Greenhouse gas accounting in Environmental Permitting Regulations (EPR) permitting

Final report

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Executive summary

Currently there is no regulatory mechanism for accounting for the carbon impact of treatment when permitting a wastewater treatment works (WwTW) for water quality purposes. This means that it is possible that decisions are being made for water quality which have a disproportionate impact on Greenhouse Gas (GHG) emissions. For this to change, there would need to be a clear signal from Government departments, such as Defra, along with the development of an agreed tool or method for calculating GHG emissions from different treatment options and scenarios.

If a future is envisaged where GHG emissions are accounted for in permitting decisions, then there would need to be an open dialogue between water companies and the Environment Agency (EA) to allow an informed discussion on where the tipping point between water quality and GHG emissions lies. It is expected that this point would be site or at least catchment specific. Following an initial permitting decision from the EA, water companies could use the agreed tool to determine the GHG emissions from different treatment options or solutions, associated costs and the risk of non-compliance. This would then start the discussion with the EA on what the acceptable GHG emissions compared to permit compliance is.

A review of the existing and emerging accounting tools identified that with the currently available tools the EA and water companies can:

- Quantify GHG emissions from WwTW with activated sludge processes (ASP) as secondary treatment
- Calculate GHG emissions in tonnes of CO_2 equivalent

However, they cannot:

- Use the tools if they have limited input data
- Quantify GHG emissions from WwTW with trickling filters as secondary treatment
- Give estimations with updated emission factors (EF) for N_2O emissions
- Use a tool developed in the UK specifically suited for the UK water sector
- Estimate embodied carbon emissions
- Estimate GHG emissions from assets for tertiary treatment for the removal of phosphorus, organic chemicals and/or metals

A total of six GHG accounting tools and four emerging approaches were identified and evaluated to assess their suitability for permitting purposes. Five additional tools were also identified but discarded as there was limited information available.

Based on the evaluation, it was concluded that:

- The existing tools were complex and require a large range of data inputs, often including population equivalent, influent and effluent flow, biological oxygen demand (BOD) load, total nitrogen (TN) load, energy consumption on site and type of power used. It is expected that these data sets will generally be available for WwTW.

- Default values for some inputs were included within many of the tools, but it was not possible to assess whether these were valid within a UK context.
- In general, the tools target both wastewater and sludge treatment and disposal and are best suited to WwTW employing centralised aerated processes for biological treatment, such as ASP or similar processes. Disposal routes for sludge typically included anaerobic digestion, with other options also available.
- Trickling filters were generally not included within the tools. Advanced treatment options such as for phosphorus removal or addressing priority substances were not included in either the existing or emerging approaches.
- The tools tend to target scope 1 (direct emissions, including process, fugitive and fuel/combustion), scope 2 (emissions from the generation of purchased electricity used) and scope 3 (all other indirect emissions, and can include materials, waste or embodied carbon) emissions but exclude carbon associated with the provision and transport of chemicals needed for treatment.
- All tools provide the results in tonnes of CO_2 equivalent (tCO2-eq), converted from tonnes of N_2O, CH_4 and CO_2.
- Default values within the tools included emission factors (EF) for separate GHG. The available information suggests that these factors have not been updated or amended for a number of years. The 2019 Intergovernmental Panel on Climate Change (IPCC) refinement document (TFI, 2019) along with advances in monitoring technologies (Unisense and Cobalt Water Global for example) means that these default EF are outdated.
- No one tool was identified as directly implementable today for permitting purposes, due to not all treatment technologies being included, and / or the use of outdated EF. However, they do provide a good basis for developing a suitable tool in the future.

The recommendations from the research were to:

- Address the gaps in knowledge regarding embodied carbon
- Improve the N_2O EF either through updating the existing tools to take into account the IPCC refinements or (ideally) through the use of the data from monitoring activities being undertaken within the UK
- Determine the availability for the input data required within the tools, and for any data not readily available, determine the impact of using default values
- Develop a tool which incorporates emissions associated with trickling filters, tertiary and non-conventional treatment.

If and when a tool is developed, it is further recommended that pilot testing with one or two water companies is undertaken to determine how GHG emissions can be incorporated into permitting decisions in practice. Some specific steps towards developing a tool and determining its implications are provided under Future Work.

Introduction

On an international scale, the 2015 Paris Agreement set a goal to limit global warming to well below 2 °C, preferably to 1.5 °C, compared to pre-industrial levels, with anything above these limits seen as a tipping point when it comes to climate change (UNFCCC, no date). The UK Government has followed suit, publishing a 25 Year Environment Plan in 2018 to improve the Environment (HM Government, 2018). Since then, the UK Government has passed legislation to bring all greenhouse gas emissions (GHG) to net zero by 2050 (BEIS, 2019) and as of November 2019, the Government sees the 'Green Industrial Revolution' being key not only in meeting the 2050 net zero target but also for supporting the economy (PMO, 2020). Furthermore, the UK was at the centre of efforts to address climate change, with the 26th UN Climate Change Conference of the Parties (COP26) hosted in Glasgow. The UK Government defined a Net Zero Research and Innovation Framework (HM Government, 2021) which sets out key research and innovation challenges for the UK over the next five to 10 years to support the delivery of the UK's Net Zero Strategy. It presents the challenges across the carbon budget and related sectors including reducing process emissions and energy use in the treatment of wastewaters.

The Environment Agency (EA) has committed to being Net Zero by 2030, supporting the UK's strategy to achieve Net Zero by 2050. As an environmental regulator, its decisions impact the GHG emissions of the sectors it regulates. Being able to quantify these emissions (for example because of permitting decisions) will not only enable the EA to understand and value these as part of its consideration of costs and benefits in its regulatory activities, but also help the water industry to have informed discussions around different treatment options.

There is a concern, expressed through recent UKWIR projects such as those under the Chemical Investigations Programme, that future permitting of Priority Substances (PS) will result in significantly increased GHG emissions due to the scale of additional wastewater treatment required. It is also expected the next two Asset Management Plans (AMP7 and AMP8) will add around 12% of additional Scope and 2 emissions.

Despite pressures associated with population growth and tighter regulatory standards, the UK water sector achieved reductions of its gross operational GHG emissions by almost 45% between 2011-12 and 2018-19. The sector is ambitious and in 2020, water companies unveiled their plan to deliver net zero GHG emissions by 2030, two decades ahead of the UK Government's legally binding target. To meet the target, specific areas of focus relate to low emissions vehicles, water and energy saving, process emissions, renewable power, green gas, restoring native habitats, targeting innovation and offsetting residual emissions (Water UK, 2020). The Net Zero Research and Innovation Framework describes several needs to reduce GHG emissions from wastewater treatment. These include: 1) research and modelling for data improvement, 2) implementation of widescale monitoring of emissions to understand sources and optimisation of current practices, 3) research and trials to improve understanding and enable deployment of novel processes and 4) appraisal of the benefits and costs of different mitigation options for the wastewater treatment sector.

Isle Utilities Ltd. (Isle) were commissioned to identify and assesses which GHG accounting tools and methodologies are available, what latest innovations are being undertaken and what the main gaps and risks are in this space. Future work is proposed to help bridge these gaps.

Aim and objectives

The aim of the project was to provide initial background information to aid the further development of methodologies and tools to account for GHG emissions from wastewater collection and treatment in water discharge activity and groundwater activity permitting decisions for water company discharges.

The specific objectives were:

1. Review existing approaches and methods for quantifying GHG emissions from wastewater collection and treatment within the water industry or other sectors that may be applicable to the water industry.
2. Consider and report on the ‘art of the possible’ building on these approaches including the practicalities of developing a method. In short, can it be done?
3. Carry out a gap and risk analysis to identify any elements that are missing and need to be derived or improved.
4. Provide recommendations for next steps and a scope for a wider project to develop the method where appropriate. This scope should include consideration of practical application of the findings to the permitting approach.

This knowledge will enable the EA to review how emissions of GHG can be incorporated or acknowledged in permit setting, providing a holistic approach to environmental protection.

When evaluating the existing and emerging tools for the quantification of GHG emissions for the purposes of permitting, the following factors were considered as important:

- Applicable to a range of different size WwTW (based on population equivalent);
- Applicable to a range of different treatment processes, including conventional and novel and additional;
- Inputs based on data readily available to the EA or water companies;
- Utilises the most recent emission factors and other default values; and
- Applicable within England based on climatic factors and typical wastewater characteristics.

Current approaches for the quantification of GHG emissions

A description of existing approaches for GHG emission quantification was undertaken through reviewing scientific journal papers, general database searches and identifying publicly published reports. Isle also drew upon its water utility and academia network to gather further information.

Isle held interviews with four organisations inside and outside the UK to gather their opinion on the tools they are currently using or developing to estimate GHG emissions:

- Scottish Water, UK;
- Severn Trent Water, UK;
- Brunel University, UK; and
- Confidential research institution, Sweden.

A summary of the main findings from the interviews is included throughout this report.

The methodology for assessing the tools in terms of their complexity and their applicability was based on a scoring system to categorise them as 'Low', 'Medium' or 'High'. The complexity was assessed by considering the number of input data points required. The applicability was assessed based on three criteria: 1) flexibility (i.e. flexibility for the tool to be applied to small, medium or large WwTW), 2) adaptability (the need to adapt the tool if developed outside of the UK) and 3) accessibility (being freely available or available under licence). The scoring criteria for complexity and applicability are included in the Appendix.

A total of 15 existing tools or methodologies were identified to estimate GHG emissions from wastewater and / or sludge treatment. Of these, four were discarded for the purpose of this project mainly due to lack of information on input data requirements, tool structure and output details.

Out of the remaining 11 tools, five of them had limited information available (such as details on how to access and use the tool and case studies) and hence could not be assessed in detail for the purpose of this project. The name, provider, country of origin and reference to these five tools are:

1. C-Foot-Ctrl by the National Technical University of Athens (Greece) (C-Foot-Ctrl, 2016)
2. Carbon accounting guidelines for wastewater treatment by Water New Zealand (New Zealand) (Water New Zealand, 2021)
3. Benchmark simulation model by the International Water Association (Canada) (Guo et al., 2012)
4. Energy and GHG accounting model by TERI University (India) (Singh and Kansal, 2018)

5. Model of Carbon Footprint Assessment for the Life Cycle of the System of Wastewater Collection, Transport and Treatment by the Central Mining Institute (Poland) (Zawartka et al., 2020)

There was detailed information for the remaining six tools that allowed their assessment for the purpose of this project. This report focuses on these tools. The name, provider and country of origin of these tools are included below:

1. Energy performance and Carbon emissions Assessment and Monitoring (ECAM) by the International Water Association in collaboration with the German Corporation for International Cooperation GmbH (GIZ) (Germany) (ECAM, 2022)
2. Biosolids Emissions Assessment Model (BEAM) by Sylvis Environmental (Canada) (Brown et al., 2010)
3. Carbon Footprint Calculation Tool (CFCT) by VA-teknik Sodra (Sweden) (VA-teknik Sodra, 2014)
4. U.S Inventory of Greenhouse Gas Emissions and Sinks (USIGHGES) by the US Environmental Protection Agency (EPA) (USA) (USEPA, 2021)
5. Carbon Accounting Workbook (CAW) by UKWIR (UK) (UKWIR, 2021)
6. NGER Wastewater (Domestic and Commercial) Calculator (NGER) by Clean Energy Regulator (Australia) (Australian Clean Energy Regulator, 2021)

Table 1 summarises the main characteristics of these tools including an assessment of their complexity, applicability, advantages and disadvantages.

Table 1. Summary of established carbon accounting tools for WwTW.

Name	Description of tool	Users	GHG Types	GHG Scopes	Treatment stages included	Complexity *	Applicability *	Advantages	Disadvantages
ECAM	Calculates emissions from water abstraction to treated wastewater disposal in nine sub-categories. Process inefficiencies are identified by comparing results with known benchmarks. It is part of the knowledge platform by the Water and Wastewater Companies for Climate Mitigation (WaCCliM) Project (WaCCliM, 2020), is regularly updated and is free to use.	Utilities in Peru, Mexico, Thailand, Jordan	CH_4, CO_2, N_2O	1, 2, 3 - No embodied carbon	• Secondary (aerobic/ anaerobic) • Sludge digestion • Sludge disposal • Biogas flaring	Difficult	Easy	• Calculates emissions across the whole urban water cycle (abstraction - disposal). • Stores historical IPCC default values for version compatibility.	• Uses global IPCC conversion / emission factors from 2006. • Does not contain data or the methodology for assessing complex WwTW e.g. with pre-treatment, primary or tertiary treatment. • Source of some values unknown.
BEAM	Focuses on emissions from sludge treatment and disposal strategies. The tool is modular and has analytical tools to identify the greatest contributors to GHG emissions. It was validated with data from Canadian municipalities, and has been adopted in several tools and carbon accounting strategies (e.g. ECAM) (Robinson, 2020; Bioforcetech Corporation, 2021; McLeod and Lake, 2020). Free to use.	ECAM, Canadian utilities	CH_4, CO_2	1, 2, 3 - No embodied carbon	• Sludge digestion • Sludge disposal • Biogas flaring	Difficult	Medium	• Calculates emissions from a wide selection of biosolids treatment techniques. • Accounts for the life cycle carbon cost of chemicals used, e.g. production & transport to the WwTW.	• Uses global IPCC conversion / emission factors. • Some default values are taken from slightly outdated literature (>10 years ago). • Only applicable to sludge management and disposal

*Refer to Appendix for more information on the assigned scores.

Table 1 (continued). Summary of established carbon accounting tools for WwTW.

Name	Description of tool	Users	GHG Types	GHG Scopes	Treatments Included	Complexity *	Applicability *	Advantages	Disadvantages
CAW (2008 version)	Estimates operational GHG emissions in WwTW in the UK, particularly from electricity usage and sludge treatment. Calculations are done according to Defra's Carbon Reduction Commitment (CRC) and Defra guidelines, and results are reported separately. Emission and conversion factors are taken from CRC and Defra guidelines and are specific to the UK water industry. The workbook has been in place for over ten years, is updated periodically. It can be purchased from UKWIR	All major utilities in the UK	CH_4, CO_2, N_2O	1, 2, 3 - No embodied carbon	• Primary treatment / secondary treatment (not sub categorised) • Sludge digestion • Sludge disposal / storage	Difficult	Medium	• Has a detailed analysis of electricity consumption from different activities. • Calculates emissions for water treatment as well.	• Does not show equipment-specific emissions for wastewater treatment. • Assumes a standard efficiency for the whole wastewater treatment process, with no option to vary the final effluent quality.
CFCT	Developed to accurately calculate GHG emissions for WwTW in Sweden. Local emission factors are taken from the latest published literature. The tool calculates emissions based on BOD treated instead of equipment types as most Swedish WwTW have standard treatment trains for wastewater. Users can specify the fates of final effluent, sludge and biogas to more accurately calculate waste emissions. Free to use.	Most major utilities in Sweden	CO_2, CH_4, N_2O,	1, 2, 3 - No embodied carbon	• Primary and secondary treatment • Denitrification (MBBR / SBR) • Biogas flaring • Sludge / solids disposal	Medium	Medium	• Accounts for the life cycle carbon cost of chemicals used, e.g. production & transport to the WwTW. • Local emission factors are based on actual data from Swedish WwTWs.	• The tool is built to calculate emissions according to BOD treated and is unable to account for the impact of different treatment techniques on carbon emissions. • Emission factors unlikely to be relevant to the UK.

*Refer to Appendix for more information on the assigned scores.

Table 1 (continued). Summary of established carbon accounting tools for WwTW.

Name	Description of tool	Users	GHG Types	GHG Scopes*	Treatments Included	Complexity **	Applicability **	Advantages	Disadvantages
USIGHGES	Calculates process emissions in both municipal and industrial wastewater treatments in the US, mainly from secondary treatment. Where available, state-specific data is used and default values are taken from the IPCC guidelines. The tool calculates emissions based on BOD treated instead of equipment type. The tool is reviewed every year and is free to use.	US utilities (how many is unknown)	CH_4, N_2O	1, 3 - No embodied carbon, or carbon from fuel / electricity usage	• Secondary treatment (aerobic / anaerobic) • Wetlands • Sludge digestion • Final effluent discharge	Easy	Difficult	• Calculates and compares historical emissions up to 30 years ago subject to historical population and environmental data.	• Does not account for electricity usage on WwTW which is a major source of emissions (Wang et al., 2016). • The tool is built to calculate emissions according to BOD treated and doesn't quantify the impact of different treatment techniques.
NGER	Calculates process emissions from domestic/commercial wastewater treatment plants in Australia according to IPCC guidelines. It mainly accounts for emissions in secondary and sludge treatment. It offers various methods to calculate each type of emission, and reports an overall value for each greenhouse gas. Free to use.	Australian utilities (how many is unknown)	CH_4, N_2O	1, 3 - No embodied carbon, or carbon from fuel / electricity usage	• Secondary treatment (aerobic / anaerobic) • Sludge digestion • Anaerobic lagoons • Final effluent discharge • Biogas flaring	Medium	Medium	• Accounts for post-treatment emissions by specifying fate of final effluent	• Does not account for electricity usage on WwTW which are a major source of emissions (Wang et al., 2016). • Does not allow users to modify the values for emission factors.

*Scope 1 refers to direct GHG emissions (including process, fugitive and fuel/combustion), scope 2 refers to emissions from the generation of purchased electricity used and scope 3 accounts for all other indirect emissions, and can include materials, waste or embodied carbon (WRI, 2004).** Refer to the Appendix for more information on the assigned scores.

In general, all the identified tools target wastewater treatment including both wastewater and sludge (both treatment and disposal), with the exception of the BEAM tool, which focuses on sludge treatment and disposal only. All tools have been used by major water utilities in different countries and they all target scope 1, 2 and some 3 emissions (excluding embodied carbon), except for USIGHGES and NGER. These two tools only target scope 1 and 3 emissions, and hence exclude any emissions linked to electricity use, which have been reported to be one the highest contributor to GHG emissions (Wang et al., 2016). Scope 1 refers to direct GHG emissions (including process, fugitive and fuel/combustion), scope 2 refers to emissions from the generation of purchased electricity used and scope 3 accounts for all other indirect emissions, and can include materials, waste or embodied carbon (WRI, 2004). Scope 2 emission calculations could be added to these two tools, but it would require a considerable amendment to the methodology.

All tools require a large number of input data which make the tools somewhat difficult and challenging to be used. One of the tools (USIGHGES) requires low input data, but it was considered that this would make the estimation of GHG less accurate compared to the other tool, although it is unknown how much less accurate. In terms of output data, all tools report the emissions as tCO2equivalent (tCO2e). This is to account for the different potential to accelerate global warming of each GHG. As the reader is likely already aware, the standard approach to calculate the tCO2e of a GHG is to identify its Global Warming Potential (GWP) and multiply that by the amount of the GHG emitted. CO_2 is used as a common unit because it is the most abundant GHG. The GWP of CH_4 is 25 and 298 for N_2O (BEIS, 2021).

The tools only account for ASP or similar technologies. They do not estimate emissions from WwTW which employ trickling filters for biological wastewater treatment. An exception to this is the ECAM tool which accounts for CH_4 emissions from trickling filters.

Most of the tools, except for CAW, have been developed and optimised for use outside of the UK. They include country specific values and calculations, including the specific energy emission factors used for operational CO_2 emissions based on the energy mix in that country. These would need to be adapted to the UK water industry characteristics in order to be used in the UK; data published by Defra is available to do this. GHG emissions can vary not only due to the treatment processes used, but also due to the wastewater characteristics and due to weather, rainfall and/or temperature variations over a period of time.

All tools are freely available, except CAW which can be purchased from UKWIR. CAW is the only tool that cannot be used to represent specific WwTW, as it does not take into account the level of treatment achieved, i.e. the WwTW permit. CAW is used to compare the GHG emissions from different water utilities in the UK, and it cannot be used to account for effects on achieving different permit conditions at a site.

The tools have been identified as lacking some features and characteristics, specifically around embodied carbon, tertiary treatment processes and certainty around the N_2O EF used within the tools. Further details in relation to description, benefits, risks and implications are reported herein in the section entitled ‘Gap and risk analysis’.

Emerging approaches and methods for the quantification of GHG emissions

The section above described what tools and methodologies are currently available and being used to estimate GHG emissions from municipal wastewater treatment. This section focuses on what innovative methodologies, approaches or tools are being developed to improve GHG estimations.

The identification of the innovative approaches was undertaken by searching Isle’s extensive technology database which has thousands of technologies on file, as well as leveraging contacts with leading technology suppliers, water utilities and organisations.

The main emerging approaches that have been identified for GHG emission estimation are linked to establishing more accurate EF than those currently used in existing tools. This is of specific importance for N_2O emissions, with three examples of new, emerging approaches and technologies highlighted in this space.

IPCC 2019 Refinement

The first example is the 2019 refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (TFI, 2019), which introduced updates to the N_2O EF because of the advancements in scientific and empirical knowledge gained between 2006 and 2019 (Table 2).

Table 2 Comparison of IPCC EF for N_2O and CH_4 used between the 2006 Guidelines and the 2019 Refinement.

Emission factor	2006	2019
N_2O - discharge (kg N_2O-N/kg N)	0.005	0.005 - 0.019*
N_2O - aerobic, centralised wastewater treatment (kg N_2O-N/kg N)	0.005	0.016
CH_4 - wastewater treatment (kg CH_4/kg BOD)	0.000	0.018

*See Figure 1 for Three-tier approach

The changes introduced, especially the increase by 3.2 times in the EF for N_2O for treatment, represents the advancement in N_2O emissions monitoring tools that has been observed since 2006, along with the investment by water utilities worldwide to monitor them. The increase of the CH_4 EF for treatment from 0.000 to 0.018 also highlights a shift from assuming that a well-managed WwTW would not produce any CH_4 emissions to accounting for its emissions in settlement basins, other anaerobic pockets or emissions generated in the upstream sewer system and released in aerobic treatment (TFI, 2019). Despite these changes being introduced to the N_2O and CH_4 EF, a question remains as to whether the six tools assessed herein will incorporate these updated EF. An additional consideration is given to the CO_2 emissions, where the IPCC 2019 Refinement suggest that future changes should include a methodology to estimate non-biogenic (fossil) CO_2 emissions from wastewater treatment and discharge. The current approach based in the 2006 Guidelines assumes that organic carbon present in wastewater derives from biogenic organic matter and therefore, the linked CO_2 emissions are considered biogenic too and are discounted from the GHG accounting inventories (Bartram et al., 2019).

In recognition of the variability in the N_2O EF, the 2019 IPCC update also introduced a 3-tier approach (Figure 1). This approach allows for different countries to account for N_2O emissions based on the level of technology available. Tier 1 is targeted for countries where country-specific N_2O EFs are not available and therefore, general IPCC values are used. These countries include the UK, most European countries, Australia and USA. Tier 2 takes a more advanced approach as it promotes the inclusion of country-specific EFs. These are only applicable to those countries who have made significant monitoring campaigns at several WwTWs, such as Sweden. Tier 3 is the most advanced and accurate as it entails using measured N_2O emissions, and it is being led by countries like Denmark. In general, it is concluded that the lower the Tier employed, the less accurate the estimations of N_2O emissions will be, although exact differences are not known.

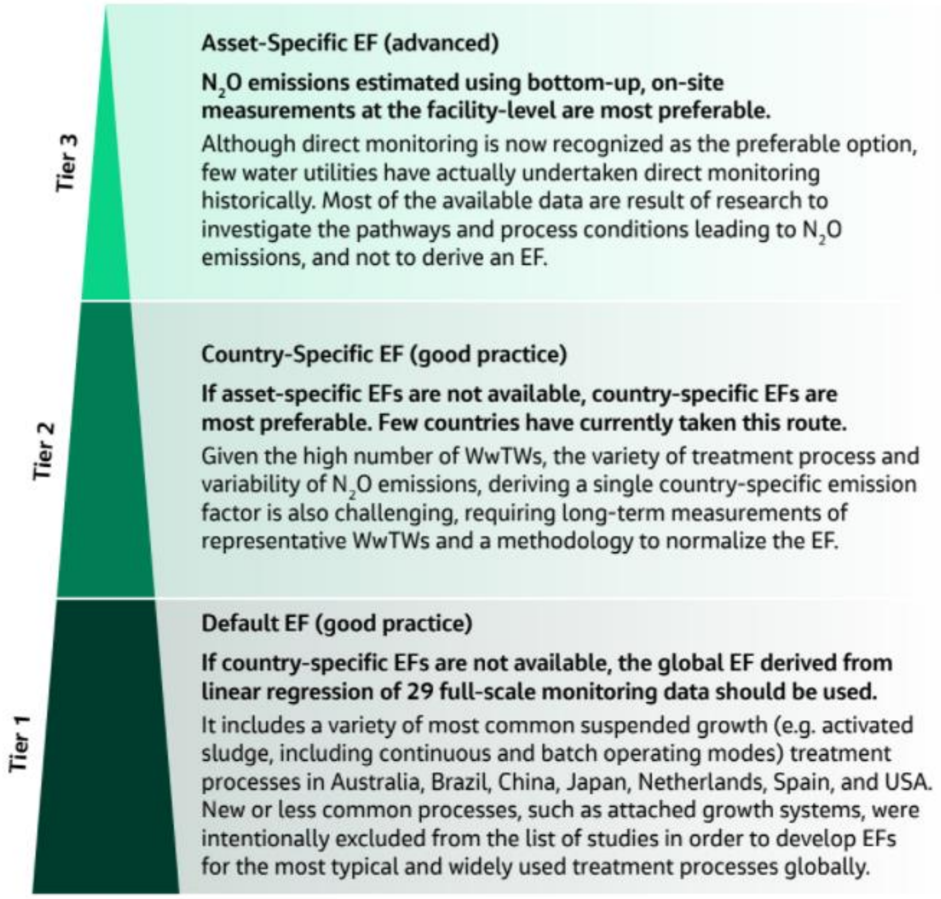

Figure 1. Three-tier approach suggested by the IPCC 2019 Refinement (Source: Brotto and Lake, 2022).

The fact that Denmark is leading the Tier 3 approach is linked to their efforts in developing technologies and solutions in the last 10 years which has resulted in the only two solutions currently commercially available to accurately measure N_2O emissions: Unisense Environment's N_2O Water Sensor and Cobalt Water Global's N2ORisk Decision Support System (DSS). The following describes these GHG measurement/sensor techniques.

Unisense Environment - N_2O Wastewater Sensor

Unisense Environment, based in Denmark, has developed a technology called N_2O Wastewater Sensor (Unisense Environment, 2022). This technology continuously measures N_2O concentrations directly in the wastewater and it calculates N_2O emissions. It is suited to WwTW where aeration is performed, including activated sludge plants or other types of aerated biological systems (typically installed at medium to large WwTW). It is recommended the sensor is operational for at least 1 year to account for seasonality effects. The sensor has a 45 second response-time and delivers a temperature compensated output. The technology consists of one controller and one or two sensors. The controller is used to calibrate, and temperature compensate the N_2O measurements as well as calculating the N_2O emission rate. The sensor consists of three components:

the sensor head, the body and the housing, all of which need to be fully submerged in the wastewater during operation. The real-time signal from the N_2O Wastewater Sensor makes it possible to implement active control strategies such as changing dissolved oxygen setpoints to minimise N_2O emissions. The N_2O emissions can be used to calculate site-specific N_2O EF to be used in the GHG accounting tools.

A number of water utilities have employed Unisense's solution to measure N_2O emission at some of their WwTW. One notable example is Danish water utilities, where they have monitored a 350,000 population equivalent (p.e.) WwTW for N_2O emissions for 18 months. They have reported that the measured N_2O emissions are 60% higher than those defined by the IPCC 2019 Refinement (Unisense Environment, 2020). Note that from Table 2 it can be seen that the latest IPCC EF are already significantly higher than their previous values, which most of the accounting tools still use.

The Danish work also found that there was a considerable seasonal variability in the N_2O emissions, being higher in spring/summer (between March and July) compared to autumn/winter (between August and February), something that the analysed tools do not account for as the emissions are reported on an annual basis. Outside of Denmark, the UK is also undertaking or planning monitoring campaigns, including use of the Unisense solution. Severn Trent is currently employing the Unisense sensor to measure N_2O emissions at some of their largest WwTW. Through the interview Isle conducted, Severn Trent reported that based on results from one particular WwTW, they estimate their total emissions from processes could be in the region of 190 kt N_2O/year compared to the 116 kt N_2O/year estimated with CAW, which is likely to underestimate N_2O emissions. Severn Trent is now working to widen the monitoring programme and investigate how the measured N_2O emissions can be extrapolated to other WwTW. Severn Trent has also begun installing fixed CH_4 sensors, combined with drone and ground-based detection surveys to identify and fix leaks of CH_4 from sludge treatment assets. Severn Trent's next challenge is developing and trailing mitigation solutions. Scottish Water has also reported through the interview conducted that they are likely to start a similar N_2O measuring campaign with the Unisense sensors in 2022 at some of their largest WwTW.

There are two main limitations to the Unisense solution. The sensor needs to be fully submerged in wastewater, which means it is only suitable for installation in aeration tanks and not in trickling filters. The technology is therefore only applicable to those WwTW, typically large and some medium-size, which employ aeration tanks or similar technologies for secondary treatment. Unisense offers an alternative technology based on laboratory-type sensors to be used in trickling filters. Compared to the N_2O Wastewater sensor, the laboratory sensor requires more operator input as well as higher calibration and data treatment requirements, and therefore it is deemed less user-friendly to operate. Additionally, the Unisense sensor can only measure and report emissions, while it cannot propose control measures to reduce the estimated emissions.

Cobalt Water Global - N2ORisk Decision Support System

Cobalt Water Global, also based in Denmark and the USA, has developed the technology N2ORisk Decision Support System (N2ORisk DSS). N2ORisk DSS provides an additional step to the Unisense solution as the technology has a machine learning element which is able to propose control measures to decrease the N_2O emissions being estimated. Ultimately, and similarly to Unisense's solutions, the output from N2ORisk DSS can help in estimating more accurate N_2O EF to be used in the GHG accounting tools and take the Tier 3 IPCC approach.

The N2ORisk DSS utilises process data from the WwTW to train its algorithm to identify the most significant sources of N_2O emissions and find more optimal ways to configure the operational conditions and treatment train. The data this tool uses can be historical or live data and it comprises water quality data (including inlet flow, dissolved oxygen (DO) concentration, NH_4 concentration, NO_3 concentration, temperature, pH and air flow data) and flows. It can be installed at any type of secondary treatment process. It is recommended the sensor is operational for at least 1 year to account for seasonality effects. The tool can estimate the risk of N_2O emissions (reported as low/high), quantitative N_2O emissions and it can also suggest mitigation measures to reduce them. The tool can optionally be coupled with the Unisense probe to compare its estimations with the N_2O emissions measured by the Unisense probes to validate the data.

The N2ORisk DSS has been employed by several water utilities in the Netherlands to estimate and reduce N_2O emissions from wastewater treatment. One example is a WwTW treating 750,000 p.e. where a 90% reduction in N_2O emissions was achieved by controlling the DO set point in relation to an inlet NH_4 peak (Cobalt Water Global, no date). Another WwTW in the Netherlands treating 175,000 p.e. reduced its N_2O emissions by 90% by controlling the DO set point according to the inlet NH_4 peaks (Cobalt Water Global, no date). Outside Denmark, Welsh Water in the UK is currently testing the N2ORisk DSS at six of their WwTW to measure and reduce N_2O emissions (Welsh Water, 2021).

The N2ORisk DSS is easy to deploy as it can be done remotely, and input data is commonly already measured on site. However, it requires around 45% higher investment compared to the Unisense solution, which may limit its use by some water utilities. One limitation remains even with such an advanced tool as the N2ORisk DSS, and this is linked to fact that it would only allow for the estimation of N_2O emissions at the WwTW where it is implemented, and it would still require extrapolation to other WwTW.

Brunel University - Strategic carbon accounting tool

Brunel University is currently developing a strategic carbon accounting tool, with no specific name yet, that can be used to assess the carbon footprint of WwTW using less input data than other available tools. A range of techniques, such as biological kinetics, stoichiometric relationships, chemical reactions, and mass balances are used alongside assumptions from literature to create a representation of the conventional UK wastewater treatment processes with minimum data inputs. IPCC methods, and emissions factors from commercial, national and custom-made databases are used to calculate the GHG emissions in tCO2e. One unique feature of the tool is that it provides an emissions profile for the entire wastewater treatment process, allowing users to identify where the largest sources of emissions are. The tool is provided in an Excel format and it is being developed specifically for the UK water sector, and it will be free. It is currently being tested at two demonstration sites, to evaluate how the integration of resource recovery technologies impacts the carbon footprint and circularity of WwTW (as part of the H2020 project DEEP-PURPLE). It can be adapted according to the client's needs, with specific Key Performance Indicators (KPIs) or features required by the water company.

Brunel University is also developing a more advanced tool called the Dynamic C-Foot-Ctrl tool, which is based on the C-Foot-Ctrl tool developed by the National Technical University of Athens (which is included in the discarded tools for the purpose of this report given the lack of information). This tool will be offered under a licence and will allow users to track the emissions as they occur, facilitate the implementation measures to reduce emissions and link the emissions with a particular activity in the WwTW.

Gap and risk analysis

In the previous sections, numerous gaps and limitations have been reported when analysing both the current and the emerging tools and approaches. This section summarises and expands on those elements, analyses the benefits that would be gained from improving them as well as the risk linked to failing to address them. This risk is scored and presented qualitatively as 'Optional', 'Desirable' or 'Critical'. 'Optional' refers to the element inclusion not significantly enhancing the outputs of the tool, but it would provide additional data. 'Desirable' is described as the element inclusion enhancing the tool outputs but not being critical. Lastly, 'Critical' means that without development, the approach or method will not be fit for purpose.

A total of six general missing elements or gaps have been identified, which are common to all tools analysed in previous two sections. Table 3 summarises what the missing elements are, the benefit it would bring if they were addressed and the scored risk (Optional/Desirable/Critical) that it would imply if they were not to be addressed.

Table 3. Summary of missing elements identified in GHG accounting tools.

Missing element	Description	Benefit	Risk
Embodied carbon	Embodied carbon refers to the GHG emissions associated with construction of the assets being used for wastewater treatment, mostly linked to the use of concrete and steel, as well as their maintenance and renewal (CIWEM, 2013). None of the analysed tools included embodied carbon in the GHG estimations. They did not include embodied carbon emissions linked to chemical use either, nor their transport. However, some UK water utilities (Severn Trent and Scottish Water) calculate the embodied carbon associated with their capital projects. Ofwat has reported that there can be error margins as high as +/- 100% when estimating embodied carbon emissions (Ofwat, 2010). More experience and strong collaboration between water utilities and third parties would allow for more accurate estimations to be made. These calculations and estimations could then be incorporated into GHG accounting tools.	Inclusion of GHG emissions associated with construction of assets. Promote the development of alternative, sustainable concrete and steel materials for construction.	Desirable for existing WwTW / Critical for new WwTW or enhancements
Seasonality effect	The reporting period in all the tools is on a yearly basis, hence the GHG emissions are averaged through the year. Recent N_2O measuring campaigns undertaken by Danish water utilities have reported a considerable seasonal variability in the N_2O emissions between warmer and colder months (Unisense Environment, 2020). Specifically, the N_2O emissions were higher in spring/summer (between March and July) compared to autumn/winter (between August and February). GHG emissions could be reported twice a year using the tools by incorporating data from the warmer and colder months or by using correction factors.	N_2O emissions would be estimated more accurately according to the season. This could be of benefit if any seasonal permits were considered.	Desirable, although it could become critical in the future given the changing climate

Table 3 (continued). Summary of missing elements identified in GHG accounting tools.

Missing element	Description	Benefit	Risk
Representative N_2O emission factors	The 2019 refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (TFI, 2019) reflects the underestimation in N_2O emissions that has existed in recent years. Interestingly, none of the analysed tools include the 2019 IPCC value for N_2O EF of 0.016 for centralised aerobic treatment as default, and they tend to include the 2006 value of 0.005 instead. The more advanced approach some water utilities have taken involves measuring N_2O emissions at some of their largest WwTW to more accurately estimate the N_2O EF at their WwTW. However, undertaking this measurement at all of the WwTW would be likely be expensive. Hence, these water utilities have opted for measuring emissions from key WwTW to then extrapolate the EF to some of their other WwTW. The method of how to do this extrapolation is yet to be determined. Danish research suggests that N_2O emissions can account for 42% of the total GHG emissions from wastewater treatment (Unisense Environment, 2020), therefore accurately estimating N_2O emissions is of key importance. The N_2O emissions are tightly linked to the regulatory requirements. Utilities in Sweden, Norway and Denmark need to comply with total nitrogen (TN) consents and therefore, they need to have nitrification and denitrification in their treatment processes producing higher N_2O emissions. Countries like the UK seldom have TN consents, and therefore their N_2O emissions are not regulated. N_2O EF should take this into account.	N_2O emissions would be estimated more accurately.	Critical
Additional assets for tertiary treatment	The removal of phosphorus, organic chemicals and metals from wastewater would require additional assets to be installed and operated, most likely as tertiary treatment processes. Some of these processes, specially Advanced Oxidation Processes (AOP), would have associated GHG emissions linked to electricity consumption and the use of chemicals (Kang et al., 2020). Disinfection, including UV, could also become more frequent in the future specially linked to storm discharges and it is an energy-intensive process. None of the GHG accounting tools included emissions associated with tertiary treatment processes. This, together with the lack of embodied carbon, makes it challenging to use the existing tools to estimate how much the removal of PS would contribute to GHG emissions.	It would allow to estimate how much the removal of PS would contribute to GHG emissions.	Desirable currently although it will become critical as technology is put in place

Table 4 (continued). Summary of missing elements identified in GHG accounting tools.

Missing element	Description	Benefit	Risk
Applicability to small WwTW	There is a variation between GHG emissions from small to large WwTW associated to the level of treatment provided. Small, some medium and a very few large WwTW employ trickling filters as secondary treatment, while large, and some medium, WwTW employ ASP or similar technologies. The tools analysed generally only account for GHG emissions from centralised aerobic treatment and not trickling filter WwTW.	GHG emissions from small and medium WwTW would be more accurately estimated.	Critical
Input data availability	The tools analysed are in general complex and require a high number of input data points. Isle has estimated that the data the EA would already have available to input in the analysed tools is between 5 and 30%. This makes it very challenging for the EA to use the existing tools to estimate how permitting would impact the GHG emissions at different sites; however, water companies are expected to have this information available and would either be able to provide it or undertake the calculations themselves.	The tools could be more easily used by the EA on a routine basis to estimate GHG emissions under permitting decisions. The tools would also be easier to use by water companies.	Critical
Energy mix specific to country	Each tool includes specific energy EF (in CO2-eq/kWh) depending on the energy mix for the country where the tool was developed. Therefore, any extrapolation of the tools to other countries would require an adaptation of the energy mix EF, using data available from Defra.	Operational CO_2 emissions would be more accurately estimated.	Desirable

From the total of six elements, four were deemed critical to be addressed with two deemed desirable. The criticality is linked to the embodied carbon, representative N_2O EF, additional assets for tertiary treatment and input data availability. Whilst these elements are deemed critical, there are several innovations being undertaken to address them. For instance, water utilities are independently and internally estimating embodied carbon emissions. The next step to fully address this gap would be around harmonising the method used amongst all utilities and incorporating it into the GHG accounting tools.

There has been an improvement in accurately determining EF for N_2O, both by external bodies like the IPCC when publishing revised EF, and the individual water utilities when undertaking on-site N_2O measurements. The next step would be in the GHG accounting the tools incorporating the IPCC 2019 EF as default values for those organisations using the IPCC Tier 1 approach. For those companies pursuing Tier 3 where they undertake their own N_2O emissions measurements, a question remains in relation to how to extrapolate the findings from measurements to other WwTW.

Little work is being done to address GHG emissions from tertiary treatment assets, especially those that would be needed in order to remove PS. Brunel University seems to be leading on this front by developing process models for a limited number of tertiary treatments such as phosphorus precipitation. However, these models are still in early stages of development and do not cover a wide range of commonly employed treatment techniques, nor those that would be needed for PS removal. A collaborative approach driven by universities, water companies, suppliers and regulators would help in bridging this gap in the future.

Some work is being undertaken to reduce the input data required in the GHG accounting tools. Specifically, Brunel University is also currently developing a tool to reduce the number of input data required for estimating GHG emissions, which would allow the EA to use such a tool more easily.

Conclusions and recommendations

Currently there is no regulatory mechanism for accounting for the carbon impact of treatment when permitting a WwTW for water quality purposes. This means that it is possible that decisions are being made for water quality which have a disproportionate impact on GHG emissions. For this to change, there would need to be a clear signal from Government departments, such as Defra, along with the development of an agreed tool or method for calculating GHG emissions from different treatment options and scenarios.

If a future is envisaged where GHG emissions are accounted for in permitting decisions, then there would need to be an open dialogue between water companies and the EA to allow an informed discussion on where the tipping point between water quality and GHG emissions lies. It is expected that this point would be site or at least catchment specific. Following an initial permitting decision from the EA, water companies could use the agreed tool to determine the GHG emissions from different treatment options or solutions, associated costs and the risk of non-compliance. This would then start the discussion with the EA on what the acceptable GHG emissions compared to permit compliance is.

This work has identified that with the currently available tools the EA and water companies can:

- Quantify GHG emissions from WwTW with ASP as secondary treatment
- Calculate GHG emissions in tonnes of CO_2 equivalent

However, they cannot:

- Use the tools if they have limited input data
- Quantify GHG emissions from WwTW with trickling filters as secondary treatment
- Give estimations with updated EF for N_2O emissions
- Use a tool developed in the UK specifically suited for the UK water sector
- Estimate embodied carbon emissions
- Estimate GHG emissions from assets for tertiary treatment for the removal of P, organic chemicals and/or metals

A total of six GHG accounting tools and four emerging approaches were identified and evaluated to assess their suitability for permitting purposes. Five additional tools were also identified but discarded as there was limited information available.

Based on the evaluation, it was concluded that:

- The existing tools were complex and require a large range of data inputs, often including population equivalent, influent and effluent flow, biological oxygen demand (BOD) load, total nitrogen (TN) load, energy consumption on site and type of power used. It is expected that these data sets will generally be available for WwTW.
- Default values for some inputs were included within many of the tools, but it was not possible to assess whether these were valid within a UK context.
- In general, the tools target both wastewater and sludge treatment and disposal and are best suited to WwTW employing centralised aerated processes for biological treatment, such as ASP or similar processes. Disposal routes for sludge typically included anaerobic digestion, with other options also available.
- Trickling filters were generally not included within the tools. Advanced treatment options such as for phosphorus removal or addressing priority substances were not included in either the existing or emerging approaches.
- The tools tend to target scope 1 (direct emissions, including process, fugitive and fuel/combustion), scope 2 (emissions from the generation of purchased electricity used) and scope 3 (all other indirect emissions, and can include materials, waste or embodied carbon) emissions but exclude carbon associated with the provision and transport of chemicals needed for treatment.

- All tools provide the results in tonnes of CO_2 equivalent (tCO2-eq), converted from tonnes of N_2O, CH_4 and CO_2.
- Default values within the tools included emission factors (EF) for separate GHG. The available information suggests that these factors have not been updated or amended for several years. The 2019 Intergovernmental Panel on Climate Change (IPCC) refinement document (TFI, 2019) along with advances in monitoring technologies (Unisense and Cobalt Water Global for example) means that these default EF are outdated.
- Most of the tools are freely available and have been developed outside of the UK, except for UK Water Industry Research's (UKWIR) Carbon Accounting Tool (CAW). It was developed for the annual reporting of GHG emissions and focuses on operational emissions.
- No one tool was identified as directly implementable today for permitting purposes, due to not all treatment technologies being included, and / or the use of outdated EF. However, they do provide a good basis for developing a suitable tool in the future.

The recommendations from the research were to:

- Address the gaps in knowledge regarding embodied carbon
- Improve the N_2O EF either through updating the existing tools to take into account the IPCC refinements or (ideally) through the use of the data from monitoring activities being undertaken within the UK
- Determine the availability for the input data required within the tools, and for any data not readily available, determine the impact of using default values
- Develop a tool which incorporates emissions associated with trickling filters, tertiary and non-conventional treatment.

If and when a tool is developed, it is further recommended that pilot testing with one or two water companies is undertaken to determine how GHG emissions can be incorporated into permitting decisions in practice.

Some specific steps towards developing a tool are provided under Future Work.

Future work

The gap and risk analysis exercise identified several areas where further work could be undertaken to tailor GHG accounting tools for potential use within permitting decisions.

The gaps and risks could be overcome by:

- Only one tool can estimate emissions from trickling filters. The tools to be used for EPR purposes should incorporate these calculations, especially given the high number of existing trickling filter WwTW in the UK.

- The Brunel University tool is being developed for the UK water sector. The current tools can be adapted for Scope 2 emissions using the Defra energy mix figures for the UK.
- The tool should include embodied carbon emissions, especially critical if the WwTW is new or being upgraded. Some water utilities have their internal embodied carbon tools that could be unified and adopted.
- Little work is being done to address GHG emissions from tertiary treatment assets. Brunel University is leading in developing models for phosphorus precipitation. However, these models do not cover a wide range of commonly employed treatment techniques, nor those that would be needed for organic chemicals and metals removal. A collaborative approach driven by universities, water companies, suppliers and regulators would help in bridging this gap in the future.

Taking these areas into account, it is recommended the following seven tasks or projects are developed. They are presented in order of when they should be undertaken, i.e. it is recommended that the Scenario Analysis is undertaken first. An approximate timescale for each of the steps is provided; Tasks 1-6 can be undertaken concurrently. Step 7 can only be undertaken once there is an agreed tool in place (or at least a provisionally agreed tool).

<u>Understanding the implications of using GHG accounting in permitting</u>

1. **Review of scenario analysis** – determine a set of theoretical scenarios to map out the decision-making process that would be required to use GHG accounting in permitting. It is suggested that in the first instance there are at least three scenarios to cover a) standard parameters (biological oxygen demand, suspended solids and ammonia), b) nutrients (namely P, but could include TN) and c) Priority Substances. For each scenario, a range of permit limits should be assigned (high, medium and low values). A range of treatment solutions (these can be theoretical) can then be assigned to each with a GHG emission equivalent compared to an assumed baseline. For each of these, the decision-making process to balance the GHG emissions against the expected water quality process should be followed to identify whether there is any missing information or policy instruments that need to be addressed. It can also be used to discuss how compliance is measured, the impact that the overperformance that is built into treatment design has on compliance and GHG emissions, and the impact that any less stringent permit limit would have on the health of the receiving water course. It is possible that such scenario analysis could also open up discussions around innovative permitting approaches, such as catchment based permitting, and / or demonstrate that different approaches are required for different parameters. It is expected that this would be a circa 6 month project, and it is recommended that it includes a workshop to work through the scenarios and subsequent analysis with key stakeholders to ensure that all aspects have been considered.

Development of an accounting tool

2. **Adaptation of existing approach or development of new tool** – Perform a thorough analysis of the ECAM tool and assess if it can simplified to allow readily available data only to be used. If it cannot be simplified to such a purpose, a new tool would need to be built. Evaluate the ease of updating the tools with the IPCC 2019 Refinement EF for N_2O emissions, or EF calculated from onsite measurements of N_2O emissions if in Tier 3 using the Unisense or Cobalt Water Global solutions. This would be a 3-month project.
3. **Development of EF from tertiary and alternative treatment** – Develop a method to estimate GHG emissions from tertiary treatment assets and alternative treatment solutions, especially those employed for PS and P removal. This should also include trickling filters and the associated primary and preliminary treatment steps. As a starting point, emissions from the technologies assessed as part of the Chemical Investigations Programme (CIP) led by UKWIR could be undertaken. Step 2 could be collaboratively undertaken by the technology suppliers and tool developers (such as Brunel University) to ensure the minimum amount of data is used when developing the methodology to be incorporated in the tool. This would be a circa 12-month project, with further refinements recommended as new technologies are developed or implemented.
4. **Update of UK relevant N_2O EF** – For those water companies in the UK measuring N_2O emissions (such as Severn Trent and Scottish Water) and translating them into EF, investigate how the EF can be extrapolated to other sites. The formation of a working group between those utilities measuring N_2O emissions would allow the development of a robust N_2O EF within the UK water industry context and according to the type of WwTW being assessed. The monitoring work is currently being undertaken by water companies. Once this is complete it is expected that this step would take around 6 months to complete.
5. **Determination of emissions from chemical use -** Conduct a literature review to quantify how much emissions due to chemicals and their transport would contribute to Scope 3 emissions already accounted for in the existing tools. A suggested starting point would be to determine an EF for ferric and aluminium use. This would be a 3-month project.
6. **Determination of embodied carbon** - Compare the methodologies and assumption employed by the UK water utilities, the EA and other sectors for calculating embodied carbon for their capital projects and develop a methodology to evaluate embodied carbon with the least amount of input data required. This could be led by a working group formed by utilities which have such a capital project carbon accounting tools (such as Severn Trent and Scottish Water, among others). This would be a 6-12 month project.

Piloting of accepted approach

7. **Evaluation of the application of the approach -** work with one or two water companies to pilot test the use of a GHG emission accounting tool. This test should include site specific, realistic scenarios to determine what the resources required for

using the tool to develop treatment options is, and what the decision pathways look like. Does it result in a different decision regarding the treatment option or the permit than if the accounting tool wasn't used? Is the impact (if any) on water quality acceptable? Is the impact on GHG emissions acceptable? This will enable the EA and the water companies to understand how the tool could be used in practice, and what the implications are. This would be a 12-month project.

This future project would aim to addressing the following project questions:

- Can a complex tool like ECAM be adapted to require less input data or do we need a new tool developed?
- How can we measure GHG emissions from trickling filters?
- How can we measure GHG emissions from tertiary treatment assets used for organic chemicals, metals and P removal?
- How can we obtain representative N_2O emission factors?
- How can we make the tool specific for the UK context?
- How can we measure the emissions from the chemicals used in wastewater treatment?
- How can the tool be used in practice and what difference does it make?

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List of abbreviations

AOP	Advanced Oxidation Process
ASP	Activated Sludge Process
BOD	Biological Oxygen Demand
CH4	Methane
CIP	Chemical Investigations Programme
CO2	Carbon Dioxide
Defra	Department for Environment, Food and Rural Affairs, UK Government
DO	Dissolved oxygen
EF	Emission Factor
GHG	Greenhouse Gases
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
KPI	Key Performance Indicators
MBBR	Moving Bed Biofilm Reactor
N_2O	Nitrous Oxide
p.e.	Population Equivalent
PS	Priority Substances
SBR	Sequencing Batch Reactor
tCO2e	Equivalent Tonnes of Carbon Dioxide
TN	Total Nitrogen
WwTW	Wastewater Treatment Works

Appendix

Table A. Complexity scoring matrix for established carbon accounting tools.

Tool	Input data points required	Overall score - Complexity
ECAM	83	Difficult
BEAM	117	Difficult
CAW	113	Difficult
CFCT	55	Medium
USIGHGES	11	Easy
NGER	34	Medium

A complexity score of ‘Easy’ was given to any tools that required less than 20 input data points, ‘Medium’ was assigned to any tools requiring between 21 and 80 input data points, and ‘Difficult’ to any tools requiring more than 81 data points.

Table B. Applicability scoring matrix for established carbon accounting tools.

Tool	Flexibility	Adaptability	Accessibility	Overall score - Applicability
ECAM	Easy	Medium	Easy	Easy
BEAM	Difficult	Medium	Easy	Medium
CAW	Medium	Easy	Medium	Medium
CFCT	Medium	Difficult	Easy	Medium
USIGHGES	Difficult	Difficult	Easy	Difficult
NGER	Medium	Difficult	Easy	Medium

‘Easy’ flexibility is assigned to those tools that can be applied to small, medium and large WwTW, ‘Medium’ when they can only be applied to two WwTW sizes and ‘Difficult’ when the tools can only estimate emissions from large WwTW. It is assumed that small and some medium WwTW use trickling filters as secondary treatment while large and some medium WwTW using an ASP process or similar aerated processes to provide secondary treatment.

‘Easy’ adaptability is assigned to those tools that have been developed in the UK and hence are readily applicable, ‘Medium’ refers to those tools that would require slight adaptations to be used in the UK water industry context while ‘Difficult’ is assigned to those tools which would need considerable changes to be adapted to the UK context.

‘Easy’ accessibility is assigned to those tools which are freely available and ‘medium’ when the tool requires a paid licence to be used.

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