (GHGI). Work detailed in this report was carried out across the NAEI18 cycle and into the beginning of the NAEI19 cycle, with the objective of improving previous wastewater emission estimates in recognition of previous UK GHGI review comments, and in preparation for the 2019 Refinement of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. The main focus of the project was improving upon the previous methodologies for industrial wastewater, given previous review comments received and the growing importance of the source within the UK GHGI.

This objective was met via a series of sub-tasks, including a review of several European greenhouse gas inventories and the review of two key point source datasets, the UK Pollutant Release and Transfer Register (UK-PRTR) and the Environment Agency's Pollution Inventory. Both sub-tasks were aimed at the identification of datasets, which could form the basis of a 'Tier 2' methodology for industrial wastewater emissions. Neither the review of European inventories nor the review of point source datasets identified a means of reaching a Tier 2 method for the UK.

Both point source datasets are hampered by a 'threshold dynamic' with regards to wastewater reporting, meaning many industrial sites may be omitted or subject to reduced reporting requirements as they do not meet the required threshold to be included in the datasets. Both datasets are also limited with regards to data on the type of treatment technology or treatment pathway used, another key variable with respect to the methodology outlined in guidance. To assess whether permits of regulated industrial sites could address this variable, a text-mining 'R' script was used to assess the permit library maintained for the NAEI and provided by the Environment Agency, however it was assessed that permit documentation is too technical in nature to categorise treatment technologies at the national level.

The Environment Agency's 'Discharge Consents Register' was identified as a new data source, which provides some detail on treatment technology. This enabled the development of a revised Tier 1 methodology for industrial wastewater treatment, that addresses the main limitations of the previous NAEI18 method, most notably the revision of the 'methane correction factor', which was previously based on 1996 IPCC Guidance and thought to be too high with regard to likely treatment practice within the UK. As a result of these revisions, reduction in methane ($CH_4$) emissions across the timeseries range from 52% to 78%. $N_2O$ emission from industrial wastewater were also estimated, whereas previously these emissions were not considered. New guidance for estimating emissions from industrial wastewater treatment, introduced in the 2019 Refinement, allowed $N_2O$ emissions to be estimated for this source. There remain several limitations to this revised method, which should be prioritised in future reporting cycles, including:

- Periodically reviewing the splits between different types of wastewater treatment, when and if new data is made available.
- Further reviewing industrial production data in future updates, particularly in regard to timeseries consistency.
- Periodically reviewing wastewater generation factors, relative to practices in the sector.

An exploratory Tier 2 approach was also developed, based upon bottom up estimates derived from the Environment Agency's 'Discharge Consents Register'. This approach was specific to England only, and therefore gave only limited coverage. A series of comparisons were made between these bottom up estimates and the Environment Agency's Pollution Inventory, a point source dataset representing operator reported data for some industrial wastewater treatment. Limited comparisons were possible, but these comparisons indicated inconsistencies between the Tier 2 approach and operator reported data for the same sites, which could not be readily reconciled.

Projections to 2050 were explored, however there is no detailed strategy or plan on how the many different industries that generate and treat industrial wastewater intend to develop or further improve wastewater technologies in the coming decades. As a result, no policy scenarios are informed by industry considerations.

In addition to the revision of the industrial wastewater model, several updates are proposed to the existing methodology for domestic wastewater emissions. Stakeholder activities were held with UK Water Industry Research (UKWIR), a research body inclusive of UK water companies, with the aim of providing further data aimed at addressing previous limitations of the domestic wastewater methodology, which is based upon the 'Carbon Accounting Workbook', a tool maintained by UKWIR. The supply of this data was supported by all participants and a formal request to change the data supplied has been submitted to UKWIR.

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# 1 Introduction

Wastewater greenhouse gas emissions are one of the many sources estimated as part of the UK's Greenhouse Gas Inventory (GHGI), a component of the National Atmospheric Emission Inventory (NAEI). Split into both industrial and domestic sources, the UK's previous NAEI18 methodology is not as developed when compared to other key sources. In addition, the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories[1], recently published, includes an improved methodology with respect to both methane ($CH_4$) and Nitrous Oxides ($N_2O$) from wastewater, hence there is a compelling case to review the available data and methodologies to improve the overall robustness of the UK's greenhouse gas emissions (GHG) estimates, by considering any revisions.

It should be noted that the 2019 Refinement has been formally adopted by the Intergovernmental Panel on Climate Change (IPCC) in May 2019[2] but is yet to be adopted by the signatories of the United Nations Framework Convention on Climate Change (UNFCCC). In other words, it has been adopted by the Convention's technical body but not by the Convention's signatories. As a result, the 2019 Refinement is not yet, as of the date of this report, a formal requirement towards the UK but does represent a likely development in the guidance that supports the GHGI. This report represents the NAEI's preparedness towards these likely developments with respect to waste. This project report summarises the work undertaken to support this end, as detailed in the proposal dated 16th September 2019. Progress with BEIS was discussed during fortnightly conference calls where several changes were made to the focus and emphasis of the project, later detailed.

Throughout the report, 'previous' denotes the approaches and or data used within NAEI18[3], whereas 'new' denotes approaches and or data that has been developed as part of this project and now implemented in NAEI19 or implemented in future cycles.

# 2 Previous approaches

The NAEI includes methodology accounting for emissions from domestic and industrial wastewater. Both methodologies are subject to limitations that need to be considered within the design of this project. A summary of these methodologies alongside their limitations, is detailed in the Sections 2.1 and 2.2 below.

## 2.1 Industrial wastewater

The previous methodology implemented within the NAEI, for emissions from industrial wastewater, can be described as a hybrid Tier 1 & 2 estimate, with use of some, albeit limited, higher tier activity data. The fundamental activity data relates to a series of estimates published by the Department for Environment, Food & Rural Affairs (Defra) in 2002[4]. These estimates pertain to the total 'organic load' (total degradable organic content within wastewater) from 11 industry sectors in the year 2000, including milk processing, breweries and malt houses, detailed in units of population equivalent[5]. There is also additional separate activity data on the production of organic chemicals, which originates from estimates of production in 2009 from 'Prodcom' statistics, an economic dataset breaking down major sectors of the economy, supported by Eurostat, the statistical office of the European Union, and compiled by the UK Office for National Statistics (ONS). This output is multiplied by wastewater generation factors per tonne of product and a factor representing the Industrial degradable organic component within wastewater, to estimate organic load within the organic chemicals industry. The data pertaining to organic chemicals therefore conforms to a Tier 1 approach, whilst data for the other 11 industries can be considered as a Tier 2 method.

The organic load estimates for organic chemicals and the organic load for the other 11 industries, are scaled according to the 'index of production' (IOP) for each industry[6], a dataset detailing growth or decline by industry produced by the ONS, to approximate the organic load in other years of the timeseries.

Once scaled across the timeseries, the organic load is multiplied by an emission factor per unit of organic load (chemical oxygen demand [COD]), derived from applying the 'maximum $CH_4$ producing capacity' and a 'methane

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1 From here onwards referred to as 'the 2019 Refinement'.

2 IPCC (2019), 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories - Background information on the development of the 2019 Refinement, available at: https://www.ipcc-nggip.iges.or.jp/public/2019rf/background.html

3 NAEI18 refers to the latest year of inventory data, in this case 2018, typically delivered 2 years after the latest year, e.g. 2018 inventory data is published in 2020.

4 Defra (2002), Sewage Treatment in the UK - UK Implementation of the EC Urban Waste Water Treatment Directive, available at: http://www.defra.gov.uk/publications/files/pb6655-uk-sewage-treatment-020424.pdf

5 Population equivalent (PE) is the number expressing the ratio of the sum of the organic load produced during 24 hours by industrial facilities to the individual pollution load in household sewage produced by one person in the same time.

6 ONS (2019), Index of Production, available at: https://www.ons.gov.uk/economy/economicoutputandproductivity/output/datasets/indexofproduction/current

correction factor' (MCF), to estimate methane emissions from treatment. The MCF originates from the 1996 IPCC Guidelines and represents the factor for Australia, Canada and USA, and is assumed representative of UK treatment practices. The 2006 Guidelines, however, include MCFs per treatment pathway (or treatment technology) and therefore offers a more refined approach than an MCF representative of average practice nationally, provided data detailing treatment pathways/technologies is available. Prior to the work undertaken within this project, no data was identified, meaning the previous approach continued to use the MCF from the 1996 IPCC Guidelines and was not fully compliant with the 2006 IPCC Guidelines.

It should be noted that estimates within the previous NAEI18 approach cover only methane emissions from treatment of industrial wastewater. Revised methodologies for estimating $CH_4$ emissions from wastewater discharge, and $N_2O$ emissions from industrial wastewater treatment and discharge, have only recently become available in the 2019 Refinement. Previously, in the 2006 IPCC Guidelines, $N_2O$ emissions from industrial wastewater were thought to be insignificant[7], however the 2019 Refinement found that emissions were non-negligible, based on the latest scientific research.

The main limitations associated with the previous approach were:

- The previous MCF, which requires an approach not compliant with the 2006 IPCC Guidelines. The refinement of the previous NAEI18 approach requires sourcing and processing data pertaining to the proportion of wastewater treated through different treatment pathways/technologies, revising the MCF.
- Sourcing of country-specific activity data, if available, replacing the scaling of organic load data by the IOP, which is highly uncertain given data is available for only one year.
- The estimation of emissions from 'new' sources within the 2019 refinement, including $CH_4$ emissions from wastewater discharge and $N_2O$ emissions from industrial wastewater treatment and discharge. This is yet to be a formal requirement; however, it proves proactive to consider their feasibility.

## 2.2 Domestic wastewater

The current methodology implemented as part of the NAEI, for emissions from domestic wastewater, can be described as a combination of Tier 1 and Tier 2 estimates, with use of some country-specific parameters. Emissions reported in this category arise from wastewater handling, sludge treatment and disposal in the UK's municipal waste-water treatment system and private waste-water management systems. Methane is released from handling of wastewater and its residual solid by-products (i.e. sludge) under anaerobic conditions, due to the decomposition of organic matter by bacteria. Nitrous oxide is released from human sewage during wastewater handling due to the release of nitrogenous material from proteins.
Emissions are estimated for the following sources:

- UK $CH_4$ emissions from municipal waste-water treatment. UK-specific method, using activity data for the municipal wastewater treatment volumes, organic content and sludge treatment and disposal routes. Emission factors are derived from water company reporting since 2013 and extrapolated back to 1990. Method corresponds to a Tier 2/3 approach.
- UK $CH_4$ emissions from private waste-water management. Default IPCC methodology using UK-specific per capita Biochemical Oxygen Demand (BOD) and estimated population using private waste-water management systems.
- UK $N_2O$ emissions. Default IPCC methodology applied to UK time series of population and protein intake estimates from food surveys.

### 2.2.1 UK $CH_4$ emissions from municipal waste-water treatment

The UK estimates for methane from municipal domestic and commercial waste-water and sewage sludge treatment and disposal are derived from a time series of activity data for (i) total mass of sewage sludge disposed, and (ii) population equivalent of effluent treated in the municipal water treatment systems. The UK GHG inventory mostly follows the UK water industry GHG emission estimation methodology developed by UK Water Industry Research (UKWIR) and used by all UK water companies to generate their annual emission estimates from all sources/activities.

Wastewater undergoes several different processes in Wastewater Treatment Plants (WWTPs) before being safely released into receiving water bodies and the environment. The management of organic waste and consequently

[7] The 2006 IPCC Guidelines provides a methodology for $N_2O$ emissions from domestic wastewater treatment, inclusive of any industrial wastewater co-discharged with domestic wastewaters, but notes that 'the $N_2O$ emissions from industrial sources are believed to be insignificant compared to emissions from domestic wastewater'. IPCC (2006), Section 6.3.4, Chapter 6, Volume 5, available at: https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

the emission performance of the treatment works depend on the different combinations of treatment options and wastewater characteristics. The Carbon Accounting Workbook (CAW) was commissioned by UKWIR, in order to monitor WWTP performance, estimating the input water characteristics and the GHG emissions from these activities.

The CAW accounts for plant specific processes using country-specific emission factors that reflect UK circumstances. It is used by all UK municipal water and wastewater companies to report emissions to Ofwat, Defra, BEIS and other stakeholders. It provides emission factors for sub-processes within the industry, enabling water companies to calculate their $CH_4$ emissions based on their stock of water treatment equipment and effluent inputs to individual water treatment works. From the aggregated industry reported emissions and activity data, implied emission factors for each of the treatment and disposal approaches can be derived. The company reported data from the CAW is adapted to provide detailed data for the inventory. This data is delivered to BEIS and then forwarded onto the inventory team at Ricardo Energy & Environment for use in the NAEI. For the 2013 inventory cycle, a methodology report was provided that included a number of the underlying assumptions and emission factors.

The activity data reported by each company includes data that are used to estimate company GHG emissions:

- Total amount of sludge disposed (kt total dissolved solids (tds));
- Population Equivalent (PE) Served, this is the estimated resident and non-resident (e.g. tourist) population served which acts as an alternative indicator of sewage load; and
- Volume of biogas used ($m^3$).

Prior to the development of the CAW, the activity data used to estimate GHG emissions for the early part of the time series (before 2012) were published by the UK Government and are available at an aggregated level (across countries: England and Wales, Scotland, Northern Ireland, and with no detail on treatment).

In addition, for 2013 onwards, company reported data from the CAW has been available to estimate GHG emissions from the disposal of sewage sludge. The activity data (kt tds per year) has been reported across the following sewage sludge disposal routes:

- Incineration;
- Composted;
- Landfill;
- Land reclamation;
- Farmland;
- Disposal at sea (up to the year 1999, when this activity was banned); and
- Other.

The approach for collecting the required activity data for the early part of the time series is explained in detail in the UK GHGI National Inventory Report[8]. This is a combination of data reported to water regulators across the UK, and Defra statistics. Since the requirements of reporting sludge disposal activity and the number of sewage sludge disposal routes have changed over the years, causing data gaps, gaps between data are interpolated. In general, the overlap in time-series between Defra statistics and water regulators' data, on one hand, and company-reported data, confirms that the total and split of disposal methods are largely consistent with each other.

When no specific approach for estimating emissions associated with waste disposal routes was provided, the IPCC default approach was used. To estimate emissions from the dumping of sewage to sea, a practice banned in 1999 in the UK[9], the 2006 IPCC default approach using the Methane Correction Factor (MCF) for sea, river and lake discharge has been used. Discharges would have only been to the cold seas with low organic loadings around the UK, so this is likely to be a very conservative approach for estimating emissions. Similarly, the emission factor for composted sewage sludge treatment is derived from the 2006 IPCC guidelines.

$CH_4$ emissions from sewage sludge disposed to landfill and incineration are accounted for in categories 5A and 5C (Solid Waste Disposal and Incineration respectively), and hence no estimates are included in 5D1 (Domestic wastewater treatment) to avoid a double count. Waste disposed of via 'other' means has been given a weighted average emission factor based on the emissions from other disposal methods. Where the treatment before disposal is not specified, the treatment split is estimated based on the profile given in CAW reported data for since 2013; for

[8] BEIS (2020), UK Greenhouse Gas Inventory, 1990 to 2018: Annual Report for submission under the Framework Convention on Climate Change, available at: https://uk-air.defra.gov.uk/assets/documents/reports/cat09/2004231028_ukghgi-90-18_Main_v02-00.pdf

[9] Commission Directive 98/15/EC, available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:31998L0015&from=EN

example it was only after 2013 that the sludge disposed to landfill has been disaggregated based on treatment, this split has been used to estimate the treatment split for the earlier years where none is specified.

### 2.2.2 UK $CH_4$ emissions from private waste-water management

An estimate of the number of households that are likely to be using off-grid systems in the UK in 2013 has been made based on data provided by the Environment Agency (EA), the Scottish Environmental Protection Agency (SEPA), the Northern Ireland Department of the Environment (NIEA) and Natural Resources Wales (NRW). A time series of emissions has been developed using population data. This time series of number of households has been combined with ONS data for average household occupancy and the calculated volume of waste produced per person per year based on water company statistics to produce an estimate of total waste-water being disposed of via off-grid systems.

The emissions are then calculated following the method set out in the 2006 IPCC Guidelines, based on the proportion of the population using septic tanks and a BOD value assumed to be similar to the BOD per capita implied by the data provided by the major water companies.

### 2.2.3 UK $N_2O$ emissions

Nitrous oxide emissions from the treatment of human sewage are based on the 2006 IPCC default methodology, combining the UK population, the annual total protein consumption per person and different factors accounting for the fraction of nitrogen in the sewage. The UK GHGI estimate of protein consumption is derived from the Expenditure and Food Survey published every year by Defra, which is considered more representative of UK protein consumption per capita than FAO (The Food and Agriculture Organization of the United Nations) Data. The protein consumption per capita in the UK is the total of the 'household intake' and the 'eating out intakes'. The latter is an estimate of the small amount of additional protein from consuming meals eaten outside the home. Its timeseries is only available from 2000 onwards; for values between 1990 and 2000 an average of the data available is applied.

The $N_2O$ emissions from sludge spread on agricultural land are reported under IPCC source category 3D Agricultural Soils and emissions from waste incineration are included in 5C. Therefore, to avoid a double count in the UK GHG inventory, the emissions reported in 5D1 are the difference between the UK total from the IPCC default method, and the estimates included in 3D and 5C.

### 2.2.4 Main limitations

The main limitations associated with the current approach are:

- Historic water company reporting of emissions is not comprehensive. Emissions data are only available from 2009 onwards, and only from up to 9 of the 12 UK water companies in any one year before 2013; for example, in 2009, emission reporting by water companies was estimated to cover around 53% of total UK water treatment. Despite limitations to data collection in previous years, the current approach relies on the best available data. There is good consistency across the emission factors derived from the different water companies and the data are based on UK-specific water treatment facilities.
- Since 2013, following the implementation of the CAW, data has been received from all 12 of the water companies with some data gaps. In order to increase accuracy and completeness in emission estimates from wastewater treatment, it would be beneficial to receive more comprehensive annual data returns from each wastewater company in a timely manner.
- While the current approach, based on the 2006 IPCC Guidelines, does not consider $N_2O$ emissions from domestic wastewater treatment a significant source, the 2019 Refinement presents updated guidance to estimate $N_2O$ emissions from centralised WWTPs.

Due to the more extensive limitations in comparison to the current approach for domestic wastewater, it was agreed that improving the industrial wastewater estimates was the main focus of this project.

## 2.3 Legislative developments towards historic emission estimates and projections

Multiple regulations apply to wastewater treatment. These have evolved since the beginning of the timeseries (1990), coinciding with increased interest on protecting and improving water quality. Legislative developments pertaining to wastewater treatment are detailed below. Where possible the elements of regulation have been delineated between domestic and industrial, to align with the separation of sources within this report. Legislation considered below pertains to wastewater treatment and, with the addition of discharge emissions now part of the 2019 Refinement, is extended to any legislation that may be relevant to discharge activities or water quality. Legislation or elements of legislation, regarding water abstraction, were not considered. Legislation can be split roughly into two categories, legislation that directly impact wastewater treatment, and legislation that requires or further regulates the standards or conditions of UK water bodies, placing an indirect pressure on wastewater treatment.

It should be noted that the recent Environment Bill[10] may alter water quality standards and the substances that are taken into account in assessing water quality, particularly in respect to domestic legislation implemented with respect to the Water Framework Directive (2000). It is not year clear, however, how any changes may impact specifically upon wastewater treatment.

| | |
|---|---|
| 1991 | • **The Urban Wastewater Treatment Directive (1991)** – Introduced as an EU Directive, the legislation requires compliance of treatment technologies for areas or 'agglomerations' of a certain size, defined by population equivalent. This typically requires at least secondary treatment for the largest agglomerations by the end of the year 2000, or smaller agglomerations by 2005. The majority of the Directive is concerned with urban wastewater, consisting of mainly domestic wastewater. Industrial wastewater, not co-discharged into urban wastewater treatment systems, is required to meet standards set by the state's competent authority, by end of the year 2000, if the industrial wastewater treatment plant is over a threshold of 4000 population equivalent.<br>• **The Water Resources Act (1991)** - set out the functions of the National Rivers Authority (now the Environment Agency) and introduced water quality classifications and objectives for the first time. |
| 1995 | • The **Environment Act (1995) -** led to restructuring of environmental regulation and placed a duty on the companies to promote the efficient use of water by customers. It created a new body, the Environment Agency, which took over the functions of the National Rivers Authority, Her Majesty's Inspectorate of Pollution, the waste regulation functions of local authorities and certain elements of the Department of the Environment. Natural Resources Wales now exercises the functions of the Environment Agency in Wales. |
| 2000 | • **Water Framework Directive (2000)** - creates a single system of water management, based around a natural river basin – which may form part of two or more local government areas. The Directive sets objectives and deadlines for improving water quality. It looks overall at both the ecology of the water and its chemical characteristics. |
| 2006 | • **The New Bathing Water Directive (2006)** - aims to protect public health and the environment by keeping coastal and inland bathing waters free from pollution. |

# 3 Review of other national greenhouse gas inventories

As an initial stage in analysis, several greenhouse gas inventories from selected countries were reviewed. These countries have similar international inventory reporting requirements, but also similar regulatory frameworks for managing wastewater emissions due to also being subject to EU legislation, which is in turn implemented domestically. There are, therefore, likely similarities to the UK in industry practices, data collected and reporting by the industry, which can be used to either to support a justification for applying a methodology in the UK or point to alternative sources of data.

Countries were selected according to the known quality of their inventories, which, whilst no overall indicator of quality is given for any specific inventory, can be inferred from knowledge of the inventory through Ricardo Energy & Environment's experience of international reviews. Countries selected include; Germany, Denmark, The Netherlands, and Italy. The review covered relevant sections of each country's National Inventory Report (NIR)[11] . For the majority of countries, the review focused primarily on emissions from industrial wastewater treatment, as this is the area most in need of development under this scope of work. As a summary, the main outcomes of this tasks are:

[10] UK Parliament (2020), Bill 220 2019-21 (as amended in Committee), available at: https://services.parliament.uk/Bills/2019-21/environment/documents.html

[11] Germany: 2020 National Inventory Report, Section 7.5 beginning on page 715: https://unfccc.int/documents/226313, Denmark: 2020 National Inventory Report, Section 7.5 beginning on page 540: https://unfccc.int/documents/228013, The Netherlands: 2020 National Inventory Report, Section 7.5 beginning on page 256: https://unfccc.int/documents/226476, Italy: 2020 National Inventory Report, Section 7.5 beginning on page 321: https://unfccc.int/documents/223571

- Denmark and Germany have the most extensive methodologies, for both domestic and industrial wastewater, out of the inventories reviewed. For Denmark, the methodology is based primarily on detailed national monitoring of all treatment plants, including those for industrial wastewater treatment. For Germany data regarding the split of treatment technologies across industrial sectors is based on a 2014 research report, detailing 184 anaerobically operating facilities, at a total of 136 industrial sites. Both countries therefore benefit from data/processes not directly replicable in the UK.
- The Netherlands and Italy both use methodologies based upon limited data, with The Netherlands basing organic load received by treatment plants on design capacity and Italy estimating organic load using production data. They serve as examples of the limitations inventory compilers face when considering emissions from these sources.
- None of the inventories reviewed provided further data sources that could serve as the basis for improving UK estimates.

# 4 Review of the UK's Pollutant Release and Transfer Register

The UK's Pollutant Release and Transfer Register (PRTR) facilitates the reporting of pollutant releases or transfers from industrial sites to the EPRTR (European PRTR) under the EPRTR Regulation[12], which in turn fulfils obligations under the UNECE Kyiv Protocol on Pollutant Release and Transfer Registers. The UK PRTR includes data on releases of pollutants to air, water and land and off-site transfers of waste and of pollutants in wastewater from industrial sites that exceed specific capacity thresholds. Facilities are categorised according to 65 economic activities and 9 sectors, the majority industrial, which can be readily mapped to the focus sectors detailed within the 2006 IPCC Guidelines and 2019 Refinement, delineating between urban wastewater treatment plants, and industrial wastewater treatment or discharge. Specifically, the EPRTR Regulation requires the reporting of total nitrogen and total organic carbon (TOC), for releases to water, if the release exceeds 50,000 kg within a year. The UK PRTR, therefore, could provide at least some necessary activity data to estimate both $CH_4$ and $N_2O$ emissions from industrial wastewater.

Ricardo Energy & Environment reviewed the latest data available from the UK PRTR, which, at the time of review, related to releases from 2017 as the latest available year[13]. It should be noted that the UK PRTR includes data from 2007 onwards and is therefore limited in providing a full timeseries for the inventory, from 1990 onwards. The use of this data therefore would need to be integrated with other data of a similar nature, or the remainder of the timeseries estimated via splicing[14]. It should also be recognised that the UK PRTR does not provide any further information about the technologies and modes of wastewater treatment that are used at each industrial site. Such information would need to be sourced elsewhere. A mapping was produced between the industrial sectors identified as emissive within the 2006 IPCC Guidelines and 2019 Refinement, and the PRTR main industrial activity sector, activity and, when applicable, sub-activity.

As the PRTR relies on a series of thresholds, first to define what activities are in scope relative to capacity and secondly to determine whether releases are required to be reported, there exists the potential for reporting to be inconsistent relative to changes in capacity or changes in the magnitude of a release, what we term the 'threshold dynamic'. A key evaluation criterion, therefore, in order to use UK PRTR data within the inventory, is the consistency of TOC or total nitrogen values and the number of sites across the available timeseries. Time-series consistency is a guiding principle to the inventory, which means that, as far as possible, the time series should be calculated using the same method and data sources in all years. This 'threshold dynamic', apparent within the PRTR's design, could be argued as problematic when considering this principle.

For TOC, the UK PRTR included data for only 8 of the 16 industrial sectors highlighted as emissive for $CH_4$ within the 2006 IPCC Guidelines and 2019 Refinement. Some industrial sectors had only a single site recorded in 2017. A total of 28 plants across all relevant industrial sectors reported values for TOC in 2017. Trends across the timeseries were highly variable, often reflecting the variability in the reporting of specific plants across years relative to thresholds. As a result, the number of sites is often highly correlated with TOC values. Such a result is to be anticipated; however, a high degree of correlation suggests the number of plants, interacting with thresholds, more readily determines the level of TOC for each industrial sector as opposed to changes in activity at each individual site. Similar dynamics are observed for total nitrogen. Reporting of total nitrogen within the UK PRTR is more

[12] Formally known as Regulation (EC) No 166/2006 of the European Parliament and of the Council concerning the establishment of a European Pollutant Release and Transfer Register and amending Council Directives 91/689/EEC and 96/61/EC. Within this document, this regulation will be referred to its common name as the 'EPRTR Regulation'.

[13] The European Pollutant Release and Transfer Register (E-PRTR), Member States reporting under Article 7 of Regulation (EC) No 166/2006, European Environment Agency,

[14] Splicing refers to a range of techniques detailed in Section 5.3.3 of Volume 1, Chapter 5 of the 2006 IPCC Guidelines, that enable one or more methods to be combined to form a complete time series. A common example would be extrapolation according a proxy, or extrapolation.

consistent in terms of sector coverage with 7 out of 8 industrial sectors highlighted as emissive for $N_2O$. Fewer sites report total nitrogen, however, with only 10 sites reported in 2017 across all relevant industrial sectors.

The results of this analysis emphasise that, although containing relevant activity data, the UK PRTR captures only a limited number of sites. It should be noted that the PRTR includes over 50 pollutants reported across three mediums, so this analysis applies to only a limited proportion of PRTR reporting. Thresholds are a focus within future reviews of the EPRTR Regulation and its associated guidance, and, where appropriate, can be revised to ensure the majority of releases for any specific pollutant and medium combination are captured. After discussion with BEIS, it was decided that the UK PRTR, as a route for obtaining necessary activity data, would not feature within the final model. It may, however, as detailed in Section 6, provide a useful metric towards the actual performance of specific sites relative to other data.

## 4.1 Review of the UK's Pollution Inventory

The UK's Pollution Inventory acts as the basis for the UK's PRTR submission[15]. The database contains a wider array of sites, including those where the site falls below the release threshold but exceed the capacity threshold, and acts as a preliminary dataset. This enables a wider assessment of whether reported data could inform the development of industrial wastewater estimates. Data is publicly available from 2013 onwards and is therefore similarly limited in providing a full timeseries for the inventory, from 1990 onwards. The Pollution Inventory is analogous to the UK PRTR as it does not provide any information about the technologies and modes of wastewater treatment that are used at each industrial site. In cases where the reporting site falls below the release threshold, the value is redacted. Data was extracted from each annual file published since 2013 and filtered for 'total organic carbon (TOC)' and 'Nitrogen - as total N' releases to controlled waters or wastewater. Entries for sites labelled as 'Water Industry' were removed from the scope of analysis as these sites pertain to domestic wastewater treatment.

Sector coverage is difficult to assess, owing to differing categorisations, with a number of distinct industry sectors within guidance coming under a single category within the data 'REGULATED INDUSTRY SECTOR' field. The 'ACTIVITY DESCRIPTION' field, however, provides a more delineated categorisation of sectors, that can be readily mapped to industry sectors presented in guidance. Once mapped, data can be readily evaluated against guidance and compared to other sources, such as the discharge consents detailed in Section 6.

The Pollution Inventory, when mapped, includes data for only 6 of the 16 industrial sectors highlighted within the 2006 IPCC Guidelines and 2019 Refinement as emissive for $CH_4$, and only 3 of the 8 industrial sectors considered emissive for $N_2O$. The number of sites reporting is significantly lower for similar sectors when compared to the sites considered by the consented discharge database. The category 'Making of Food Products/Dairy', within the consented discharge database contains 235 sites operating in 2018. The sum of those sites reporting total organic carbon (TOC) in 2018, that would fall under the 'Making of Food Products/Dairy' within the Pollution Inventory, is approximately 122 in comparison. This figure falls to just 45 when sites below the reporting threshold are removed. Meaning only 45 sites, out of a possible 235, are captured with site specific data. For the category 'Making of Basic Metals/Iron+Steel/Foundry/Casting', the sites reporting in 2018 within the Consented Discharge Database is 33, whereas the Pollution Inventory reports only 8 for total organic carbon, falling to 1 with sites below the reporting threshold removed. Similarly, the category 'Making of Chemicals + Chemical Products' within the consented discharge database is associated with 73 sites in 2018, whereas the Pollution Inventory reports on 27, once sites below the reporting threshold removed. It is clear the Pollution Inventory does not capture all potential sites, and a number of sites do not exceed the reporting threshold for releases. The Pollution Inventory, therefore, similar to the UK PRTR, is limited by a similar 'threshold dynamic'.

# 5 Review of Industrial Permits

Most wastewater treatment sites require some form of permit, issued by a regulatory authority, setting out specifications of any required process or standards. Reviewing such permits could help our understanding of wastewater treatment, specifically towards industrial treatment practices by informing on:

- The treatment technologies/pathways being employed,
- The proportion of industrial sources of wastewater which treat water onsite or co-discharge waste to municipal water treatment; and,
- How these practices might differ depending on the industrial sector.

Ricardo Energy & Environment maintain a 'permit' library, for the purposes of the NAEI. The library contains over 1,400 permits for industrial sites considered under the UK's environmental permitting regulations. This database is populated and maintained using a web-scraping tool, developed by Ricardo Energy & Environment, which identifies

[15] Environment Agency (2012), 'Pollution inventory reporting – general guidance notes', available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/307943/LIT_7665_3febc9.pdf

and downloads all industrial permits published by the main UK regulatory authorities (e.g. Environment Agency, Natural Resource Wales). These permits are typically employed to evaluate the context of reported emissions data from industrial sites and help inform the NAEI estimates towards industrial processes and stationary fuel combustion. However, in the context of wastewater, it is thought one route to characterise industrial wastewater estimates is through the evaluation of permits. As industrial activities generate large volumes of wastewater, the permit would typically detail whether this wastewater is disposed through connection to the centralised sewer system or treatment on-site with direct discharge into a nearby water body.

Although supporting EU legislation, enforced through the environmental permitting regulations, contains detailed classifications of industrial activity, in the case of wastewater from industries, it is thought wastewater considerations would be embedded within existing permits as opposed to a stand-alone permit for wastewater activities. However, a stand-alone permit may be required if the wastewater undergoes a form of on-site treatment managed by a separate legal entity to the industrial site where the wastewater is generated. As a result, all industrial permits were considered within the review, not simply those where wastewater is the main activity, or where wastewater treatment may be indicated within the permit's title.

An R script was written using the Quanteda package. Quanteda is an R package for managing and analysing textual data[16]. This R script enabled all permits to be 'text-mined' once placed in a central folder location. The 'KWIC' or 'key words in context' function analyses all text within each permit, identifying a series of keywords and extracting keywords within their surrounding context. An output was generated detailing the keyword, its surrounding sentence structure, and the originating permit document. Analysing this output enables a user to evaluate whether the permit and the associated industrial site considers wastewater discharge. Keyword phrases were based on the description of technologies contained within Volume 5, Chapter 6 of the 2019 Refinement[17] and guidance documents published by the Environment Agency[18], the main competent authority enforcing environmental permitting with regards to wastewater. Table 1 details the keyword phrases used.

**Table 1 –Keyword phrases for text mining**

| Keyword: | Origin: | Associated with: |
|---|---|---|
| Primary treatment | 2019 Refinement | - |
| Secondary treatment | 2019 Refinement | - |
| Tertiary treatment | 2019 Refinement | - |
| Organic content | Environment Agency Guidance | - |
| Co-discharge | Environment Agency Guidance | - |
| Sewage sludge | Environment Agency Guidance | - |
| Stabilisation pond | 2019 Refinement | Secondary treatment |
| Polishing pond | 2019 Refinement | Tertiary treatment |
| Trickling filter | 2019 Refinement | Secondary treatment |
| Anaerobic reactor | 2019 Refinement | Secondary treatment |
| Carbon adsorption | 2019 Refinement | Tertiary treatment |
| Ion exchange | 2019 Refinement | Tertiary treatment |
| lagoon | 2019 Refinement | Secondary treatment |
| Disinfection | 2019 Refinement | Tertiary treatment |
| Discharge to water | Environment Agency Guidance | - |
| Urban wastewater treatment | Environment Agency Guidance | - |
| Trade effluent | Environment Agency Guidance | - |
| Sewage effluent | Environment Agency Guidance | - |
| Effluent treatment plant | Environment Agency Guidance | - |
| Wastewater | Environment Agency Guidance | - |
| ETP | Environment Agency Guidance | - |
| Public sewer | Environment Agency Guidance | - |

[16] Benoit, Kenneth, Kohei Watanabe, Haiyan Wang, Paul Nulty, Adam Obeng, Stefan Müller, and Akitaka Matsuo. (2018) "quanteda: An R package for the quantitative analysis of textual data". Journal of Open Source Software. 3(30), 774. https://doi.org/10.21105/joss.00774.
[17] 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 5 Waste, Chapter 6 – Wastewater Treatment and Discharge, https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/5_Volume5/19R_V5_6_Ch06_Wastewater.pdf
[18] Environment Agency, Water discharge and groundwater activity environmental permit. (2018). https://www.gov.uk/government/collections/water-discharge-and-groundwater-activity-environmental-permits

| | | |
|---|---|---|
| Denitrification | Environment Agency Guidance | Tertiary treatment |
| Nitrification | Environment Agency Guidance | Tertiary treatment |

Text mining identified over 1921 instances of keyword phrases. These instances originate in the documentation for 277 industrial sites. The majority of permit documents identified by the script pertain to food and drink processing, paper and pulp manufacturing, meat and poultry and other organic chemical industries, in line with what the IPCC 2019 Refinement describes as 'major industrial wastewater sources'[17]. Although multiple industrial sites are indicated to have on-site effluent treatment plants (ETPs), results for other keyword phrases (Table 2), such as the main treatment classifications, or specific technologies associated with each stage of treatment, were not easily identified. Such a result suggests that permits, whilst noting effluent treatment, may not use terminology for technology or treatment stages, limiting analysis. After discussion with BEIS, it was decided that permit analysis, as a route for obtaining necessary activity data, or information regarding treatment technologies, would not feature within the final model.

**Table 2 – Highlighted results of the text mining of industrial permits.**

| Industrial activity | Effluent Treatment Plant (number of plants) | Primary treatment (number of plants) | Secondary treatment (number of plants) | Tertiary treatment (number of plants) |
|---|---|---|---|---|
| Agriculture | 2 | - | - | - |
| Aluminium | 3 | - | - | - |
| Cement | 1 | - | - | - |
| Ceramic fibre | 1 | - | - | - |
| Food and drink | 30 | 3 | - | - |
| Inorganic chemicals | 7 | - | - | - |
| Milk | 6 | - | - | - |
| Oil and gas | 2 | - | - | - |
| Organic chemicals | 10 | - | - | - |
| Other chemicals | 2 | - | - | - |
| Paper and pulp | 13 | 2 | 2 | 4 |
| Pharmaceuticals | 2 | - | - | - |
| Slaughterhouses | 7 | 1 | - | - |
| Textiles | 1 | - | - | - |
| Grand Total | 87 | 6 | 2 | 4 |

# 6 Discharge Consents Registers

Discharge consents may be required under permit conditions for wastewater discharge activities. For England, these consents are recorded within a publicly available register. Similar registers exist for other regulatory agencies for the Devolved Administrations. The 'discharge consents register' contains the consents for a range of treatment plants operated by water companies and industrial sites, in addition to other forms of discharge such as sewer overflows, or discharges from commercial premises such as pubs and bars.

Crucially the register also contains a series of 'determinands'. Determinands are tied to discharge consents by a permit reference, and typically refer to the properties of a sample when measured, with regards to specific maximums[19] (e.g. maximum biochemical oxygen demand [BOD] when measured according a specific sampling method[20]). The database also includes a table of effluents, with variables representing different measures of flow (e.g. dry weather flow [DWF]), and a variable characterising the type of treatment technology or lack of treatment.

Limited information is available regarding the dataset itself, such as the definitions and coverage of different tables and fields. Ricardo Energy & Environment, with the assistance of BEIS, did contact both the Environment Agency's

[19] Water Quality Archive Documentation, Environment Agency. https://environment.data.gov.uk/water-quality/view/doc/reference

[20] Biochemical Oxygen Demand Method Statement, ALS Environmental, (2016). https://www.alsenvironmental.co.uk/media-uk/method_statements/coventry/waste-water-inorganics/method-statement-was001.pdf

Enquiries and the Environment Agency via network contacts. The enquires unit clarified that there was currently no user guide for the database, and therefore limited information they could provide, but through contacts, Ricardo Energy & Environment was able to clarify that the database contains 'all water discharges permitted as 'water discharge activity' or 'groundwater activity' under the Environmental Permitting Regulations'[21]. It was also clarified that the specified treatment technology is sufficient to provide an indication of practices across the industries[21].

A teleconference was held with the Environment Agency on the 7th July 2020. During this meeting further details regarding the discharge consents register were clarified. It was noted that, with the exception of the UK's PRTR and the Environment Agency's Pollution Inventory, no other UK dataset concerning discharges from industrial sites currently exists[22]. A full dataset could be made by integrating and processing similar datasets from each devolved administration. The implications of this are explored in Section 7.4.2. It was also clarified that use of the discharge consents likely overestimates activity data such as the flow of wastewater, organic content, or total nitrogen. Most discharge consents impose maximum limits and, although some relates to means, it is unlikely that maximums correctly characterise average actual performance at industrial sites[22]. It was noted that a potential method of resolving this tendency to overestimate would be to analyse those sites reporting in the PRTR and the estimated parameters within the discharge consents[22].

# 7 Model design – industrial wastewater

A two-step model design was agreed with BEIS to re-develop and expand the model for industrial wastewater[23]. The first step requires a Tier 1 model to be built for both treatment and discharge, by sourcing the necessary activity data. A Tier 1 approach uses the production output of different wastewater intensive industries as its fundamental activity data and is therefore easier to achieve, whilst a Tier 2 estimate, the second step, incorporates measured data to replace parameters such as the amount of wastewater generated, or its organic content, in addition to any specific emission factors. A two-step approach enables the inventory team to fully assess the implications of country specific data, in comparison to a more simplistic baseline. Such an approach also complies with how the 2006 IPCC Guidelines and 2019 Refinement are intended to be used, by gradually building complexity, progressing through the tiers.

## 7.1 Tier 1 approach for methane emissions from industrial wastewater treatment and discharge

### 7.1.1 Activity data

The Tier 1 approach initially requires production data for each of the specific industries identified within the 2019 Refinement as wastewater intensive. Production data was sourced from Eurostat's 'Prodcom' database, which provides a detailed disaggregation of UK production by product. This enables a bottom up approach to defining the coverage of each industry specified within the 2019 Refinement, by combining the production estimates for various products. In total, data for 481 individual products was sourced and allocated to industry sectors. As this data is used as the fundamental activity data for both Tier 1 estimates of $CH_4$ and $N_2O$ emissions, this was a joint exercise for both pollutants. Key industries for $CH_4$ emissions include[24]:

- Alcohol refining
- Beer & malt
- Coffee
- Dairy products
- Fish processing
- Meat & Poultry
- Organic chemicals
- Petroleum refineries
- Soap & detergents
- Plastics & resins
- Pulp & Paper
- Starch production

[21] Personal Communication, Rob Paddinson, Senior Advisor, Environment Agency, 6th May 2020
[22] Personal Communication, Rob Paddinson, Senior Advisor, Environment Agency, 7th July 2020
[23] Personal Communication, Sam Bradley, BEIS, 19th May 2020
[24] Defined as those present in Table 6.9 of the Volume 5 Chapter 6 of the 2006 IPCC Guidelines and Table 6.12 of the Volume 5 Chapter 6 of the 2019 Refinement, excluding those industries that are only present in Table 6.12, defined as 'key sources of $N_2O$'.

- Sugar refining
- Vegetable oils
- Vegetables, fruits & juices
- Wine & vinegar

It should be noted that the Prodcom database typically includes production estimates for the UK from 1995 onwards, meaning production data prior to 1995, back to 1990, has been estimated using the 'splicing' techniques described in Section 5.3.3 of Volume 1, Chapter 5 of the 2006 IPCC Guidelines. A 'surrogate' approach was used, where a proxy dataset, related to the specific industry, is used to simulate the trend in activity data. Surrogates selected pertain to value indexes from the UK's Blue Book, an official dataset published by the ONS, describing economic activity in the UK. Specific indexes map onto specific industries above (e.g. the 'Manufacture of chemicals and chemical products' index could be applied to the 'organic chemicals' sector) and the Blue Book dataset provides a timeseries back to 1990.

In line with best practice, regression analysis was used in selecting the appropriate surrogate datasets, by evaluating the $R^2$ value between the index and the production data at the sector level, for the years 1995-2018. If a positive $R^2$ greater than 0.55 (with 1 = perfect correlation) was observed, the trend from 1990-1994 was estimated based on the relationship between production estimates and the Blue Book Index. In selected cases, it may be necessary to interpolate between production values from values for surrounding years, if production for a product is not reported in a specific year.

### 7.1.2 Emission methodology

The Emissions methodology is described in full within Section 6.2.3 of Chapter 6, Volume 5 of the 2019 Refinement. Equations from the relevant section of the 2006 IPCC Guidelines are detailed below where necessary, to help illustrate the calculation procedure.

**Equation 1 - Estimation of total organically degradable material in wastewater for industry [IPCC (2006): Vol. 5, Chapter 6.2.3.3, Equation 6.6]**

| Parameter: | | | | | | |
|---|---|---|---|---|---|---|
| $TOW_i$ | = | $P_i$ | x | $W_i$ | x | $COD_i$ |
| Description: | | | | | | |
| Total organically degradable material in wastewater for industry i, kg COD/yr | | Total industrial product for industrial sector i, t/yr | | Wastewater generated, $m^3/t_{product}$ | | Chemical oxygen demand (industrial degradable organic component in wastewater), kg COD/$m^3$ |

As seen in Equation 1 above, production estimates for each industry ($P_i$) are subsequently multiplied by wastewater generation factors ($W_i$) from Table 6.9 of Volume 5, Chapter 5 of the 2006 IPCC Guidelines. Wastewater generation factors are not specified within Table 6.9 for soap and detergents, sugar refining, or the coffee industry and therefore are sourced from academic literature or country-specific sources. A default value for fish processing is also omitted from Table 6.9 of the 2006 IPCC Guidelines, however a default value for fish processing is present in Table 6.12, Volume 5 Chapter 6 of the 2019 Refinement. Values for sugar refining were sourced from scientific literature sources, ranging between 0.4 – 2.5 $m^3$ of wastewater per tonne of product[25]. An average value of 1.45 $m^3$ of wastewater per tonne of product was chosen. Coffee processing and manufacturing is also subject to a wide range of wastewater generation estimates, ranging between 1-20 $m^3$ of wastewater per tonne of product, depending on the degree of washing, fermentation or finishing[26]. It is thought that a sizeable proportion of coffee beans are washed and fermented at source, prior to import[27], however the manufacturing of instant soluble coffee requires 'dewatering', creating effluent[28]. As a result of value of 3 was chosen, representing more minimal processing. In lieu of any wastewater generation factor for soap and detergents, the value for organic chemicals is used as a proxy.

[25] Bantacut and Aulia, (2019), Assessment of Chemical Oxygen Demand Balance for Energy Harvesting in Sugar Mills Wastewater Treatment, available at: https://search.proquest.com/openview/4f53fee7b2f37560897a89ac4d88fde1/1?pq-origsite=gscholar&cbl=1606374

[26] Von Enden and Calvert, (2003), Review of Coffee Waste Water Characteristics and Approaches To Treatment, available at: https://pdfs.semanticscholar.org/0284/0f32dbd8108e8f4e40eb7637e827f762bae4.pdf;review

[27] CBI, (2016), Product Factsheet United Kingdom Coffee-2016, available at: https://www.cbi.eu/sites/default/files/market_information/researches/product-factsheet-the-united-kingdom-coffee-2016.pdf

[28] Environment Agency, Nestle Boiler Plant Tutbury operated by Nestle UK Limited, available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/317575/Decision_Document.pdf

It should be noted that the wastewater generation factors specified within the 2006 IPCC Guidelines are technology specific and originate from one study[29]. This study employed measurements for several sites, including two meat processing plants and one chicken processing plant, but estimates for other industries are based on literature and expert interviews[29]. As this study is not published[30] and given the uncertainty towards treatment technologies, it seems appropriate, where possible, to validate or replace such estimates with country specific data.

Ricardo Energy & Environment sought to obtain further discharge consent permit documents for several key sites, however these have to be requested individually via the Environment Agency public register and often relate to the original consent, not variations overtime. Nor are these easily categorised within the Environment Agency's internal systems, so unavailable on bulk by sector. Permit variations for those environmental permits considered under the 2010 Industrial Emission Directive (IED) are required to be published and are publicly available without the need for requests[31]. Revised wastewater generation factors were derived for both the pulp & paper industry and dairy industry, by using the production estimates specified within and the wastewater discharge volume estimated or limited by the permit conditions. COD factors per volume of wastewater was also derived by dividing the estimated or maximum permitted COD value and the discharge volume estimated or limited by the permit conditions. Derivation of these factors is described in Annex 0.

The amount of wastewater generated was multiplied by COD factors (Kg/m$^3$ of wastewater) to estimate the total organically degradable material within the wastewater for each industry. COD factors were derived from the 2006 IPCC Guidelines, 2019 IPCC Refinement, or, as noted above, estimated from permit conditions of specific plants.

Industrial wastewater may be treated on-site or discharged via agreement to the municipal sewers, to be treated downstream by a water company. 'Co-discharge' is facilitated by water companies themselves and regulated via OFWAT[32]. The 2006 IPCC Guidelines accounts for co-discharge by applying a correction factor for additional industrial BOD discharged into municipals sewers, equating to 25% additional total organics in wastewater. This factor is based on expert judgement from a limited study, so recommends that *'information from industrial discharge permits may be available to improve [the co-discharge factor] I, otherwise expert judgment is recommended'*. In the UK, data on 'trade effluent' is collected from UK municipal water and wastewater companies as part of the Carbon Accounting Workbook reporting, detailed in Section 2.2.1. Domestic wastewater estimates, therefore, include the trade effluent component, which is part industrial but may also originate from commercial premises. To remove any potential for double-counting, the total organically degradable material in wastewater for industry ($TOW_i$) is adjusted by removing the total organics in trade effluent received and reported by municipal water and wastewater companies, as detailed in Equation 2.

**Equation 2 - Adjustment of total organically degradable material in wastewater to account for co-discharge into municipal sewers.**

| Parameter: | | | | |
|---|---|---|---|---|
| $TOW_{ia}$ | = | $TOW_i$ | - | $TOW_{ico\text{-}discharge}$ |
| Description: | | | | |
| Total organically degradable material in wastewater for industry adjusted to correct material in wastewater for industry co-discharged in municipal sewers, kg COD/yr | | Total organically degradable material in wastewater for industry i, kg COD/yr | | Total organically degradable material in wastewater for industry co-discharged and reported by municipal water and wastewater companies ico-discharge, kg COD/yr |

Emission Factors for each treatment or discharge pathway were determined by multiplying the 2006 IPCC Guideline value for the maximum methane production capacity per kg of COD by the respective Methane Correction Factor (MCF), as detailed in Equation 3 below. The MCFs are detailed by treatment technology/pathway in Table 6.8 of Volume 5, Chapter 6 of the 2019 Refinement. For constructed wetlands, the MCF originates from Table 6.4 of the 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, more commonly known as the 'Wetland Supplement'[33]. The MCF chosen was for 'surface-flow' wetlands, being a common type of constructed wetland for treatment of municipal wastewater. Surface-flow wetlands are also subject to the highest MCF, providing a conservative estimate in lieu of data or literature to more accurately determine the type of wetlands used.

[29] IPCC (2000), CH4 And N2O Emissions From Wastewater Handling - Attachment 1 Executive Summary of Paper on Greenhouse Gas Emissions from Industrial and Domestic Water Treatment , available at: https://www.ipcc-nggip.iges.or.jp/public/gp/bgp/5_2_CH4_N2O_Waste_Water.pdf

[30] Doorn et al (1997), Estimates of Global Greenhouse Gas Emissions from Industrial and Domestic Wastewater Treatment, available at: https://cfpub.epa.gov/si/si_public_record_Report.cfm?Lab=NRMRL&dirEntryID=115121

[31] Environment Agency (2020), Industrial Emissions Directive (IED): environmental permits issued, available at: https://www.gov.uk/government/collections/industrial-emissions-directive-ied-environmental-permits-issued

[32] OFWAT (2001), Trade Effluent Appeals, available at: https://www.ofwat.gov.uk/publications/trade-effluent-appeals/

[33] IPCC (2014), 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, available at: https://www.ipcc.ch/site/assets/uploads/2018/03/Wetlands_Supplement_Entire_Report.pdf

**Equation 3 - Estimation of emission factors for industrial wastewater [IPCC (2006): Vol. 5, Chapter 6.2.3.2, Equation 6.5]**

| Parameter: | | | | |
|---|---|---|---|---|
| $EF_j$ | = | $B_0$ | x | $MCF_j$ |
| **Description:** | | | | |
| emission factor for each treatment/discharge pathway or system (j), kg $CH_4$/kg COD | | maximum $CH_4$ producing capacity, kg $CH_4$/kg COD | | methane correction factor (fraction) |

Each Emission Factor is then weighted according to the percentage utilisation of the treatment or discharge pathway within each industry prior to being applied to the total organically degradable material within the wastewater for each industry to determine emissions (Equation 4). The percentage utilisation of treatment or discharge pathways was determined through analysing the Environment Agency's Discharge Consent Database and presented by industry, so that each industry had a specific treatment split. The above factors are combined in Equation 4 to calculate CH4 emissions from industrial wastewater. As there is no data supporting sludge removal or methane flaring/recovering within each industry, a default value of zero is used in the below for recovering/flaring ($R_i$) or sludge removal ($S_i$). This element may not be captured by discharge consents and it remains an element for improvement.

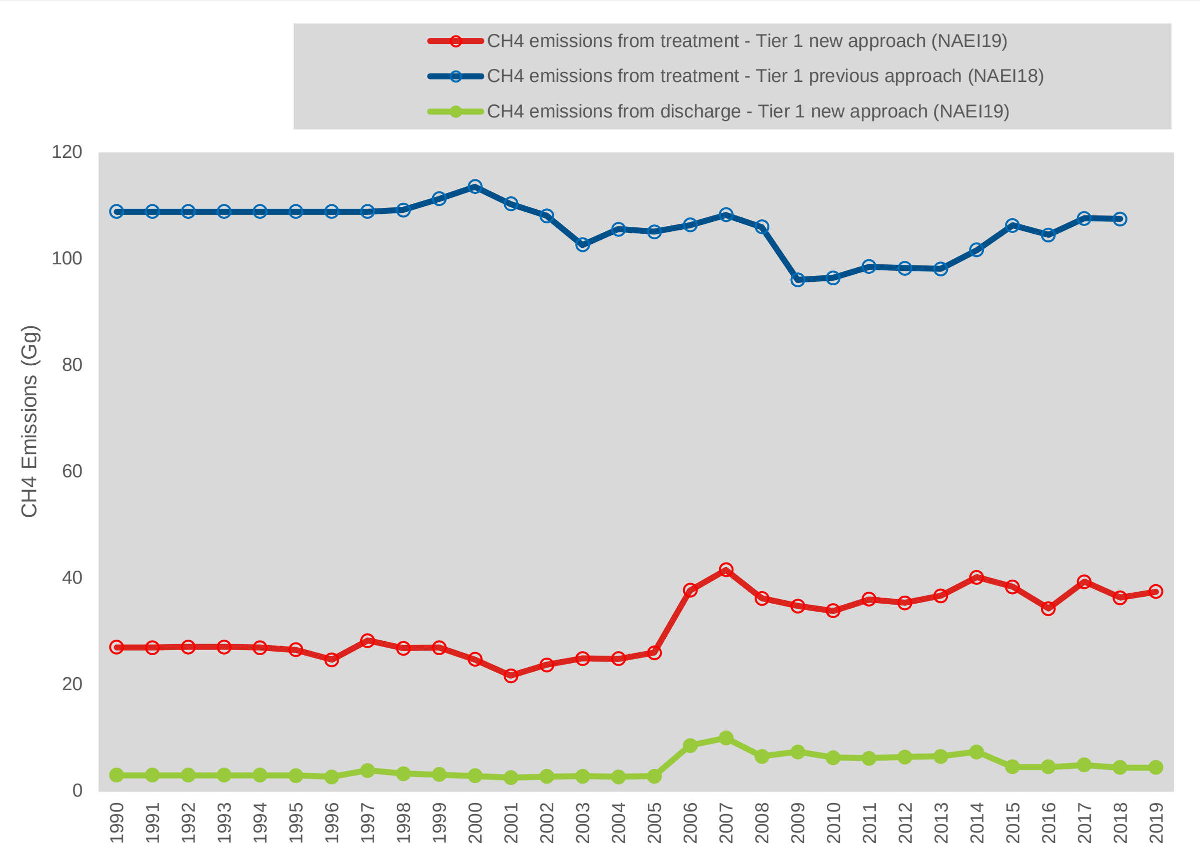
**Equation 4 - $CH_4$ emissions from industrial wastewater [IPCC (2006): Vol. 5, Chapter 6.2.3.1, Equation 6.4]**

| Parameters: | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $CH_4$ Emissions | = | Σ [ ($TOW_{ia}$ | - | $S_i$) | x | $EF_i$ | - | $R_i$) | ] | x | $10^{-6}$ |
| **Description:** | | | | | | | | | | | |
| $CH_4$ emissions in inventory year, Gg $CH_4$/yr | | Total organically degradable material in wastewater for industry adjusted to correct material in wastewater for industry co-discharged in municipal sewers, kg COD/yr | | organic component removed from wastewater (in the form of sludge) in inventory year, kg COD/yr | | emission factor for industry i, kg $CH_4$/kg COD for treatment/discharge pathway or system(s) used in inventory year. If more than one treatment practice is used in an industry this factor would need to be a weighted average. | | amount of $CH_4$ recovered or flared in inventory year, kg $CH_4$/yr | | | conversion of kg to Gg |

### 7.1.3 Comparison to previous estimates

Comparing between the $CH_4$ emission estimates for industrial wastewater treatment and the estimates compiled as part of the previous approach, described in Section 2.1, it is clear that a Tier 1 methodology indicates reduced emissions from this source. Reduction in emissions across the timeseries, range from 52% to 78%. This is primarily connected to the way in which, with limited data, the previous approach applies the MCF, not necessarily fundamental differences between the methodological stages. The previous MCF originates from the 1996 Guidelines and represents the factor for Australia, Canada and USA, and is assumed representative of UK treatment practices. The 2006 Guidelines employed in the new Tier 1 approach above, however, include MCFs per treatment pathway (or treatment technology). Following the approach outlined in the 2006 IPCC Guidelines offers a more refined approach than an MCF that representative of average practice per industry, with some treatment practices, such as centralised aerobic treatment plants, leading to no $CH_4$ emissions.

**Figure 1 - Comparison between the revised Tier 1 approach for CH4 emission from industrial wastewater treatment and the previous approach**




## 7.2 Tier 1 approach for nitrous oxide emissions from industrial wastewater treatment and discharge

### 7.2.1 Activity data

The Tier 1 approach for $N_2O$, similar to the approach for $CH_4$, requires production data for each of the specific industries identified within the 2019 Refinement as highly emissive. It should be noted that sectors considered emissive in this case differ to those considered as emissive under the calculation for $CH_4$. The 2019 Refinement notes these sectors as those defined in Table 6.12 of Volume 5, Chapter 6, including: alcohol refining, beer & malt, fish processing, iron and steel manufacturing, meat & poultry processing, nitrogen fertilisers, plastics and resins, and starch production. All of these sectors are accounted for within the methodology considered below.

The Tier 1 approach uses the same activity data detailed in Section 7.1.1 but for those sectors highlighted as relevant for $N_2O$.

### 7.2.2 Emission methodology

The Emissions methodology is described in full within Section 6.4 of Chapter 6, Volume 5 of the 2019 Refinement. Equations from the relevant section of the 2019 Refinement are detailed below where necessary, to help illustrate the calculation procedure.

Unlike the methodology for $CH_4$, where discharge was integrated into the treatment pathways and therefore not separate in method, the approach for $N_2O$ considers emissions from treatment and discharge separately, with the latter accounting for the degree of nitrogen removed during the treatment process, and therefore the likely amount discharged in to receiving water bodies.

Production estimates per industry sector are combined with wastewater generation factors ($W_i$) from Table 6.12 of Volume 5, Chapter 5 of the 2019 Refinement, to estimate the total nitrogen in industrial wastewater entering treatment ($TN_{INDi}$), as described in Equation 5 below.

**Equation 5 - Estimation of total nitrogen in industrial wastewater [IPCC 2019 Refinement: Vol. 5, Chapter 6.4.1.3, Equation 6.13]**

| Parameter: | | | | | | |
|---|---|---|---|---|---|---|
| $TN_{INDi}$ | = | $P_i$ | x | $W_i$ | x | $TN_i$ |
| **Description:** | | | | | | |
| Total nitrogen in wastewater entering treatment for industry i, kg TN/yr | | Total industrial product for industrial sector i, t/yr | | Wastewater generated, $m^3/t_{product}$ | | Total nitrogen in untreated wastewater for industrial sector i, kg TN/$m^3$ |

As detailed in Section 7.1.2, wastewater may be discharged via agreement to the municipal sewers, to be treated downstream by a water company. As with methane emissions, the methodology for nitrous oxide emissions also must account for co-discharge to avoid the potential for double-counting. Unlike the methodology for methane emissions, the CAW reporting by municipal water and wastewater companies does not include key activity data relating to the degree of industrial co-discharge, in this case the total nitrogen in wastewater co-discharged from industry. As a result, the total nitrogen in wastewater entering treatment for industry to account for co-discharge cannot be directly adjusted. In lieu of data, the methodology adjusts for co-discharge by subtracting the a percentage of total nitrogen relative to the proportion of organically degradable material in wastewater co-discharged from industry to the total organically degradable material in wastewater from industry ($TOW_{ico\text{-}discharge} \div TOW_i$ , as referenced in Equation 2).

$N_2O$ emissions from industrial wastewater treatment is then determined via Equation 6.Treatment splits (given by the degree of utilisation) are identical to those used in the calculation of $CH_4$ in equation 4 and therefore consistent between pollutants.

**Equation 6 - Estimation of $N_2O$ emission from industrial wastewater treatment plants [IPCC 2019 Refinement: Vol. 5, Chapter 6.4.1.1, Equation 6.11]**

| Parameter: | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $N_2O\ Plants_{IND}$ | = | $\Sigma_i$ | $[\ T_{ij}$ | x | $EF_j$ | x | $TN_{INDi}]$ | x | 44/28 |
| **Description:** | | | | | | | | | |
| $N_2O$ emissions from industrial wastewater treatment plants in inventory year, kg $N_2O$/yr | | | Degree of utilisation of treatment/discharge pathway or system j, for each industry i in inventory year | | Emission factor for treatment/discharge pathway or system j, kg N2O-N/kg N | | Total nitrogen in wastewater from industry i in inventory year, kg N/yr | | Conversion of kg $N_2O$-N into kg $N_2O$ |

Nitrogen removal by different treatment technologies varies between 10 and 85%, meaning the nitrogen content of wastewater effluent then discharged is highly dependent on the treatment process. The total nitrogen content in the industrial wastewater effluent discharged is calculated via Equation 7, which accounts for the fraction of nitrogen removed during treatment. The fraction of total wastewater nitrogen removed is taken from Table 6.10c of the 2019 Refinement. The treatment splits are calculated as the sum of the splits for each industry and therefore consistent between pollutants, though differ by their characterisation with 'centralised aerobic treatment plant[s]' split into primary, secondary and tertiary technologies, each denoting additional stages of treatment.

**Equation 7 - Estimation of total nitrogen in industrial wastewater effluent discharged [IPCC 2019 Refinement: Vol. 5, Chapter 6.4.1.3, Equation 6.14]**

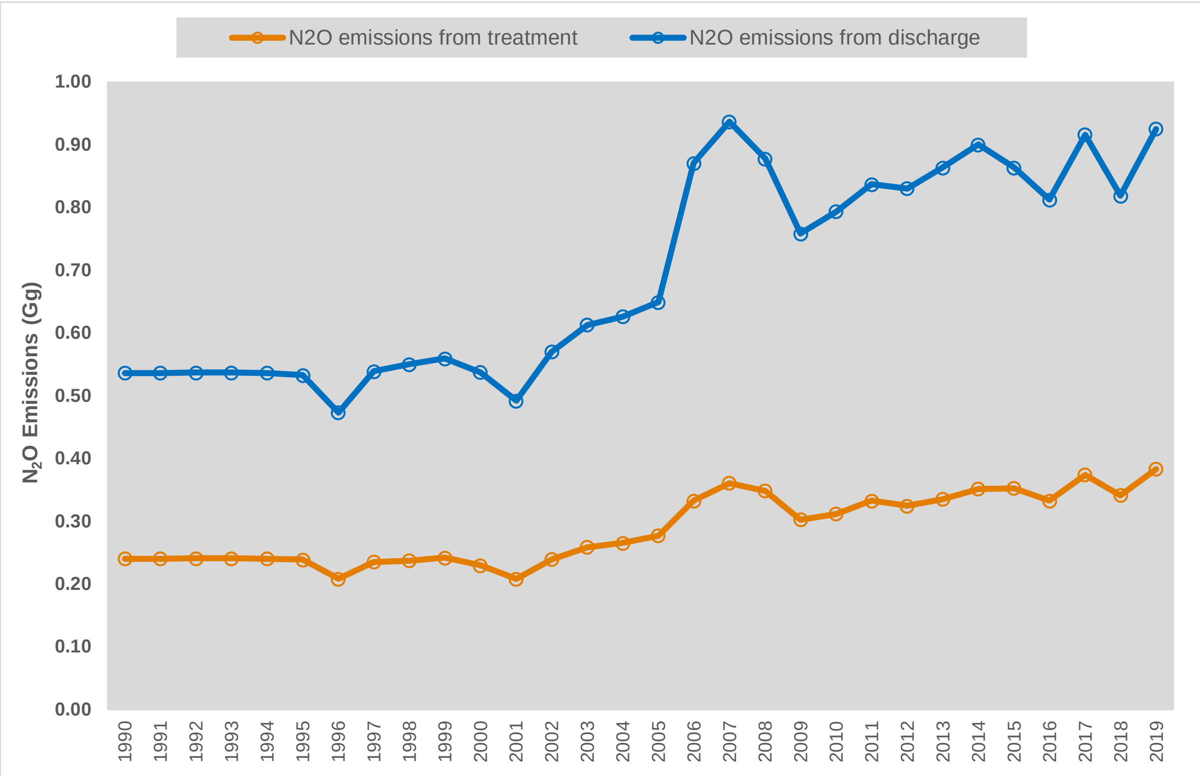
| Parameters: | | | | | | | |
|---|---|---|---|---|---|---|---|
| $N_{Effluent,IND}$ | = | $\Sigma_j$ | $[TN_{INDi}$ | x | $T_j$ | x | $(1-N_{REM,j})\ ]$ |
| **Descriptions:** | | | | | | | |
| Total annual amount of nitrogen in the industrial wastewater effluent discharged, kg N/yr | | | Total nitrogen in wastewater from industry i in inventory year, kg N/yr | | degree of utilisation of treatment system j in inventory year | | Fraction of total wastewater nitrogen removed during wastewater treatment per treatment type j. |

$N_2O$ emissions from discharge of industrial wastewater is then estimated by combining $N_{effluent,IND}$ with emission factors to determine emissions. Emission factors are lifted from Table 6.8A of the 2019 Refinement and correspond to a Tier 1 approach, owing to the use of just one emission factor relating to an average across aquatic environments which may be nutrient impacted (e.g. assumptions regarding the rate of denitrification in rivers or estuaries). The consented discharge database does provide a characterisation of the waterbody subject to each discharge, however no further data on the nature on that waterbody regarding its status or condition. Application of a Tier 3 approach for $N_2O$ emissions from industrial wastewater discharge is dependent on establishing nutrient-impacted water bodies, which would require further research. Tier 1 is seen as appropriate given the degree of data available.

### 7.2.3 Emission estimates

Figure 2 displays the new $N_2O$ estimates across the timeseries. Similar to the trend presented in Figure 1, the activity data plays a strong role in determining the variation across the timeseries, with a jump in estimates from 2005-2006 and a decline in 2008. To allow for comparison, the AR4 global warming potentials were applied to the estimates. For 2018, $N_2O$ emissions from both industrial wastewater treatment and discharge combined make up 25% of total emissions from industrial wastewater, whereas $CH_4$ makes up the remaining 75%. $N_2O$ emissions therefore play a lesser role in determining the overall level and significance of industrial wastewater within the wider inventory.

**Figure 2 - $N_2O$ emissions from industrial wastewater discharge and treatment**




## 7.3 Implications of a Tier 1 approach for industrial wastewater

To assess the implications of a Tier 1 approach, the Approach 1 Key Category Analysis (KCA) was rerun for the 1990-2018 GHGI. KCA refers to a technique within the 2006 IPCC Guidelines to identify and prioritise areas of the inventory with significant influence on a country's level and trend of GHG emissions. Adopting the Tier 1 approach would involve dropping the previous NAEI18 method for estimating $CH_4$ emissions from industrial wastewater, detailed in Section 2.1, and taking up the revised estimates detailed in Sections 7.1 and 7.2, which would therefore consider $N_2O$ emissions from industrial wastewater for the first time within the NAEI.

The 2019 Refinement, in addition to providing a methodology for $N_2O$ emissions from industrial wastewater, also includes adjustments to the guidance on the degree of aggregation used within key category analysis. Previously the 2006 IPCC Guidelines recommends that the analysis should be performed at the level of IPCC categories or subcategories at which the IPCC methods and decision trees are generally provided in the sectoral volumes, but, within Table 4.1, Chapter 4, Volume 1, recommends an aggregated approach combining domestic and industrial wastewater into a single category. This is despite separate decision trees being presented in the guidance for wastewater for industrial and domestic emissions.

The 2019 Refinement, however, in revised guidance for key category analysis notes that, for wastewater treatment and discharge, 'if there are differences in data sources, assumptions applied and uncertainties for different types of wastewater treatment (domestic or industrial wastewater and or different discharge routes) these should be disaggregated'[34]. There exists, therefore, legitimate means through which industrial and domestic wastewater emissions should be considered separately. This is complicated, however, by the general requirement within guidance that more detailed higher tier methods should be selected for key categories. If changing the degree of aggregation impacts upon the selection of key categories, this could be seen as avoiding this requirement. This analysis is therefore presented according to two scenarios:

- Scenario 1 - KCA performed at level 5D – Wastewater treatment and discharge
- Scenario 2 - KCA performed at level 5D1 and 5D2 – denoting between domestic and industrial wastewater respectively

The analysis is presented excluding emissions from land use and land use change (LULUCF), therefore maximising the chances of wastewater categories being key categories. Categories are presented for each gas separately, meaning each row of a key category analysis represents a unique gas/category combination, with the exception of groups of gases such as perfluorocarbons (PFCs), though these are not relevant for wastewater treatment and discharge. The base year in the analysis refers to emissions in 1990, with the exception of fluorinated gases (f-gases) which have a base year of 1995. The latest year refers to emissions in 2018, the latest available NAEI year for both the previous and revised approaches. Key categories with respect to level are those that when summed together in descending order of magnitude, add up to 95% of the total level within that year. With regards to trend, categories whose trend diverges most from the total trend are considered as key, when this difference is weighted by the level of emissions or removals of the category in the base year, and summed to a cumulative total of 95%.

KCA results are presented as green or red with the position or rank out of the total key categories e.g. (29/31) – there are 31 key categories, with 5D being position 29, meaning there are 28 preceding categories, more significant with regards to level or trend that constitute key categories, including 5D. In this case the cell would be coloured red. If the figure presented was 32/31, this would mean 5D is not a key category, as the range of key categories include 31 categories, with 5D outside of this range. For this case, the cell in the Table 3 below would be green.

**Table 3 – Key Category Analysis (KCA) results considering domestic and industrial wastewater jointly (scenario 1) and separately (scenario 2)**

| Scenario: | Description: | Base year* | Latest year* | Trend* |
|---|---|---|---|---|
| Previous approach (NAEI 2018) | 5D – Wastewater treatment and discharge – $CH_4$ | (26/26) | (21/26) | (27/26) |
| | 5D – Wastewater treatment and discharge – $N_2O$ | (42/26) | (35/26) | (50/26) |
| Scenario 1 | 5D – Wastewater treatment and discharge – $CH_4$ | (28/25) | (26/27) | (40/26) |
| | 5D – Wastewater treatment and discharge – $N_2O$ | (41/25) | (34/27) | (42/26) |
| Scenario 2 | 5D1 – Domestic wastewater treatment and discharge – $CH_4$ | (31/25) | (35/27) | (73/26) |
| | 5D1 – Domestic wastewater treatment and discharge – $N_2O$ | (42/25) | (36/27) | (50/26) |
| | 5D2 – Industrial wastewater treatment and discharge – $CH_4$ | (43/25) | (33/27) | (38/26) |

[34] IPCC (2019), Table 4.1, Chapter 4, Volume 1 of the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, available at: https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/1_Volume1/19R_V1_Ch04_MethodChoice.pdf

| Scenario: | Description: | Base year* | Latest year* | Trend* |
|---|---|---|---|---|
| | 5D2 – Industrial wastewater treatment and discharge – $N_2O$ | (62/25) | (48/27) | (54/26) |

As seen in Table 3 above, adopting Tier 1 estimates within Scenario 1, still identifies category '5D – Wastewater treatment and discharge' as key, with respect to $CH_4$ emissions within the latest year. $N_2O$ emissions would be increased under this Scenario, as new sources of emissions have been added to the category for the first time. Under Scenario 2, no categories for either pollutants are considered key and each pollutant and category combination is far outside the range of possible key categories.

## 7.4 Tier 2 approach for methane and nitrous oxide emissions from industrial wastewater treatment and discharge

A Tier 2 approach was suggested as part of the two-step design of the project. As the Consented Discharge Database is limited only to England, a Tier 2 approach was attempted only for England to explore what is possible with the data currently available. Similar datasets exist for both Wales and Scotland, although the structure and variables within those datasets differ from the database for England.

Each discharge consent is assigned a technology or discharge pathway based on the same method used to derive the percentage utilisation of the treatment or discharge pathway within each industry. If the discharge consent is associated with an 'unspecified' treatment or discharge pathway, the average technology or discharge pathway within the associated industry is applied in later emission factors.

The estimated annual wastewater generated is estimated based on the flow limits and statistics associated with each permit reference and/or outlet number. Flow estimates are detailed as part of the 'Effluent' table of the database, and the 'Determinands' table. Flow estimates within the 'Effluent' table are detailed by four measures of flow, all specified in cubic metres ($m^3$):

- DWF – (Dry weather flow) – Average daily flow to a treatment works during a period without rain.
- MAX_DAILY – (Maximum daily release)
- MEAN – (Mean rate per second)
- MAX_RATE – (Maximum rate per second)

Depending on the values available for each of the measures above, the annual estimated flow was calculated in order of the following preference; DWF, MAX_DAILY, MEAN, MAX_RATE. Flow measures are also detailed in the 'Determinands' table of the Database, specified in the following units:

- Megalitre per day
- Cubic metre per day
- Litre per second
- Cubic metre per hour
- Megalitre
- Gallons per hour
- Megalitres per week
- Cubic metre per second

Each unit was converted into cubic metres per year via a dynamic lookup of conversions. Once converted, if flow measures from both the 'Effluents' and 'Determinands' table exist for the same permit reference and/or outlet number, the largest estimate is chosen.

Once an annual estimate of wastewater generated has been determined, the estimate is duplicated across the period of the timeseries of which the discharge consent is active, based on the date the consent was effective and, if specified, the date in which the consent was revoked. If no date for revocation is specified, the consent is assumed to remain active up until and including the latest inventory year (in this case 2018).

The COD or BOD (biological oxygen demand) values from the 'Determinands' table, for each discharge consent, were assigned via the permit reference. If the discharge consent was not associated with a respective COD or BOD value, the average of all reported values for the specific industry was used. BOD values were converted to

COD, via a BOD to COD conversion factor of 2.4, the ratio between maximum $CH_4$ producing capacity for BOD and COD specified in Table 6.2 of Volume 5, Chapter 6 of the 2006 IPCC Guidelines. COD values were applied to the wastewater generated timeseries derived from extrapolating annual wastewater flow estimates across the consent period, to generate a timeseries of COD within the wastewater.

Finally, an EF was supplied based on the treatment technology specified in the 'Effluents' table. If no treatment technology was specified, or the treatment technology is detailed as 'unspecified', a weighted average of all reporting treatment technologies is applied for the listed sector.

### 7.4.1 Comparison with the Pollution Inventory

During the teleconference held with the Environment Agency on the 7th July 2020[35], It was noted that in using the Consented Discharge Database, there exists the potential for overestimates, as the regulatory limits imposed through the consent may reflect only the necessary regulatory criteria not the actual level or characteristics of the effluent. In this sense there may be a gap between the regulatory and operational performance of an industrial site.

To explore this possibility, the sites detailed in the Pollution Inventory, dating back to 2013, were evaluated and cross-checked with the Consented Discharge Database. Sites presents within both datasets were identified through the post code, as a common field in both datasets. The sites were checked by comparing the names for the company within each dataset to ensure the postcode represented the same site. For COD, or total organic carbon, 78 sites were identified as common to both datasets, 48 of which were subject to being below the capacity threshold for reporting in 2018, and hence did not detail a specific value for comparison. For total N, 73 sites were identified as common, 53 of which were subject to being below the capacity threshold in 2018. Out of these remaining sites, only 2 sites could be compared, due to an inconsistent timeseries.

Two sites that do indicate a consistent factor, were the Britvic Soft Drinks site in Norfolk and the EPC chemical site in Essex. For the Britvic Soft Drinks site in Norfolk, data in both datasets indicates that the annual COD load calculated through the Consented Discharge Database was overestimated by a factor between 1.3 to 2.0, though this result has limited application beyond the 'Making of Beverages/Breweries/Soft Drinks' sector presented in the Database. Data for the EPC chemical site in Essex suggests the annual total N calculated through the Consented Discharge Database could be underestimating by a factor of a 1000, though it is likely the values stated in the Consented Discharge Database, upon which the total N is based, are unrepresentative, given they denote permit limits, not real performance. Results for these sites are presented in Table 4 below.

A difference is anticipated (i.e. a ratio other than 1), owing to the likely gap between the regulatory and operational performance of a particular wastewater treatment plant. A lack of consistency, however, between the two datasets for the same sites indicates the Tier 2 estimates are likely to be highly uncertain. It should be noted that this is a limited exercise. If a wider array of factors could be calculated through this comparison, with sufficient coverage and consistency across industry sectors, such factors could be applied to align the Tier 2 estimates with typical operational performance. Given the limited potential for comparison, such application is not currently possible.

**Table 4 - Ratio between sites in the Environment Agency's Pollution Inventory and the Environment Agency's Consented Discharge Database**

| Industry sector | OPERATOR NAME | SITE ADDRESS | Element | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| Food & Drink (vegetable, fruits and juices) | Britvic Soft Drinks Limited | Carrow Works King Street Norwich Norfolk | Factor (COD) | - | - | 1.30 | 1.81 | 1.93 | 1.96 |
| Chemicals (organic chemicals) | EPC United Kingdon PLC | Exchem Organics Great Oakley Works Harwich Essex | Factor (Total N) | 0.001 | 0.001 | 0.001 | 0.002 | - | - |

35 Personal Communication, Rob Paddinson, Senior Advisor, Environment Agency, 7th July 2020

### 7.4.2 Implications of a Tier 2 approach for industrial wastewater

After discussions with the Environment Agency, it is clear that the current devolved nature of environmental permitting inhibits the development of a national dataset, and whilst the Pollution Inventory and the UK PRTR do include those sites reporting, our analysis suggests this captures too few sites. Whilst Ricardo Energy & Environment have identified a series of similar datasets for each Devolved Administration, it is likely that processing each dataset into a central national register would prove too intensive with regards to the budget for annual updates and would likely require expert input from the likes of the Environment Agency in supporting such effort.

As a cursory exercise, Ricardo Energy & Environment analysed the 'Consented Discharges to Controlled Waters'[36] dataset available from Natural Resource Wales', the environmental regulatory body for Wales. Whilst key parameters, such as the type of treatment deployed, are near identical to those detailed within the dataset for England, elements such as the sector descriptions assigned are distinct, with less identification for those sites considered industrial. Such limitations would make building a coherent set of tier 2 estimates, for each industry sector listed in guidance, complex.

Whilst it could be argued that the current, England specific, Tier 2 approach could be scaled to the national level, this would add significant uncertainty, when, in this case, the Tier 1 approach developed is more substantiated in terms of data and coverage.

## 7.5 Uncertainty assessment

Efforts to revise the previous methodology for industrial wastewater have the dual purpose of addressing the limitations detailed in Section 2.1 and, in doing so, reducing the uncertainty. Table 5 below provides for a qualitative comparative assessment of key data components of both the previous and revised methodologies. As the previous methodology accounted for $CH_4$ emissions from industrial wastewater treatment, the comparative assessment focuses only on the data used to estimate this source and pollutant, as this is directly comparable between the previous and revised methods. Our assessment indicates that uncertainty of the method, overall, is reduced, though several elements remain that are uncertain and should be prioritised in ongoing improvements to the NAEI and in annual compilation. It should be noted that, in Table 5 not all elements are directly comparable due to differences in method, for example, owing to the use of organic load estimates, the previous approach relies only on wastewater generation factors for 1 out of the 12 industrial sectors estimated, whilst the revisions Tier 1 approach utilises wastewater generation factors for every industrial sector.

Owing to slight differences in the method, there are specific aspects of the $N_2O$ methodology, laid out in Section 7.2, where the specific considerations apply. For instance, though both the $CH_4$ and $N_2O$ methodologies rely on the same dataset detailing treatment technologies/pathways by industry, the $N_2O$ method relies more on the differentiation within certain technologies, such as the level of primary, secondary or tertiary treatment, than the $CH_4$ method, adding additional uncertainty.

[36] Natural Resource Wales (2020), 'NRW_DS116329 Consented Discharges to Controlled Waters JUL20.zip', available at: https://naturalresourceswales.sharefile.eu/share/view/s05adea6ab5d4df58/fo289e69-abc0-4acb-9923-271512440118

**Table 5 – Qualitative uncertainty analysis for industrial wastewater.**

| Previous approach: | | | Revised methodology: | | |
|---|---|---|---|---|---|
| Component: | Description: | Uncertainty rating: | Component: | Description: | Uncertainty rating: |
| Activity data | The previous approach uses data from a series of estimates published by Defra in 2000[37], relating to total 'organic load' from 11 industry sectors, including milk processing, breweries, and malt houses. Additional Prodcom estimates for the organic chemicals sector are also used, with an estimate for 2009. 'Index of Production' data, for each sector is used to scale data for the rest of the timeseries. | High | Activity data | Our revised Tier 1 methodology used Eurostat's Prodcom statistics to provide product data by industrial sector. This data undergoes several checks by Eurostat, the statistical office of the European Union, including checks to identify errors[38]. Our own assessment identifies multiple cases where the timeseries appear incomplete, or where potential errors are evident. As a result, our compilation process includes a 'flag & review' procedure, where, if a product contributes more than 20% towards the total for an industrial sector, in any one year or more, it is reviewed, gap filling if necessary. The need for this process underlines the likely uncertainty in the use of these statistics, particularly at the sector total level employed within the method. Eurostat's Prodcom data provides a timeseries from 1995- to the latest NAEI year. To complete the timeseries back to 1990, extrapolation according to the Index of Production is employed, with an assessment of correlation coefficients to determine whether extrapolation is appropriate. Ideally, a full timeseries would be available, however, in lieu of data for 1990-1994, extrapolation is necessary. The IOP data, however, is employed in a much more limited way than the previous approach. | Medium |
| Wastewater generation factors | The previous approach uses wastewater generation factors only for organic chemicals, with other data already expressed in organic load, therefore not requiring this step. For organic chemicals, the IPCC default value of 67 $m^3$ per tonne, though no assessment of whether this value is appropriate was completed. | N/A | Wastewater generation factors | As the revised approach uses wastewater generation factors for all industrial sectors, they have more prominence in the revised methodology than the previous approach. We remain critical of the wastewater generation factors cited throughout the 2006 IPCC Guidelines and the 2019 Refinement, owing to the limited data upon which they are based. In line with guidance, these have been reviewed against permit data where available. It remains, however, that a complete assessment for each sector, is not possible, owing to the manual nature of the review and the fact that several permits include quantities of the industrial product as background data to the permit, not as required contents. | High |

[37] http://www.defra.gov.uk/publications/files/pb6655-uk-sewage-treatment-020424.pdf

[38] Eurostat (2020), Statistics on the production of manufactured goods (prom) National Reference Metadata in Euro SDMX Metadata Structure (ESMS) Compiling agency: UK, Office for National Statistics (ONS), available at: https://ec.europa.eu/eurostat/cache/metadata/EN/prom_esms_uk.htm

| | | | | | |
|---|---|---|---|---|---|
| Methane Correction Factor | As noted in Section 2.1, the previous approach used the MCF for Australia, Canada and USA sourced from the 1996 IPCC Guidelines, and assumed this representative of UK treatment practices. This assumption was necessary as the 2006 IPCC Guidelines represented an updated methodology, providing MCFs by treatment technology/pathway, thereby requiring data on the split of treatment technologies/pathways for each industry sector. No appropriate data, until now, had been identified. The MCF for Australia, Canada and USA, in comparison to the range of values presented in the 2006 IPCC Guidelines, is notably high, and multiple reviews have commented upon whether the use of this value is appropriate. We share these concerns, and this is one of the motivating factors behind the revisions presented in this report. It is likely this variable, was a source of considerable uncertainty in the previous method. | Very high | Methane Correction Factor | The revised methodology uses data from the Environment Agency's Consented Discharge database to provide treatment splits for each industrial sector. This allows for the calculation of a weighted MCF for each industry, in accordance with industry practice. Whilst this reduces the uncertainty owing to the more appropriate use of industry specific data, rather than a national estimate implicit of all treatment practices, the timeseries of treatment splits is fixed overtime owing to inconsistencies in discharge consents, particularly in the early timeseries. This is a key element to consider for improvement and justifies designating the uncertainty status of this element 'medium' as opposed to low. | Medium |
| Overall assessment: | | High | Overall assessment | | Medium |

Quantitative estimates of uncertainty, for each pollutant in 5D2, has been developed for consideration within the Assessment of Uncertainty detailed in the UK GHGI. Uncertainty analysis should be seen, first and foremost, as a means to help prioritise national efforts to reduce the uncertainty of inventories in the future.

These estimates consider the uncertainty for activity data and emission factors separately and consider only emissions from industrial wastewater treatment. Estimates for the uncertainty of emission factors consider also intermediate parameters, such as MCFs or wastewater generation factors. Estimates for the uncertainty of activity data consider only data for industrial production, parameter $P_i$ in Equation 1 and Equation 5. Uncertainties are estimated via the square-root of the sum of squares for default values sourced from IPCC Guidance. In the case where multiple default values exist for a single parameter, such as multiple values for MCFs based upon the treatment split, the uncertainty is weighted by the overall emission from each treatment/discharge pathway. Quantitative estimates of uncertainty are detailed in Table 6 below.

**Table 6 - Quantitative estimates of uncertainty for industrial wastewater treatment.**

| IPCC category | Pollutant | Activity data uncertainty (%) | Emission factor uncertainty (%) |
|---|---|---|---|
| 5D2 | $CH_4$ | 25% | 83% |
| 5D2 | $N_2O$ | 25% | 129% |

The uncertainty associated with $CH_4$ emission estimates is lower than that for $N_2O$ with regards to emission factors, but identical with regard to activity data. This is due to the fact that, as detailed in Section 7.2.1, the same activity data is used as the basis for both emission estimates. The uncertainty associated with the emission factors for $N_2O$, is notably high owing to the uncertainty range presented in IPCC Guidance for 'Centralised, aerobic treatment plants' (-99%, +181%, 95% Confidence interval), which, in the weighting for $N_2O$, features heavily (73% of the overall emission from all treatment/discharge pathways). Whereas for $CH_4$, this treatment/discharge pathway holds no weighting as the MCF is 0, with the weighting leaning towards other treatment/discharge pathways with narrower ranges of uncertainty. Annex 6A.5 of Chapter 6 Volume 5 of the 2019 Refinement, notes this uncertainty originates in the variety of EFs derived from the review of scientific literature, owing to differences in plant design and optimisation.

## 7.6 Projections

Projections have been developed for new and updated sources of emissions up until and including 2050. This is based upon first identifying a suitable projections dataset upon which to develop a baseline projection, secondly a literature review of potential developments within wastewater treatment, determining possible scenarios. As this exercise mainly considers emissions from industrial wastewater, and this in turn consists of a number of industries, specific care must be given to selecting suitable projection datasets. Unlike domestic wastewater and larger wastewater treatment companies, who recently committed to a net zero strategy by 2030[39], there is no universal strategy to reduce emissions amongst the number of industries considered under industrial wastewater emissions.

There is also considerable uncertainty owing to the current circumstances concerning EU Exit and COVID-19 pandemic economic measures, and how this may impact levels of production and the expansion of industries and therefore wastewater generation.

### 7.6.1 Baseline projection

Two projection datasets were considered: employment projections from University of Warwick 'working futures' and the BEIS UEP Gross Value Added (GVA) projections by industry. Employment projections could be disaggregated by role and industry, meaning those roles most logically connected to production could be considered. Projections for 'process, plant and machine operatives' were considered. Employment projections were only available up until 2024, however projections up until 2027 could be made available by request[40].

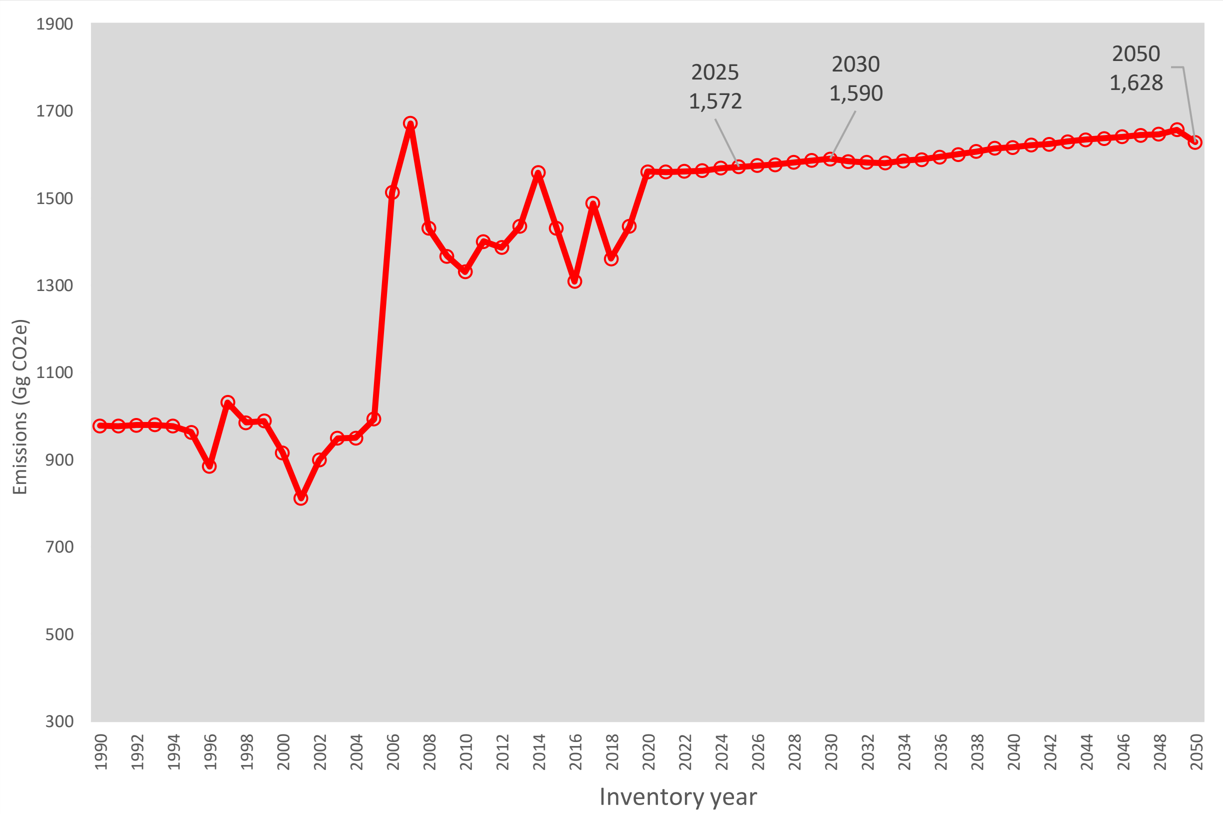
The Working Futures projections showed little to no correlation with activity data, or in some cases even negative correlation. Activity is not correlated to the number of plant operatives by sector. The UEP GVA projections by industry showed a greater degree of correlation. Emissions were grouped into two aggregated sectors, including 'food/beverages' and 'other production', with 'pulp & paper' and 'Organic chemicals' as standalone sectors. The GVA projections is applied to the activity data only, with no changers in other parameters, such as the treatment

[39] Water UK (2020), Delivering a Net Zero Water Sector, available at: https://www.water.org.uk/news-item/delivering-a-net-zero-water-sector/
[40] University of Warwick (2020), Working Futures 2017-2027, available at: https://warwick.ac.uk/fac/soc/ier/wf7downloads

technologies/pathways or wastewater generation factors. This projection, therefore, is overly simplistic, as it serves that, even under a baseline scenario, because treatment incurs costs to industrial sites, a baseline scenario may feature reductions in wastewater generation, owing to cost incentives to improve the efficiency in the production process, or improvements in treatment technology to be cost saving. It does however provide an initial indication towards future trends, provided production processes remain more or less unchanged.

The baseline projection of all sources combined is detailed in Figure 3. Here, all sources and pollutants are converted into $CO_2$ equivalents ($CO_{2e}$, using AR4 Global Warming Potentials) and displayed as a single projection. In 2019, total emissions from all sources and pollutants was estimated at 1,435 Gg $CO_{2e}$, increasing to 1,590 Gg $CO_{2e}$ by 2030, a 11% increase. This trend continues to 2050, peaking at 1,628 Gg $CO_{2e}$, a 2.4% increase upon 2030.

**Figure 3 - Baseline projection for all sources and pollutants as a single projection.**



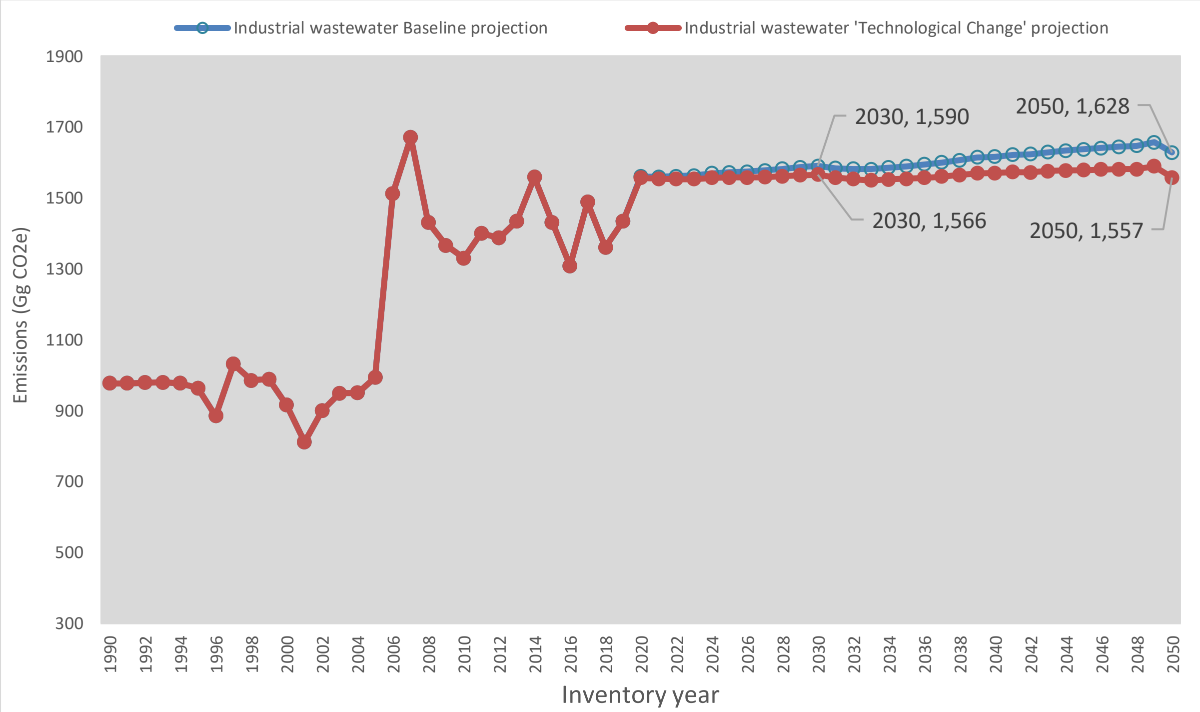

## 7.6.2 'Technological Change' projection

A literature search did not identify any information that may inform upon proposed policies or technology change within the treatment or discharge of industrial wastewater. Further correspondence with the wastewater team within Defra did not yield any further information[41], however efforts are ongoing to improve the understanding of emissions from these sites and possible technological change in light of climate policy. In an effort to provide a projection alternative to the baseline, a 'technological change' projection was developed. This is not informed by any external data source, and therefore does not serve as a ready projection realistic of any policies. Within the projection we assume a decline in the percentage of wastewater treated via 'primary' treatment to zero across the period of 2019-2050. Half of this reduction is allocated to 'secondary' treatment plants, and half allocated to 'tertiary' treatment plants. This is to recognise the inherent logic between these treatment options, and the likelihood that water quality standards will continue to be upheld in the future, placing pressure on improving the treatment technology of select on-site treatment.

The result of this projection, in comparison to the baseline, is detailed in Figure 4. By 2030, the turnover of technological change, between primary, secondary and tertiary treatment plants results in a 1.6% decrease upon the baseline by 2030, increasing by 2050 to a 4.3% decrease upon the baseline, or a reduction in 71 Gg $CO_{2e}$. It should be noted that these reductions are not informed by any external data, and therefore should not be used as a ready projection realistic of any potential policies.

[41] Person communication, Anne Jones, Defra

**Figure 4 - Baseline and 'Technological Change' emission projections to 2050**




# 8 Domestic wastewater – proposed changes to the Carbon Accounting Workbook

Currently, the 2006 IPCC Guidelines does not consider $N_2O$ emissions from centralised WWTPs as a significant source. The 2019 Refinement notes that $N_2O$ emissions are more important than previously thought, specifically when wastewater is discharged into eutrophic conditions or nutrient-impacted water bodies. New evidence suggests that emissions in sewer networks and from nitrification or nitrification-denitrification processes at WWTPs can be significant. Therefore, the 2019 Refinement includes updated guidance to estimate domestic $N_2O$ emissions from centralised WWTPs, since $N_2O$ is generated as a by-product of nitrification, or as an intermediate product of denitrification.

In order to account for losses of nitrogen occurring within the wastewater treatment process, it is necessary to determine the type of treatment deployed: nitrogen removal varies between 0% (no treatment) and 80%, for advanced biological tertiary treatment. The information currently provided by the wastewater companies or available in industrial permits or national statistics does not include the use of each type of treatment. Therefore, it would be difficult to apply this new method.

While reviewing the information in the CAW, the tool deployed by UKWIR described in Section 2.2.1, it became apparent that wastewater companies already include in their reports the total $N_2O$ emissions from receiving water bodies. Since this additional data is not included in the data from the CAW that the Inventory team receives every year, a change to the specific data supplied by each company seemed necessary, in order to fulfil the new obligations towards the 2019 Refinement.

The proposed changes to reporting of data from the CAW to support the NAEI was discussed with UKWIR and representatives from water companies during a conference call on Friday 12$^{th}$ June 2020. The supply of this data was supported by all participants and a formal request to change the data supplied has been submitted to UKWIR.

# 9 Improvements to the Overseas Territories and Crown Dependencies inventories

Generally, activity data for the Overseas Territories and Crown Dependencies (OTsCDs) is not collected and available from the typical datasets that are collated for use in the core UK inventory. As such, fully harmonising the methodologies for OTsCDs with that used for the rest of the UK is not always practical or possible due to data limitations. Therefore, independent, and often simplified compilation methodologies are applied for the OTsCDs across all reporting sectors. The description of methods is reported in the Annex A3.6 of the UK's NIR[42] to explain the appropriateness of methods and to justify geographical inconsistency in methodology.

As such, the wastewater inventory for the OTsCDs has historically been completed at Tier 1 level. For context, emissions from waste category 5.D for the OTsCDs have been estimated to contribute 1.3% of the UK total for category 5.D and only 0.01% of the UK national total GHG emissions.

In order to update the OTsCDs inventories to be representative of the 2019 Refinement, two main actions are required:

- Update the relevant default emission factors within the inventory compilation spreadsheets that have changed between IPCC 2006 and the 2019 Refinement.
- Investigate the availability of additional activity data and information on treatment systems to confirm appropriateness of methodologies and to inform the development of new emission estimates (principally related to wastewater treatment plants).

Updating the default Tier 1 emission factors is a relatively straight forward task once appropriate activity data has been sourced. In order to confirm existing, and acquire updated activity data, representatives from the OTsCDs were contacted by email. The key aspects that were requested were:

- To identify treatment pathways for domestic wastewater, which may include:
    - Uncollected (discharge direct to sea, river, lake etc.)
    - Collected (septic tanks, pit latrines, treatment plants with primary, secondary or tertiary treatment). For advanced treatment plants, we would like to gather detailed information (where possible) on the treatment steps/ processes utilised.
- To gain information on when new systems / facilities opened
- To identify whether any companies / industries exist that treat wastewater on site (typically this may be food and drinks sector, breweries, distilleries, fish processing)

After initial contact and subsequent follow up, representatives from Jersey, Cayman Islands and Guernsey responded to indicate that they were able to engage with this activity. Existing data and information related to Falkland Islands and Isle of Man indicates that no wastewater is treated by facilities, with direct discharge to water sources and use of septic tanks being the prevalent treatment pathways. Therefore, further contact was deemed extremely low priority and not explored further. No responsive contact point could be attained for Bermuda, although existing inventory data indicates that only 5% of wastewater is treated by a sewage treatment plant, making this a low priority data point.

As of October 2020, detailed data on wastewater treatment has been received from Jersey covering the period 2005-2019. The data includes facility level activity data (as $m^3$/year) and organic loading (as BOD/COD) as well as nitrogen content in the wastewater. This data can be incorporated into the inventory. Although initial contact was received from Cayman Islands and Guernsey, no such detailed facility data has been acquired that would enable significant improvements at this stage.

The actions completed under this project will enable updated default parameters to be incorporated into the GHG inventory for the OTsCDs. In addition, improved and more detailed timeseries data for the wastewater treatment facility in Jersey has been received. At this point, no further activity data improvements have been made available, or identified for Guernsey, Cayman Islands and Bermuda.

It is not yet evident whether sufficient and accurate data is being used to represent the treatment of wastewater in wastewater facilities across the OTsCDs. It is therefore considered premature to submit a recalculated inventory for the OTsCDs based on the 2019 Refinement at this stage. Given the current non-mandatory status of the 2019 Refinement, it is further considered unsuitable to implement and justify a partial and uncertain application of the 2019 Refinement at Tier 1 level across the OTs and CDs. Further minor recalculations are likely to result from the contact that has been made to date, and such work will now continue as part of the cyclical inventory preparation for the OTsCDs GHG inventory.

# 10 Conclusion

[42] BEIS (2020), A3.6 UK Crown Dependencies and Overseas Territories Annexes: 1990-2018 GHGI, available at: https://uk-air.defra.gov.uk/assets/documents/reports/cat09/2004231037_ukghgi-90-18_Annex_v02-00.pdf

Work undertaken has been successful in resolving the limitations of the previous methodology used to estimate industrial wastewater emissions, though notably has not achieved a Tier 2 method. A new Tier 1 methodology has been produced, compliant with the 2006 IPCC Guidelines and inclusive of the additional sources of $N_2O$ that now feature in the 2019 Refinement to the 2006 IPCC Guidelines. This new Tier 1 method is based on a series of analysis carried out on Prodcom data sourced from Eurostat, the Environment Agency's Consented Discharge Database, and permits for those industrial sites publicly available and regulated by the Industrial Emission Directive (IED). Whilst a Tier 2 methodology was attempted, this was only possible for England given the current devolved nature of industrial permitting. National datasets do exist, in the form of the UK Pollutant Release and Transfer Register (PRTR) and the Environment Agency's Pollution Inventory. This data was analysed and evaluated and found to be problematic with regards to the scope of sites included, the lack of fields denoting treatment technologies, and a limited timeseries. Nor was it possible to derive treatment technologies from permit documentation made previously available by the Environment Agency to Ricardo, owing to inconsistencies in terminology and their unavailability in bulk.

The comparison between the previous Tier 1 method and the new Tier 1 estimates do represent a marked improvement, owing to the use of specific emission factors for treatment technologies. Previously, as noted in Section 2.1, the method used emission factors from the 1996 IPCC Guidelines representative of a country's wastewater treatment performance, the factor used, however, was notably high in comparison to the mix of emission factors later available in the 2006 IPCC Guidelines. This disparity was noted in multiple reviews but could not effectively be addressed without the identification of a dataset that would provide the split of treatment technologies across industries. Data provided by the Environment Agency Consented Discharge Database provides the first characterisation of treatment split. There remain areas of uncertainty, which should be prioritised in future reporting cycles, including:

- Periodically reviewing the treatment splits, when and if new data is made available.
- Further reviewing Prodcom data in future updates. It may be the case that in future reporting cycles Prodcom data is no longer updated for the UK. In this case, it may be necessary to liaise with the Office for National Statistics, to ensure the data continues, or an alternative dataset is sought.
- Periodically reviewing wastewater generation factors, relative to practices in the UK

These points of uncertainty should be handled through the use of the 'issue log' in annual compilation, where points are raised concerning data and methodology, for consideration of NAEI experts. Implementation of the above into the NAEI, is likely to be of interest in future review cycles. In order to be proactive in laying out the underlying approach behind this improvement and in recognition of a number of past review queries concerning industrial wastewater, draft text for the next National Inventory Report, to be provided as a summary and reference to this report, is detailed in this report in Section 10.1.

Whilst a Tier 2 method has not been achieved, this analysis does provide a set of recommendations that may, together, realise a Tier 2 method, but require further resource and development, primarily by other agencies outside the NAEI consortium. These recommendations are:

- The development of a national dataset that captures, in addition to annual data on key variables such as total organic carbon and total nitrogen treated, metadata such as the treatment technology and volume of wastewater treated.
- The above should be considered within the context of revisions to existing national datasets, such as the Environment Agency's Pollution Inventory, such as revising downwards the threshold for releases for both total organic carbon and total nitrogen, which, when applied, only capture a limited number of sites, potentially exempting the majority of sites from reporting.
- As the Environment Agency manage the Pollution Inventory, with assistance of devolved regulatory agencies, it suits that this is a task best led by, or with technical input from, the Environment Agency.
- For the historic timeseries, from 2013 onwards, metadata regarding the treatment technology and volume could be determined by integrating the Environment Agency's Consented Discharge Database with the Pollution Inventory. Whilst this has been attempted under this project (see Section 7.4.1), the Environment Agency should be able to more readily map between different identifiers.

## 10.1 Text for the National Inventory Report

Between the 2018 and 2019 NAEI GHGI reporting cycles, BEIS has funded an improvement item targeted at improving the emission estimates for industrial wastewater treatment, in addition to emissions from the discharge of both domestic and industrial wastewater into water bodies. This was implemented due to, in part, a number of past review comments regarding the limitations of the previous Tier 1 emission estimates, and part in pre-empt of the 2019 Refinement to the 2006 IPCC Guidelines. This annex presents the implementation of a revised Tier 1 emission estimates for industrial wastewater (5D2), alongside a number of findings relevant to wastewater data in the UK.

### 10.1.1 Previous Tier 1 estimates for Industrial Wastewater

By way of context, the previous Tier 1 emission estimates are estimated through a series of estimates published by the Department for Environment, Food & Rural Affairs (Defra) in 2000. These estimates pertain to the total 'organic load' (total degradable organic content within wastewater) from 11 industry sectors, including milk processing, breweries and malt houses in units of population equivalents.

Additional, separate activity data towards the production of organic chemicals is used to provide an emission estimate from this sector, via production estimates in 2009 from 'Prodcom' statistics, an economic dataset breaking down major sectors of the economy, supported by Eurostat and the UK Office for National Statistics. This output is multiplied by wastewater generation factors per tonne of product and a factor representing the Industrial degradable organic component within wastewater, to estimate the total organic load within the organic chemicals industry.

The organic load estimates for organic chemicals and the organic load for the other 11 industries, are scaled according to the 'index of production' (IOP) for each industry, a dataset detailing growth or decline by industry, to approximate the organic load in other years of the timeseries.

Once scaled across the timeseries, the organic load is multiplied by an emission factor per unit of organic load (chemical oxygen demand [COD]), derived from applying the 'maximum $CH_4$ producing capacity' and a 'methane correction factor' (MCF), to estimate methane emissions from treatment. The MCF originates from the 1996 Guidelines and represents the factor for Australia, Canada and USA, and is assumed representative of UK treatment practices. The 2006 IPCC Guidelines, however, include MCFs per treatment pathway (or treatment technology) and therefore offer a refined approach when compared to the previous MCF, provided data describing treatment pathways/technologies is available.

The NAEI team understands the main limitations associated with the previous approach to be:

- The sourcing and processing data pertaining to the proportion of wastewater treated through different pathways/technologies, revising the MCF by implementing the methodology present in the 2006 IPCC Guidelines.
- Sourcing of key country specific activity data if available, replacing the scaling of organic load data by the Index of Production with wider estimates on total organic carbon or total nitrogen per industry sector.
- The estimation of emissions from 'new' sources within the 2019 refinement to the 2006 IPCC Guidelines, including $CH_4$ emissions from wastewater discharge and $N_2O$ emissions from industrial wastewater treatment and discharge.
- $CH_4$ emissions from wastewater treatment (5D) is a key category, therefore require at least a Tier 2 method.

### 10.1.2 Revised Tier 1 estimates for Industrial Wastewater

Multiple routes to achieve the above were considered, including a review of permit documentation and the UK's Pollutant Release and Transfer Register (PRTR). Both have limitations regarding their ability to inform the above. A text-mining review of the library contains over 1400 permits for industrial sites considered under the environmental permitting regulations, maintained by Ricardo Energy & Environment, revealed limited instances where information on treatment technology is detailed. Such a result implies a limited ability for permit documentation to inform treatment pathways/technologies.

Similarly, though the UK PRTR represents a national dataset reporting total organic carbon or total nitrogen by industrial installation, analysis suggests its use is limited by an absence of detail on treatment technologies, a limited number of reporting sites and a short timeseries. The use of the UK PRTR is specifically limited by the use of high release thresholds for releases to waterbodies, meaning a number of sites that exceed the capacity thresholds, therefore requiring reporting, are not then obligated to report site specific releases. The UK also hosts a Pollution Inventory, an extension beyond the UK PRTR to include a number of other environmental permitting activities and reporting. This, similarly, is limited by the same issues. Utilising country specific data from these datasets, in addition to researched information sourced from permit documentation, therefore is unlikely to meet the needs of a Tier 2 methodology.

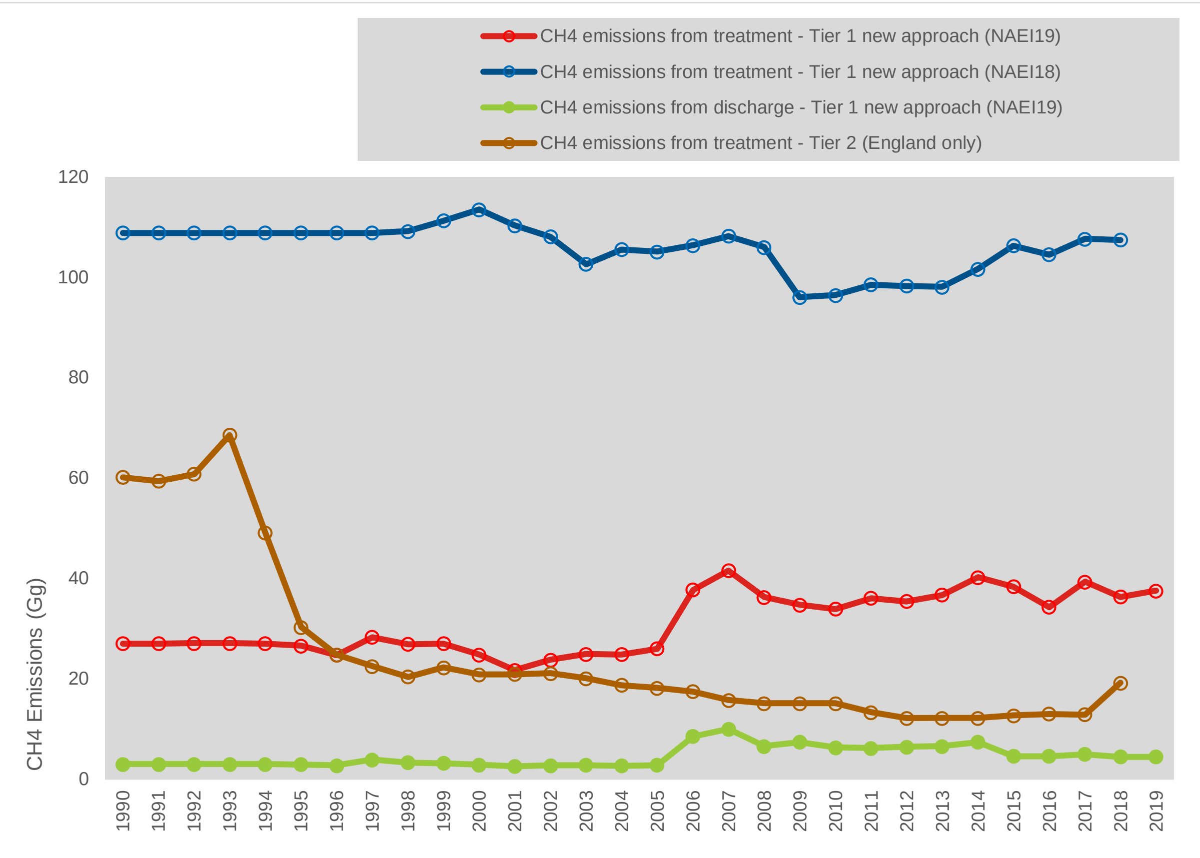
One potential route, further investigated, was the use of the Environment Agency's 'discharge consents register', detailing the consents for a range of treatment plants operated by water companies and industrial sites, in addition to other forms of discharge such as sewer overflows, or discharges from commercial premises such as pubs and bars.

Crucially the register also contains a series of 'determinands', typically referring to the properties of a sample when measured, with regards to specific maximums or regulatory limits (e.g. maximum biochemical oxygen demand [BOD] when measured according a specific sampling method). The database also includes a table of effluents, with variables representing different measures of flow, and a variable characterising the type of treatment technology or lack of treatment. The register therefore offers the potential to provide an initial Tier 2 estimate and inform upon parameters such as the split of treatment pathways/technologies. Notably, however, whilst similar register exists for other Devolved Administrations, the Environment Agency's 'discharge consents register currently considers England only, and other registers are formatted according to the requirements of different regulatory agencies, complicating the derivation of a combined UK register.

The split of treatment pathways/technologies, however, enabled a revised Tier 1 estimate, using production data sourced from Eurostat's Prodcom Database, with emission factors and wastewater generation factors sourced from the 2019 Refinement to the 2006 IPCC Guidelines, the 2006 IPCC Guidelines or analysis of the permits released by the Environment Agency under the Industrial Emission Directive. A Tier 2 estimate was also developed, but accounts only for England in scope, needing to be scaled to the national level. An assessment of comparable elements, such as wastewater generation, between the two approaches, highlighted wide disparities for specific sectors, such as chemicals, but little to no disparity for food & drink. An underestimate was anticipated, considering that the Tier 2 estimates include only England in scope, but estimates of generated wastewater were consistently higher than revised Tier 1 estimates.

As shown in Figure 5, substantial variation in wastewater generation estimates were observed across the Tier 2 timeseries, along with several likely outliers identified, indicating substantial uncertainty in the early 1990s. When compared on an emissions basis, $CH_4$ emissions are similar for the Tier 2 and revised Tier 1 estimates, beyond 1995. Both, however, are substantially below the previous Tier 1 estimates, by at least 44%.

**Figure 5 - $CH_4$ emissions from wastewater treatment (5D): comparison of NEIA 2018 emissions and revised estimates using Tier 1 and Tier 2 (England only) approach**



# Appendix – Derivation of alternative factors

| Industry type | Wastewater generation (W) ($m^3$/tonne) | Calculation | Notes | Source | Comparison to IPCC default |
|---|---|---|---|---|---|
| Dairy Products | 14 | = AVERAGE(960/((3200/7)),((1800/((17300+8550)/365)))) | First value based on IED permit production estimates and wastewater generation estimates (3,200 tonnes of milk per week, generating 960 metres cubed of wastewater per day) from Yeo Valley's Lag Farm Dairy. Second value based on production estimates for cheese and whey from The First Milk Cheese Company Limited, Lake District Creamery. At the creamery, 17,300 tonnes of cheese and 8,550 tonnes of whey are produced annually. Limit of 1,800 metres cubed per day of wastewater in permit schedule. | | +7 |
| Pulp & Paper | 10 | = =AVERAGE(15000/((550000/365)),(40500/((750000+365000)/365)),7000/(425000/365)) | The first value within average equation, is based on IED permit production estimates for Palm Paper Ltd, producing 550,000 tonnes per annum divided by the permit wastewater flow rate per day. Second value, from the IED permit notice for the Kemsley Paper Mill, operated by DS Smith Paper. Tonnages of paper produced per year as specified from all three of the paper making units, with 750,000 tonnes produced from units 3 & 4. Unit 6 produces 365,000 tonnes per year. Maximum daily wastewater flow specified as 40,500 metres cubed per day. Third value originates from the IED permit variation notice for SAICA Paper UK Limited's Partington Paper Mill, which specifies a approximate annual production of 425,000 tonnes of recycled paper and a flow rate through effluent treatment of 7000 metres cubed per day. | | |

| Industry type | COD (kg/m3) | Calculation | Notes | Source | |
|---|---|---|---|---|---|
| Coffee | 5.9 | NA | Based on the COD within the permit variation notice for Nestle's Tutbury factory, where instant coffee is produced. | | |
| Petroleum Refineries | 0.43 | =AVERAGE(((12*1000)/18000),200/1000) | First value within average equation is based on the IED permit for Teeside Crude Oil Stabilisation Plant. Permit provides a COD value of 12 tonnes/day, with a nominal flow rate of 18000, metres cubed of wastewater. Site uses biological effluent treatment. The second value originates from the IED permit notice for the Total Lindsey Oil Refinery in Lincolnshire, which specifies a COD value of 200 micrograms/litre. | | |

| Industry type | COD (kg/m3) | Calculation | Notes | Source | |
|---|---|---|---|---|---|
| Pulp & Paper | 0.21 | =210/1000 | COD value for Partington Paper Mill, operated by SAICA paper mill. Wastewater treated by the on-site effluent treatment plant (ETP) via primary, secondary and tertiary treatment stages. | | |

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