Water and Wastewater Companies for Climate Mitigation

WaCCliM

ECAM 2.2

Energy Performance and Carbon Emissions Assessment and Monitoring Tool

Methodology

Manual v2.2 – December 2018

The Water and Wastewater Companies for Climate Mitigation (WaCCliM) project, is a joint initiative between the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and the International Water Association (IWA). This project is part of the International Climate Initiative (IKI). The German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) supports this initiative on the basis of a decision adopted by the German Bundestag.

On behalf of:

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

of the Federal Republic of Germany

Implemented by:

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

IWA the international water association

Acknowledgements

The ECAM-tool has been developed as part of Water and Wastewater Companies for Climate Mitigation (WaCCliM) project. WaCCliM is a joint initiative between the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and the International Water Association (IWA). This project is part of the International Climate Initiative (IKI). The German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) supports this initiative on the basis of a decision adopted by the German Bundestag.

ECAM is an open source *software tool. Together with IWA and GIZ, the web interface and new features for the ECAM tool V2.2 were developed by Institut Català de Recerca de l'Aigua (ICRA). The tool was first developed for WaCCliM project in 2015 as an Excel tool by the consortium Urban Water Commons (LNEC and ITA, Universitat Politècnica de València) in collaboration with Cobalt Water Global. The Excel tool laid the foundation and basic equations for the web-tool.*

For more information on the WaCCliM project, please visit *www.wacclim.org*

For technical support on ECAM, please contact the helpdesk: *info@wacclim.org*

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List of Abbreviations and Symbols

BOD	*Biochemical Oxygen Demand*
CCF	*Climate Carbon Feedback*
CH_4	*Methane*
CO_2	*Carbon Dioxide*
CO_2e	*Carbon Dioxide Equivalent*
ECAM Tool	*Energy Performance and Carbon Emissions Assessment and Monitoring Tool*
FD	*Fuel Density*
FS	*Faecal Sludge*
GHG	*Greenhouse Gas*
IPCC	*Intergovernmental Panel on Climate Change*
KPI	*Key Performance Indicator*
MCF	*Methane emission Correction Factor*
N_2O	*Nitrous Oxide*
NCV	*Net Calorific Values*
PAT	*Pumps working As Turbines*
PI	*Performance Indicator*
Serv.pop.	*Serviced Population*
UWS	*Urban Water System*
WaCCliM	*Water and Wastewater Companies for Climate Mitigation*
WS	*Water Supply*
WWTP	*Wastewater Treatment Plant*

1 Introduction

About this manual

This document provides a detailed explanation on the theoretical background of the second version of the web-based “Energy performance and Carbon Emissions Assessment and Monitoring” (ECAM v2.2) tool. The main assumptions and the key considerations that form the basis of the tool are explained. An overview of variables, performance indicators and related equations, as well as benchmark values and references are given. Additionally, the manual helps users with evaluating different scenarios for specific system configurations.

Chapter 2 describes the scope of application of ECAM. It indicates how the system boundaries are defined, which types of greenhouse gas emissions can be assessed with the tool and what the overall tiered approach entails. In chapter 3, a comprehensive overview of the calculations, factors and assumptions for the various greenhouse gases can be found for each stage of the water cycle. Finally, chapter 4 sheds light on how ECAM can be applied to reflect different scenarios.

Topics that are described in detail include:

- Population data required to use the tool;
- Emission factors used to calculate emissions from energy consumption;
- Direct and indirect GHG emission sources for methane and nitrous oxide;
- Sludge management options;
- GHG emissions avoided from nutrient recovery and water reuse
- Performance indicators with reference values and implications;
- Guidance on population types;
- Annex containing all the inputs and outputs of the ECAM tool with their respective code, description, unit, and whenever applicable equations and benchmark values and
- References and links to source materials.

Note that this methodology document may be used in conjunction with the **ECAM user manual**, which describes the different functionalities and features of the tool. It can be downloaded from the “help page” in the ECAM tool.

For further support on the ECAM tool, please contact the helpdesk info@wacclim.org.

About ECAM

Background

ECAM is a web-based free and open-source decision support tool that is part of the knowledge platform developed by the Water and Wastewater Companies for Climate Mitigation (WaCCliM) Project. WaCCliM is guiding drinking water and wastewater utilities on a journey to energy and carbon neutrality. Limiting climate change to 1.5°C requires substantial reductions in greenhouse gas (GHG) emissions in all sectors.

The urban water sector has under-recognized opportunities to reduce carbon emissions that will contribute to the successful implementation of the Paris Agreement through increasing the Nationally Determined Contributions (NDCs) of supporting countries. The Energy Performance and Carbon Emissions Assessment and Monitoring (ECAM) Tool, offers a solution for utilities wanting to quantify their GHG emissions and contribute to NDCs through reducing indirect and direct emissions from energy use and wastewater management.

Objective

ECAM tool assists water utilities in using their own data to transform it into a source of valuable information on energy performance and GHG emissions. ECAM is the first of its kind to allow for a holistic approach of the urban water cycle to drive GHG emission reduction in water utilities, even those with limited data availability. It promotes transparency, accuracy, completeness, comparability and consistency. It is designed to assess the carbon emissions that utilities can control within the urban water cycle and prepares utilities for future reporting needs on climate mitigation. By combining carbon and energy assessments, ECAM takes into account that reducing operational costs is a main driver for utilities. It can be used for:

- GHG emissions assessment
- Energy performance assessment
- Identifying of opportunities for reducing CO_2 emissions and reducing energy consumption
- Developing scenarios when investigating possible measures to improve performance
- Monitoring the results after the implementation of improvement measures

Approach

ECAM follows a tiered approach, with an increasing level of detail from Tier A to Tier B. The Initial GHG Assessment (Tier A) provides an overview of major GHG sources and quantities using basic assumptions. The Detailed GHG Assessment (Tier B) provides a more advanced level of GHG

assessment using detailed data to gain a more accurate and refined picture of a utility's GHG emissions and energy performance, as data is entered for each stage of the urban water cycle (drinking water abstraction, treatment and distribution. Wastewater collection, treatment and discharge/reuse) as well as their individual facilities (pump stations, treatment plants, network divisions) can also be characterized. ECAM considers as well faecal sludge management in one of its components. Proceeding from Tier A to Tier B, there is also an increasing degree of certainty in GHG emissions.
Input data includes: type of systems, performance parameters, serviced population and natural constraints. For each stage of the urban water cycle, data is used to derive key and complementary Performance Indicators (PIs) for the GHG and energy assessment. Additionally, the energy situation of the utility is assessed to evaluate if energy savings are an economic driver to reduce GHG emissions.

Finally, opportunities for improvements are identified while possible solutions can be evaluated with ECAM, keeping in mind that the different stages of the urban water cycle are interlinked and that a holistic approach is necessary prior to defining specific measures. Some of the assessment results are compared with known benchmarks so that inefficiencies can be highlighted, and decision makers can prioritize improvements in the utilities' most promising stages.

2 Scope of Application

2.1 Target group

Water utility managers and technicians, consultants, climate change professionals, academics, and policy makers who are interested in understanding the conceptual background of the ECAM tool are the target group. In addition, anyone interested in urban water cycle, particularly the energy consumption and greenhouse gas (GHG) emissions from urban water cycle and how this could be tackled to improve the system towards sustainability and efficiency could benefit from this guide.

2.2 Basic Functions

The basic function of the ECAM tool is to assist water utilities in assessing GHG emissions, energy performance and identifying opportunities for further improvements by using their own existing data as a source of valuable information.

ECAM offers water utilities the following:

- A tool for GHG reduction
- A tool to assess carbon footprint, energy consumption and service levels
- A tool to reduce operational costs
- A tool to strengthen performance monitoring and decision making
- A tool to develop scenarios on the future impact of GHG reduction measures.
- A tool to calculate emissions within the water sector via a transparent and sound approach which quantifies GHG reductions, a prerequisite for accessing climate financing

What ECAM offers the water sector:

- A tool for monitoring, reporting and verifying the water sector's GHG reduction contribution to the NDCs
- Requires only data typically available in utilities in developing and emerging economies
- The same methodology can be applied to utilities nationwide, facilitating national benchmarking and knowledge exchange between utilities

2.3 System boundaries and holistic approach

Typically, in the water sector, emissions are assessed separately and using different tools. The ECAM tool however, has been developed to facilitate the assessment of systems via a holistic approach, considering all stages of the urban water cycle and the interlinkages between stages (*Figure 2-1*). The aim is to maintain the overview on the entire urban water cycle in the analysis, to convey the notion that sub-systems are inter-related. For a detailed overview of GHG sources in the urban water cycle and the interrelations between urban water stages and their GHG implications, please go to the Roadmap to a low-carbon urban water utility.

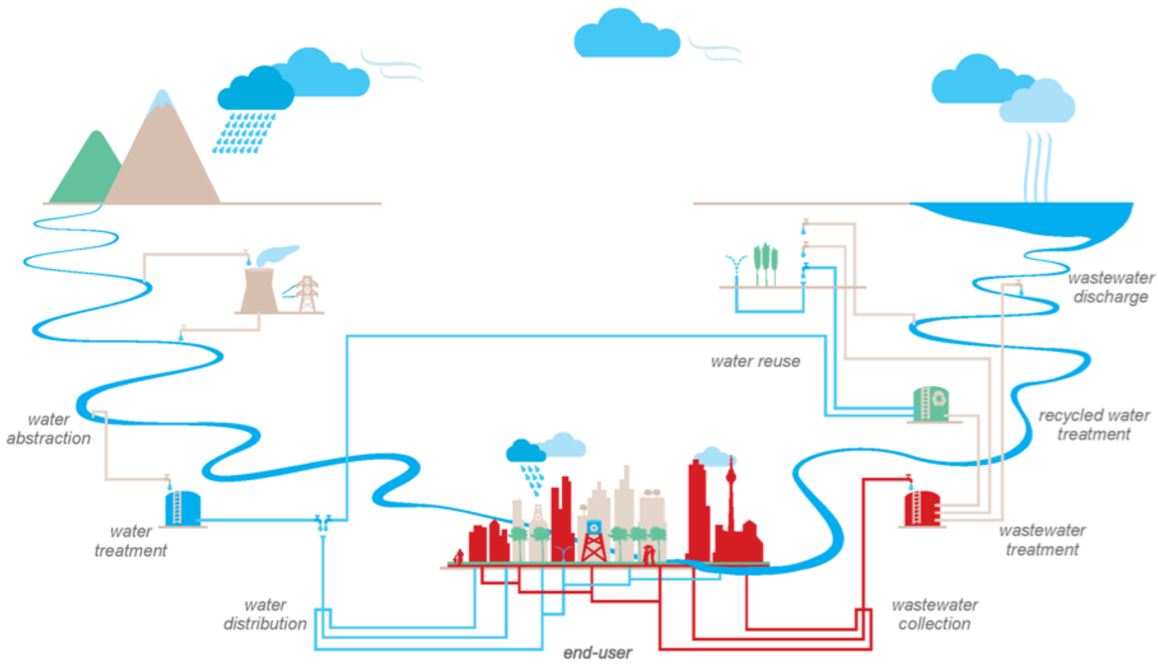

Figure 2-1 Stages of the Urban Water Cycle - ECAM promotes a holistic approach for the whole urban water cycle

The applied framework of the urban water cycle includes the water supply, wastewater and faecal sludge management processes (water abstraction, water treatment, water distribution, wastewater collection, wastewater treatment, wastewater discharge/reuse, faecal sludge containment, treatment and reuse/disposal). *Figure 2-2* shows the utility activities considered in ECAM Tool, inside and outside of their physical boundaries (dashed lines).

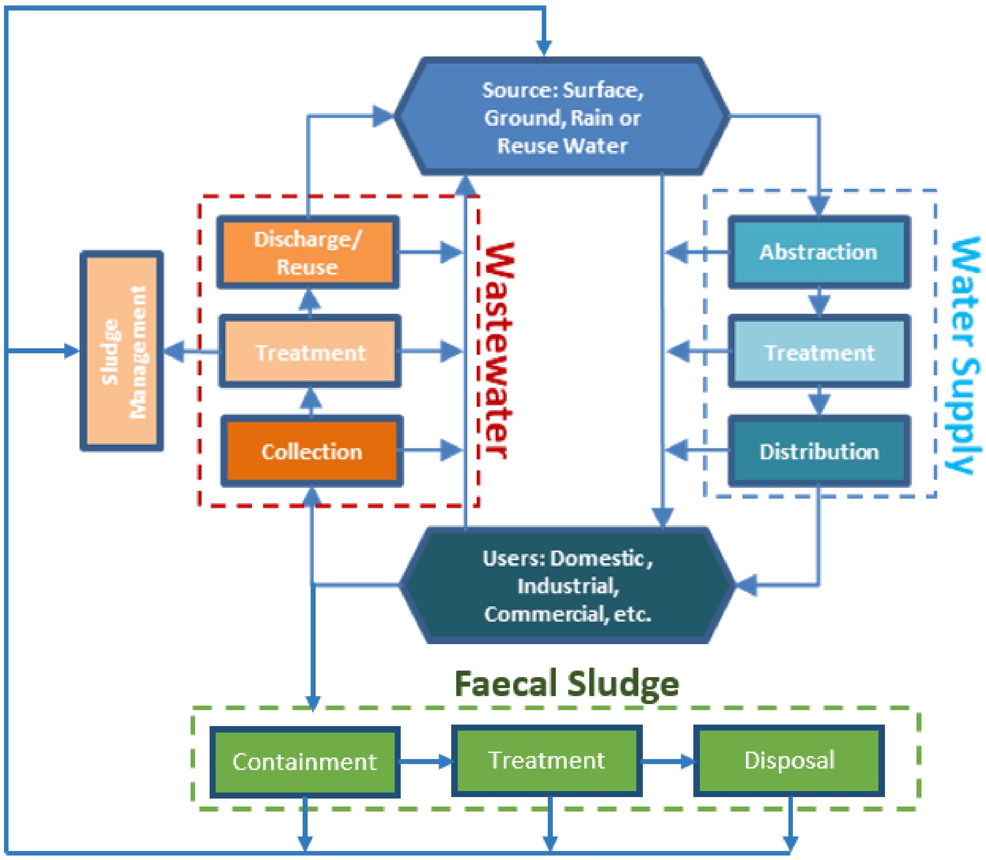

Figure 2-2 System boundary

Navigating the Urban Water Cycle stages

In ECAM the user experience starts with Tier A- Initial GHG assessment, which includes the whole drinking water, wastewater and faecal sludge system allowing users to make straightforward assessments with back-of-the-envelope calculations. The experience continues with Tier B – Detailed GHG assessment, in which the user can introduce more accurate values to calculate the GHG emissions of the drinking water, wastewater and faecal sludge systems. With this advanced assessment, users can evaluate Energy Performance to identify potential energy savings for the 6 stages of the water cycle (Abstraction, Treatment, Distribution and Collection, Treatment, Discharge/Reuse) and their individual facilities (pump stations, plants, network divisions).

Some of the assessment results are compared with known benchmarks so that inefficiencies can be highlighted, and decision makers can prioritize improvements in the utilities' most promising stages.

2.3.1 The GHG assessment

Three categories of GHG emissions are included in ECAM. Direct emissions that are not associated with grid-energy usage (Scope 1), Indirect emission associated with grid electricity usage (Scope 2), and other indirect emissions (non-grid energy) as per the Intergovernmental Panel on Climate Change (IPCC) definitions have been added in Scope 3 (see *Table 2-1*). The "non-grid energy" related GHG emissions are associated with activities within the boundary of the utility, or which are a consequence of the services provided outside of the utility boundary.

Table 2-1 Overview of all GHG emissions from drinking water and wastewater system

	Water abstraction	Water treatment	Water distribution	Wastewater collection	Wastewater treatment	Wastewater discharge	Faecal Sludge Containment	Faecal Sludge Treatment	Faecal Sludge Disposal
Scope 1 – Direct emissions									
CO_2, CH_4 and N_2O emissions from on-site engine stationary fossil fuel combustion	•	•	•	•	•	•			
CH_4 from sewers or biological wastewater treatment				○	•				
CH_4 from faecal sludge containment							•		
CH_4 from faecal sludge treatment								•	
N_2O from sewers or biological wastewater treatment				○	•		•		
CH_4 and N_2O from sludge digestion					•				
CH_4 and N_2O from faecal sludge treatment								•	
Scope 2 – Indirect emissions									
Indirect emissions from electric use	•	•	•	•	•	•	•	•	•
Scope 3 –Other indirect emissions									
CO_2, CH_4 and N_2O emissions from truck transport of water (drinking water, wastewater, reused water) fossil fuel combustion			•	○		•			
Emissions from the manufacture/transport of chemicals		○			○			○	
Emissions from the construction materials used	○	○	○	○	○	○	○	○	○
CH_4 and N_2O from faecal sludge Management									•
CH_4 and N_2O from sludge management					•				
CH_4 and N_2O emissions from collected wastewater discharge without treatment				•					
CH_4 and N_2O emissions from not collected wastewater discharge without treatment				•					
CO_2, CH_4 and N_2O emissions from sludge transport off-site					•				•
N_2O and CH_4 emissions from effluent discharge in receiving waters						•			•
○ *Emissions not quantified in the ECAM tool, even though they exist*		• *Emissions quantified in the ECAM tool*							

The emissions are counted in terms of CO_2 equivalents (CO_2e). The equivalence for methane (CH_4) and nitrous oxide (N_2O) correspond to the 100-year global warming potential (GWP) for greenhouse gases (GWP100, AR5) reported by IPCC. In ECAM, users can choose which values for the GWP are applied by selecting the preferred IPCC report (*Table 2-2*).

Table 2-2 Global warming potential for different IPCC report years

Global warming potential for 100 year horizon				
Report	**CO_2 (CO2 equivalents)**	**CH_4 (CO_2 equivalents)**	**N_2O (CO_2 equivalents)**	**Comments**
IPCC 5th AR (2014/2013) CCF	1	34	298	with climate-carbon feedbacks[1]
IPCC 5th AR (2014/2013)	1	28	265	without climate-carbon feedbacks
IPCC 4th AR (2007)	1	25	298	
IPCC 3rd AR (2001)	1	23	296	
IPCC 2nd AR (1995)	1	21	310	
IPCC 1st AR (1990)	1	11	270	

2.3.2 Tiered approach

Tier A – Initial GHG Estimation

In Tier A, the ECAM tool focuses on grid energy consumption for the drinking water, the wastewater and faecal sludge systems and approximate quantification of both "direct emissions," and "other indirect emissions" not related to grid-energy consumption based upon reasonable assumptions and typical wastewater and faecal sludge treatment design conditions. A complete list of the estimations made at the Tier A level can be accessed directly from the Tier A screen in the tool or can be found here. The intent is that the user can quickly gain an estimate of the global emissions and identify where the biggest opportunities for GHG reduction exist, and what areas to focus on in terms of data collection and assessment. The output figures are pie charts and donuts representing respectively all GHG emissions and all electrical energy use in the water cycle. Colour coding is applied to distinguish GHG and energy related emissions from drinking water and wastewater systems.

[1] Climate Carbon Feedback: Theoretical concept based on the assumption that the four major carbon sinks (atmosphere, biosphere, oceans and sediments) will reduce their capacity to uptake CO_2 due to the ongoing climate change with direct effect on GWP of GHG emissions.

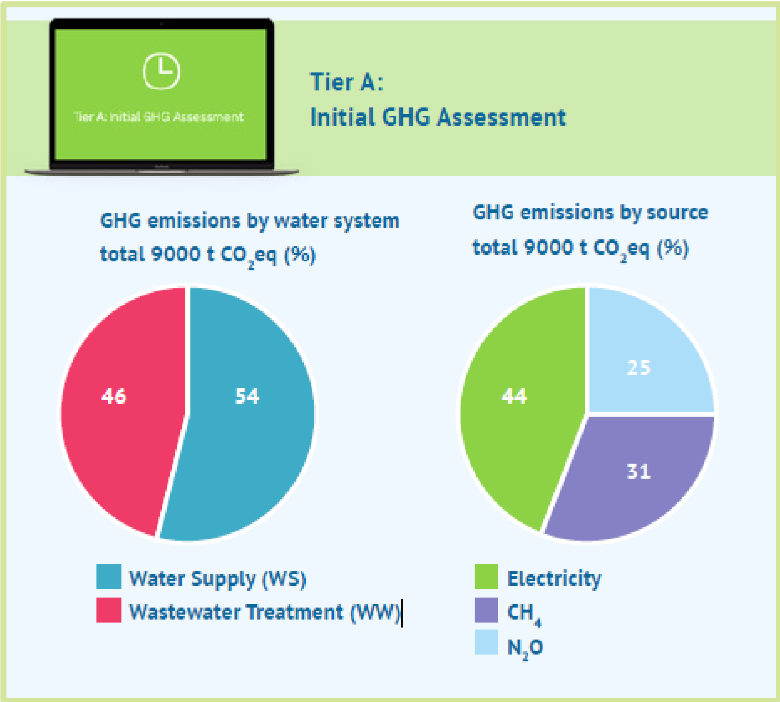

Figure 2-3 Pie chart information obtained from Tier A assessment

Tier B – Detailed GHG assessment

Tier B focuses on analysing system performance in depth with more accurate and more complete data inputs. Some of the inputs might be the same as in Tier A; however, in Tier B there is an opportunity to be more accurate by spending time collecting and verifying the data. Depending on the stage, it also includes data inputs related pumping performance, the use of topographic energy, water efficiency, sludge management, treatment type and performance, biogas production and many others as mentioned below. Along with the detailed analysis, the tool can assess energy performance & GHG emission at different stages and sub-stages of the urban water cycle. The data inputs in Tier B assessment include:

- Grid-energy consumption;
- Data related to non-grid energy GHG emissions of drinking water, wastewater system and faecal sludge:
    - Fuel used in engines (based on Diesel, Petrol or Natural Gas)
    - From treated wastewater discharged to a water body (based on nitrogen load);

- Wastewater treatment process (based on population, treatment type, BOD load and BOD removed)
- Sludge treatment and transport and disposal (based on volume, sludge type, dry mass)
- Biogas valorization (based on composition, volume)
- Type of Faecal sludge containment
- Flood conditions of the faecal sludge containment
- Fraction of the sludge contain that is emptied
- Characteristics of the Faecal Sludge (volume, BOD concentration and load)
- Faecal Sludge treatment process
- Type of disposal/reuse
- Biogas valorisation from faecal sludge (based on composition, volume)

Tier B – Advanced assessment: Sub-stages

This assessment level focuses on stage specific GHG emissions and energy performance for the three parts of the water cycle i.e. drinking water, wastewater and faecal sludge, as opposed to the global drinking water, wastewater and faecal sludge emissions obtained from Tier A. The output figure under energy summaries is a donut representing all electrical energy use in the water cycle by stage, colour-coded for each of the stages of the urban water cycle. Tier B also allows assessing the energy consumption in more detail. By providing further data, the user can zoom in at the performance of specific facilities (also referred to as sub-stages) such as individual pump stations, which may be benchmarked. Outputs are represented by a donut indicating the electrical energy consumption, colour-coded by stage of the urban water cycle. Each stage can be split into the sub-stages, for benchmarking selected facilities.

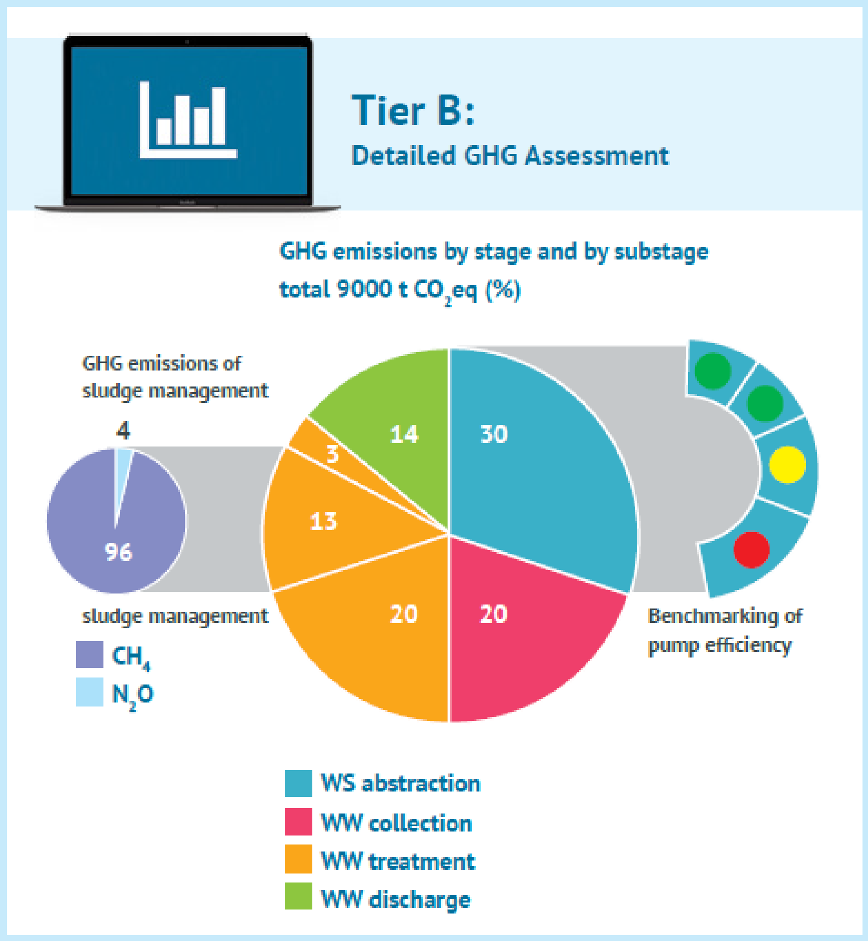

Figure 2-4 Pie chart information obtained from Tier B assessment

3 Methodology and conceptual background

3.1 Emissions from urban water cycle

As indicated in chapter 2, three categories of GHG emissions are included in ECAM. GHG emissions associated with grid-energy use (scope 2 – indirect emissions) and the GHG emissions not related to grid-energy use: “scope 1” (direct emissions) and “scope 3” (other indirect emissions). ECAM was developed to be consistent with the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories. This methodology has been further complemented with emission calculation methods from the Biosolids Emissions Assessment Model (BEAM), as well as with knowledge from recent scientific studies for specific aspects e.g. sludge storage.

3.2 Direct GHG emissions (Scope 1)

Sources of direct GHG emissions from within the UWS are summarized herein to understand the scope of ECAM, how they are accounted for, and how relevant the direct emission performance indicators (PIs) may or may not be to actual performance of the system and reducing direct GHG emissions.

CO_2, CH_4, and N_2O emissions from on-site stationary fossil fuel combustion sources:

These can include on-site engine generators and engines for driving process and/or pumping equipment used at water treatment and pumping facilities. These emissions will be based upon default emission factors for the appropriate fuel type and fuel consumption per IPCC guidelines.

CH_4 emissions from sewers: Methane is a potent greenhouse gas with a global warming potential of 34 CO_2-equivalents over a 100-year time horizon as reported by IPCC (2013). Methane can be produced in sewers via conversion of organic carbon by methanogenic archaea under anaerobic conditions, and then released into the atmosphere via manholes and atmospheric discharge points. Although methane emissions have been measured in both gravity (de Graaff *et al.*, 2012), and pressure sewers (Guisasola *et al.*, 2008), the risk of production tends to be greater in pressure sewers since there is generally no air/water interface to diffuse oxygen into the liquid phase and promote aerobic conditions. Methane production is also directly related to the detention time of the wastewater in sewer anaerobic conditions. Although IPCC (2006) indicates that closed underground sewers, which are predominant in the UWS, do not contribute significant CH_4 emissions, studies have shown the contrary. One study (Guisasola *et al*., 2008) found sewage methane to contribute GHG emissions between 12 – 100% of those from a WWTP itself. However, there are not yet any conventional methods for estimating these emissions that can easily be implemented by a water utility. Therefore, they are not included in the GHG estimation framework proposed herein.

CH_4 emissions from biological wastewater treatment:

The principal factor in determining the CH_4 generation potential of wastewater is the amount of degradable organic material in the wastewater. A wide range of fermentative bacteria break down large organic molecules to smaller ones such as fatty acids and alcohols and a smaller range of more specialised organisms convert these low molecular weight compounds into methane and carbon dioxide. CH_4 emissions from wastewater treatment can make up a significant portion of the WWTP carbon footprint (Daelman *et al*., 2013), and in cases such as anaerobic lagoon (>2m) it can be even much greater and can result from the following:

- Dissolved methane that is produced and transported from the collection system and that is then stripped a the WWTP headworks or in the aerobic reactors
- Dissolved methane that is produced from anaerobic digestion and is left in the reject water that is recycled to the aerobic tanks, where a fraction of the dissolved methane is ultimately stripped
- Methane gas produced in anaerobic digestion that escapes
- Methane gas produced in anaerobic digestion that is not fully combusted in cogeneration (Daelman *et al.,* 2012) or thermally destructed by flaring

Methane gas escaping from digested sludge storage facilities (Daelman *et al.,* 2012) anaerobic treatment systems. The IPCC methodology addresses all of these except the methane originating in the sewers and dissolved methane. The methodology also does not include the emission from the biogas flaring as these are not significant. The CO_2 emissions are of biogenic origin, and the CH_4 and N_2O emissions are very small and are not included in the estimation. Therefore, with exception of the sewer and dissolved methane, the following emission types are included in ECAM from:

- CH_4 from wastewater treatment
- CH_4 from onsite fuel engines
- CH_4 from anaerobic digestion & flaring
- CH_4 from direct discharge of untreated wastewater
- CH_4 from truck sludge disposal transport
- CH_4 emissions from sludge

CO_2 emissions from biological wastewater treatment:

These can be emitted directly from the aerobic processes as a by-product of microbial breakdown of organic matter. IPCC considers this source to be biogenic in nature, hence not a contributor to increased CO_2 concentrations in the atmosphere. Therefore, this source will not be included in the tool for consistency with IPCC guidance.

N_2O emissions from sewers: Nitrous oxide is another potent greenhouse gas with a global warming potential of 298 CO_2-equivalents over a 100-year time horizon (IPCC, 2013). Although some studies have reported N_2O emissions to be significant from sewers (Short *et al.*, 2014), the conditions leading to N_2O emissions in sewers are still not well understood. IPCC also does not consider sewers as a source of N_2O emissions; hence, they will not be considered in the GHG assessment framework strictly for consistency.

N_2O emissions from biological wastewater treatment:

The production of N_2O is completely different from CH_4 production. N_2O can be produced from both anoxic and oxic conditions and depends on the population, whereas methane production depends on the operations and treatment technology. With the high global warming potential of N_2O, it does not take a lot to make up a significant portion of the UWS carbon footprint. N_2O has actually been seen to make up 78% of a WWTP's total GHG emissions (Daelman *et al.*, 2013); therefore, it cannot be ignored. N_2O emissions from biological wastewater treatment, specifically employing nitrification and denitrification for nitrogen removal, can result from the following main pathways:

- during hydroxylamine (NH_2OH) oxidation in the conversion of ammonia (NH_3) to nitrite (Chandran *et al*., 2011; Law *et al*., 2012)
- reduction of nitric oxide (NO) produced from nitrite in nitrifier or ammonia oxidizing bacteria (AOB) denitrification (Bock *et al.*, 1995; Chandran *et al.*, 2011; Kampschreur *et al.*, 2009)
- during heterotrophic denitrification (Hiatt & Grady, 2008)

The first two pathways listed above typically occur in aerobic reactors designed for nitrification, where the N_2O produced is immediately stripped into the atmosphere, while the third typically occurs in anoxic (or unaerated) reactors designed for denitrification, where the N_2O produced can be either diffused into the atmosphere within the same reactors, and/or stripped in downstream aerobic reactors. The IPCC methodology (2006) includes a default emission factor for N_2O from wastewater treatment; therefore, it is included in ECAM for consistency.

However, it should be noted that this emission factor is related to population; whereas it is now generally accepted from various studies that risk of N_2O emission can be directly related to operational conditions (Ahn et al.,2010; Foley *et al.*, 2010; GWRC, 2015; Kampschreur *et al.*, 2009; Porro *et al.*, 2014). For example, dissolved oxygen levels that are too low can prompt N_2O production from AOB denitrification (Bock *et al.*, 1995; Chandran *et al.*, 2011; Kampschreur *et al.*, 2009). Therefore, these operational conditions should be considered in WWTP optimization strategies when trying to minimize GHG emissions.

CH_4 emissions from faecal sludge management

Direct methane emissions are produced by bacterial decomposition of organic matter in the absence of oxygen. Aerobic decomposition of the organics in wastewater requires more oxygen than can be supplied by surface diffusion. Therefore, without additional aeration, methanogenic processes will result in the production of methane. Anaerobic conditions may occur in many steps during faecal sludge management for example in pit latrines, septic tanks, anaerobic treatment and final disposal. Emission rate is controlled by temperature, moisture, available substrate, pH and other factors.

While the focus of GHG assessment and mitigation opportunities in the water sector is on centralized treatment, it is becoming more and more evident that faecal sludge management is an important, though poorly quantified, source of methane emissions within the urban water cycle (e.g. Reid *et al*. 2014; Leverenz, Tchobanoglous & Darby, 2010).

The variation in the values can be explained by several factors such as temperature and loading rates. In addition, the presented values for the IPCC method do not consider sludge removal while (Leverenz, Tchobanoglous, & Darby, 2010) considered that sludge was removed from the septic tank while not calculating the emissions from the further treatment or disposal of the sludge.

The chemical and biological conditions of septic tanks are believed to be prevalent in conventional pit latrines (US EPA ,1999), which suggests that the CH_4 emissions are also comparable. According to IPCC (2006) relevant for the methane emission rate is whether the ground water table is lower or higher than the latrine, if the climate is wet or dry and if flush water is used or not. This can be explained by the fact that generally the methanogenic activity requires high a moisture content (Lay, Li & Noike, 1997). While latrines without flushwater still generate CH_4 emissions due to the mixing of liquid and solids, more fully aerobic systems like well-maintained composting toilets or toilets that separate liquid and solid waste can be assumed to have insignificant CH_4 emissions (Reid et al., 2014). Since the faecal sludge still has some methane production potential after emptying of septic tanks, latrines etc. (Afifah & Priadi, 2017; Rose, 2015), a further anaerobic treatment or disposal can still produce methane emission

N_2O emissions from faecal sludge management

Since nitrification (the oxidation of ammonia nitrogen to nitrate nitrogen) is prerequisite for the N_2O emissions anaerobic systems like septic tanks or pit latrines are not significant sources of N_2O emissions. US EPA (1999) discussed the possible N_2O emissions from septic tanks, pit latrines and open sewers and concluded that these systems are not likely to produce any significant direct N_2O emissions to the air. The final disposal of biosolids in the environment is however a well acknowledged source of N_2O emissions (e.g. SYLVIS ,2009; IPCC ,2006). Measurements by Leverenz and Tchobanoglous & Darby (2010) have confirmed this and showed that N_2O were not a significant source of emissions from septic tanks but they were the main source of emissions from the soil dispersion system following the septic tank.

Source separated urine as it occurs for example in urine diverting toilets contains very high concentrations of nitrogen, nitrous oxide emissions are however very limited. After collection urea hydrolyses to ammonia and ammonium ions which is accompanies by an increase of pH increases to about 9, as a result bacterial activity is inhibited and a further decomposition of urine is prevented. Spångberg, Tidåker and Jönsson (2014) developed a model based on IPCC (2006) that quantifies direct N_2O emissions from urine spreading as 1% (N_2O-N) of total nitrogen added to soil. In addition, the model assumes that 1% of the ammonia-nitrogen emitted during urine collection / storage and land application cases indirect N_2O emissions and uses reported values for 4% ammonia emissions from collection / storage of urine and 5% ammonia emissions from land application of urine.

3.2.1 Methodology for Direct GHG Emissions assessment

The 2006 IPCC Guidelines for National Greenhouse Gas Inventories have been used as the main reference for equations used to calculate the GHG emission from the different stages of the urban water cycle. In most cases the equations from the IPCC guidelines have been used directly, but in some cases alternate resources have been applied e.g. if IPCC does not account for certain aspects. In such cases, references to other methodologies used, such as the BEAM methodology (SYLVIS Environmental, 2009), for sludge management have been provided.

There are components of the equations that are taken from other literature sources, in such cases, the respective references are provided. When actual data from the utility are not available default, values are set in order to calculate the GHG emissions. If in the assessment process real data are available, the use can change the default values and, in this way, increment the accuracy of the evaluation

3.2.1.1 Onsite engines GHG

The GHG emissions from on-site engines, measured in kg CO_2e (kilogram of CO_2 equivalents), are determined by two factors:

1. Engine Fuel Type (Diesel, Petrol or Natural Gas)
2. Volume of fuel consumed

The Input Data

In the ECAM-Tool, the following data is required to estimate the GHG emissions from on-site engines:

- The engine fuel type is to be selected by a drop down menu, where the user can select their fuel type. By default, the assumed fuel is Diesel.
- The volume consumed.

This information is requested in "Detailed Assessment"

The computation

Based on the input data entered in the tool, the following intermediate values will be computed to estimate the GHG emissions from on-site engines to be used in the Performance Indicators:

1. The energy content in the volume of fuel consumed is calculated, based on the expression (IPCC, 2006):

$$\text{Energy Fuel Cons (Assumed diesel)[TJ]} = \text{Volume of Fuel consumed} * \text{Fuel density} * \frac{\text{NCV}}{1{,}000{,}000}$$

Where:

- 1,000,000: For units conversion
- NCV: Net Calorific Values [TJ/Gg] (43 for Diesel)

Fuel Density (FD) and Net Calorific Values (NCV) factors are related with the type of fuel and there are tabled values from the IPCC guidelines (*Table 3-1*).

2. The emissions from on-site engines running on fuel (in $kgCO_2e$). As fuel is burnt, the engines will emit CO_2, N_2O and CH_4 in different quantities depending on the fuel type. The total CO_2 equivalent emissions from fuel engines are computed based on the following expression (2) (Volume 2: Energy; Equation 2.1; IPCC, 2006,):

$$\text{Emissions from onsite engines [kg CO}_2\text{e]} = \text{Energy fuel consumed} * (\text{EFCO}_2 + \text{EFN}_2\text{O} * \text{CNC} + \text{EFCH}_4 * \text{CMC})$$

Where:

- EF-CO_2: Emission factor of CO_2 for the chosen fuel
- EF-N_2O: Emission factor of N_2O for the chosen fuel
- EF-CH_4: Emission factor of CH_4 for the chosen fuel
- CNC: Conversion factor for N_2O emissions into CO_2 equivalent emissions (varies from 265 to 310 based on IPCC report year selected)
- CMC: Conversion factor for CH_4 emissions into CO_2 equivalent emissions (varies from 11 to 34 based on IPCC report year selected)

Table 3-1 Fuel Properties (IPCC, 2006)

	Fuel density [kg/L]	EF CO_2(kg/TJ)	EF CH_4(kg/TJ)	EFN_2O (kg/TJ)	NCV (TJ/Gg)
Gasoline/Petrol	0.74	69 300	3	0.6	44.3
Gas/Diesel Oil	0.84	74 100	3	0.6	43
Natural Gas	0.75 [kg/m^3]	56 100	10	0.1	48

3.2.1.2 Methane from treatment process

Methane emissions are calculated in the ECAM v2.2 tool for the following processes within the boundary of the wastewater treatment plant:

- Methane emissions from wastewater treatment and faecal sludge treatment (Tiers A and B)
- Methane emissions from anaerobic digestion (Tiers A and B)
- Methane emissions from the anaerobic digestion of sludge and faecal sludge (Tiers A and B)
- Methane emissions from faecal sludge management – Containment

Methane emissions from wastewater and faecal sludge treatment

The Input Data

In The ECAM-Tool, the following data is required to estimate the GHG emissions from biogas for each level of assessment:

At Initial assessment level, no additional inputs are required other than type of treatment

- The methane emissions are based on the serviced population and BOD load per person specified and the treatment technology.

At Detailed GHG Assessment, the following data is required:

- Actual Influent and Effluent BOD5 loads.
- Actual BOD_5 mass removed as sludge
- Type of treatment

The computation

Methane (CO_2e) emitted in wastewater treatment plants or faecal sludge treatment is [kgCO2e] (IPCC, 2006):

$$\text{Methane emitted} = (\text{BOD in the influent} - \text{BOD in the effluent} - \text{BOD removed as sludge}) * \text{EF(WWTP)CH}_4 * CMC$$

Wastewater treatment and faecal sludge methane emission factor [CMC $kgCH_4/kgBOD_5$] is calculated using the IPCC Guidelines for National Greenhouse Gas Inventories (2006, Equation 6.2). The wastewater treatment methane emission correction factor (MCF) per IPCC (2006) is provided in the table 3-2. In the ECAM tool, EF value is used depending on the wastewater treatment technique. The user can also substitute specific EF values during substages of the treatment step by clicking on the EF value and then adding additional stages.

$$\text{EF(WWTP)CH}_4 = \text{B\_o x MCF}$$

Where:

- B_o = maximum methane production capacity ($kgCH_4/kgBOD_5$) as per IPCC (2006) (This is a country specific value, If country-specific data are not available, a default value of 0.6 is used)
- MCF: Tabled values (Table 3-2)

Table 3-2 Example: Methane Correction Factors (MCF) & Emission factors (EF) for some types of treatment technique using default value of 0.6 for B0 (IPCC, 2006)

Type of Treatment	MCF	EF
centralized aerobic treatment plant (well managed)	0	0
Centralized aerobic treatment plant, with minor poorly aerated zones (also applies to aerated aerobic lagoons)	0.1	.06
Centralized aerobic treatment plant, with some aerated zones (also applies to aerated aerobic lagoons)	0.2	.12
Centralized aerobic treatment plant, not well managed (also applies to aerated aerobic lagoons)	0.3	.18

Since the faecal sludge is co-treated with wastewater or separately by similar technologies, the same EF can be used for faecal sludge treatment.

Effluent BOD_5 load: 10 % of influent BOD assuming that this amount is remaining in the effluent

BOD_5 mass removed as sludge [kg]:

$$\mathrm{BOD_5 mass\ removed\ as\ sludge\ [kg]} = Influent\ BOD_5 load\ (treatment)[kg] * \%\ \mathrm{BOD\ sludge}/100$$

Where:

- % BOD sludge: the fraction of influent BOD removed with sludge (value from Table 3-3)

Table 3-3 Percent BOD removed with sludge for different treatment types (IPCC, 2006)

Main treatment technology	CH_4 Emission factor (containment) (kgCH4/kgBOD5)	% BOD sludge
No Treatment	0	0
Anaerobic Digester	0.48	10
Imhoff Tanks	0.48	10
Anaerobic Reactors – CH_4 recovery not considered	0.48	10
Anaerobic Reactors – CH_4 recovery considered	0	10
Stabilization Ponds (<2 m depth)	0.12	30
Stabilization Ponds (> 2m depth)	0.48	10
Sludge Drying Beds	0	0
Wetlands – surface flow	0.24	30

Wetlands – Horizontal subsurface flow	0.06	65
Wetlands – Vertical subsurface flow	0.006	65
Composting	0.0013	0
Activated Sludge (well managed)	0	65
Activated Sludge – minor poorly aerated zones	0.06	65
Activated Sludge - Some aerated zones	0.12	65
Activated Sludge – Not well managed	0.18	65
Trickling Filter	0.036	65

3.2.1.3 Methane emissions from anaerobic digestion sludge and faecal sludge

The GHG emissions from methane in biogas, measured in kg CO_2e (kilograms CO_2 equivalents), are determined by two factors:

1. Amount of biogas produced at the WWTP through anaerobic digestion. This amount will vary as a function of the treatment and how it is operated.
2. The type of use for the biogas: if it is flared or if it is valorised in a boiler or co-generation engine for electricity and/ or heat. Although it is highly discouraged, it is possible that the biogas is produced, but not flared or valorised, which would result in the maximum emissions.

In the ECAM Tool it is assumed that when biogas is flared, 2% of the total methane flared is released to the atmosphere, based on expert judgement that the methane is not 100% destructed from typical flaring operations. If biogas is fully valorised, the tool assumes that no methane emissions are released to the atmosphere.

The Input Data

In The ECAM-Tool, the following data is required to estimate the GHG emissions from biogas for each level of assessment:

At Initial assessment (Tier A) level no additional inputs are required.

- The biogas production is estimated based on the serviced population
- Default BOD_5 loads specific per country.
- Annual protein consumption per capita specific per country.
- Treatment Technology

Along with this the user can also select the GWP of carbon dioxide, methane and nitrous oxide according to different IPCC guidelines.

At detailed GHG Assessment (Tier B), the following data is requested if known:

- The actual volume of biogas produced by the digester or the type of treatment
- The actual volume of biogas flared
- The actual volume of biogas valorised
- Actual influent and effluent BOD_5 loads
- % of methane in biogas

The computation

Based on the input data entered in the tool, the following intermediate values will be computed to estimate the GHG emissions from biogas to be used in the Performance Indicators:

This computation is executed differently in each level according of the data provided:

Under Tier A: Initial Assessment:

The computation is based on several assumptions (see Tier A estimations list), and is carried through unless actual biogas production data is entered in Tier B.

Biogas produced (estimated at Tier A) versus actual values at detailed assessment):

$$\text{Biogas produced (Nm3)} = \text{serviced population in sewer and WWTP (pers)} * \text{country specific average } BOD_5 \text{ load (g/pers/day)} * 0.8\text{(g VS/g BOD5 load)} * 0.4\text{(N L/g VS)}/1000 * \text{Ap (days)}$$

$$\text{Biogas produced(Faecal SLudge) (Nm3)} = \text{population OSS(pers)} * \text{country specific average } BOD_5 \text{ load (g/pers/day)} * 0.8\text{(g VS/g BOD5 load)} * 0.4\text{(N L/g VS)}/1000 * \text{Ap (days)}$$

Where:

- 0.8: ratio of dry weight (g) of organic matter (volatile solids) to BOD_5 load (g) entering the plant, assuming a theoretical average for a well operated plant with primary sedimentation. This factor is derived from (Svardal & Kroiss, 2011)
- 1000: Unit conversion factor
- OSS: population with onsite treatment
- 0.4: production of biogas in N L per g of organic matter (VS) contained in the sludge. (PE: population equivalent = serviced population)
- 0.59 % CH_4 in Biogas
- 0.66: kg CH_4/Nm^3

Methane released (if the user has answered YES to the question "Are you producing Biogas?" and NO to the question "Are you valorising biogas?"):

$$\text{Methane released [kg } CO_2\text{e]} = (0.02 \text{ x Biogas produced}) * 0.59 * 0.66 * 34$$

Where:

- 0.59 based on % CH_4 in Biogas
- 0.66: kg CH_4/Nm^3
- CMC: Conversion factor for CH_4 emissions into CO_2 equivalent emissions (varies from 11 to 34 based on IPCC report year selected)
- 0.02: 2% of methane losses

Under Tier B: Detailed Assessment:

Biogas flared [Nm^3]

$$\text{Biogas flared} = \text{input}$$

Methane released:

$$\text{Methane released [kg } CO_2\text{e]} = (0.02 \text{ x Biogas flared}) \text{ x } 0.59 \text{ x } 0.66 \text{ x } 28$$

Wastewater treatment methane emission factor [$kgCH_4/kgBOD_5$] (IPCC, 2006):

$$EF(WWTP)CH_4 = 0.6 \text{ x } MCF$$

Methane (CO_2e) emitted in wastewater treatment plants and faecal sludge treatment [kgCO_2e] (IPCC, 2006):

$$\text{Methane emitted} = (\text{BOD in the influent} - \text{BOD in the effluent} - \text{BOD removed as sludge}) * EF(WWTP)CH_4 * CMC$$

Where:

- 0.02: 2% of methane losses
- 0.59: 59% CH_4 in Biogas
- 0.66: kg CH_4/Nm^3
- CMC: Conversion factor for CH_4 emissions into CO_2 equivalent emissions (varies from 11 to 34 based on IPCC report year selected)
- Ap: Assessment period in days
- MCF: Tabled values (Table 3-2)

3.2.1.4 Methane emissions from faecal sludge management – Containment

The Input Data

At Initial assessment (Tier A) level the following data are required about the containment

- Percentage of containment emptied
- Is the containment experiencing flooding or groundwater infiltration?
- Containment type

The containment types that are considered in ECAM, their CH4 emission factor (EF) and the literature source of EFs are presented in the *Table 3-4.*

Table 3-4 Methane emission factors for various containments

Main containment technology	CH_4 Emission factor (containment) ($kgCH_4$/kg BOD)	IF answer to "Is the containment experiencing flooding or groundwater infiltration?" is YES CH_4 Emission factor (containment)	Source normal EF	Source flooded EF
Pit latrine without flush water (lined or unlined) – household	0.06	0.42	IPCC V5 CH6	IPCC V5 CH6
Pit latrine without flush water (lined or unlined) – communal	0.3	0.42	IPCC V5 CH6	IPCC V5 CH6
Pit latrine with flush water use (lined or unlined)	0.42	0.42	IPCC V5 CH6	IPCC V5 CH6
Septic System	0.3	0.42	IPCC V5 CH6	IPCC V5 CH6
Fully lined tank without flush water use - not water tight	0.3	0.42	same as pit latrine without flush water*	IPCC V5 CH6
Fully lined tank without flush water use - water tight	0.42	0.42	same as pit latrine without flush water*	IPCC V5 CH6
Fully lined tank with flush water use - water tight or untight	0.42	0.42	same as pit latrine with flush water*	IPCC V5 CH6
UDDT	0	0.42		IPCC V5 CH6
Composting Toilet	0.0013	0.42	IPCC V5 CH4	IPCC V5 CH6
No containment (open defecation)	0.0270	0	based on Winrock 2008	

*based on expert judgment

At Tier B for detailed GHG Assessment, the following data is required:

- Influent BOD_5 load
- Faecal sludge density

- Volume of faecal sludge emptied
- BOD concentration of faecal sludge
- BOD removed as faecal sludge

Default values are provided for these inputs in case when the user may not have all the input data. The default values are based on the following calculations:

1. Influent BOD load

$$\text{Influent BOD load (containment)}[\text{kg}] = BOD_5(\text{g/pers/day}) * \text{ Population OSS}$$

Where:

- BOD_5 (g/pers/day): BOD_5 per person per day based on country selected
- Population with OSS : Population with onsite treatment

3. *Faecal sludge density:* the density of FS from various containments is taken from literature and presented in *Table 3-5*.

Table 3-5 Density for various FS

Type of FS	Density (kg/m³)	Source
Pit	1000	(Radford, 2014)
Untreated	1400	
Septic Tank	1100	

3. Volume of faecal sludge emptied

$$\text{FS emptied } [\text{m}^3] = (0.3\ [kg] * \text{ Days } * \text{ Population with OSS } * \%\text{Containment emptied})/\ \text{FS density}[\text{kg/m}^3]$$

Where:

- 0.3 - FS production (kgFS/person/day) (Strande et. al, 2014)
- % Containment emptied: Fraction of produced faecal sludge that is emptied from containments.

4. BOD concentration of faecal sludge: BOD values that are considered by default are given in *Table 3-6*. The user can modify and insert site specific value from laboratory test or literature value for specific area.

Table 3-6 BOD concentration for FS from different containments

Main containment technology	BOD concentration of FS [kg/m³]	Source normal EF
Pit latrine without flush water (lined or unlined) – household	67.8	Measurements of Phd student working for CFS-Lusaka
Pit latrine without flush water (lined or unlined) – communal	67.8	>>
Pit latrine with flush water use (lined or unlined)	67.8	>>
Septic System	1.35	>>
Fully lined tank without flush water use - not water tight	67.8	>>
Fully lined tank without flush water use - water tight	67.8	>>
Fully lined tank with flush water use - water tight or un-tight	67.8	>>
UDDT	67.8	>>
Composting Toilet	67.8	>>
No containment (open defecation)	67.8	>>

5. BOD removed as faecal sludge

$$\text{BOD removed as faecal sludge (empting)[kg]} = \text{FS emptied } [\text{m}^3] * \text{BOD conc. of FS } [\text{kg/m}^3]$$

The computation

Based on the input data entered in the tool, the following values will be computed to estimate the GHG emissions from FSM containment:

CH_4 emissions (containment) [kg CO_2e], based on the following expression (IPCC, 2006):

$$\text{CH}_4 \text{ emissions (containment)[kg CO}_2\text{e]} = (\text{ influent BOD load} - \text{BOD removed as faecal sludge }) * \text{EFCH}_4 * \text{CMC}$$

Where:

- $EF\text{-}CH_4$: Emission factor of CH_4 for the chosen containment (value from Table 3-4)
- CMC: Conversion factor for CH_4 emissions into CO_2 equivalent emissions (varies from 11 to 34 based on IPCC report year selected)

3.2.1.5 N_2O from treatment process

Nitrous oxide (N_2O) emissions are calculated in the ECAM v2.2 tool for emissions from the biological wastewater treatment process. As there is always the potential for either intentional or unintentional nitrification and/or denitrification based upon how wastewater treatment plants are operated, there is always the potential for N_2O emissions from the treatment process.

The Input Data

At both the Initial and Detailed assessment levels no additional inputs are required:

- The N_2O emissions are estimated based on the serviced population specified and IPCC guidelines (2006).

The computation

N_2O emissions from wastewater treatment process [kg N_2O]:

$$N_2O \text{ emissions (kg } N_2O) = \text{serviced population for WWTP (pers)} * 1.25 \text{ x } 3.2/1000/365 \text{ days} * \text{Ap(days)}$$

Where:

- 1.25: fraction of industrial and commercial co-discharged protein per IPCC 2006).
- 3.2: N_2O emission factor, 3.2 g N_2O/person/year
- 1000: Unit conversion factor
- Ap: Assessment period in days

3.3 Indirect grid-energy GHG emissions (Scope 2)

According to the energy balance presented in the *Figure 3-1*, electrical energy purchased from the grid at the entire drinking water or wastewater system level is used to calculate GHG emissions. It includes grid electricity consumed by the facilities (e.g. pump stations) of the utility and may also include consumption for buildings (e.g. lighting, heating or ventilation).

Energy balance; Energy IN = Energy OUT

Energy IN

- Grid electricity
- Renewable energy (self-produced)

Energy OUT

- Surplus renewable electricity (self-produced)
- Energy consumption for operating equipment

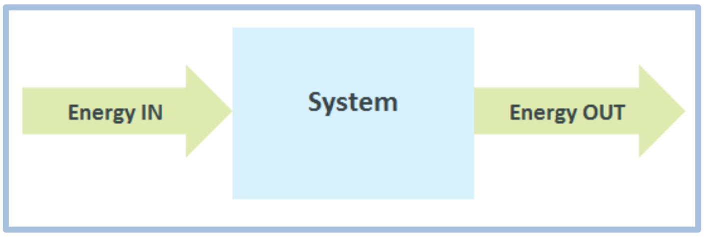

Figure 3-1 Energy balance

The energy assessment focuses on electricity consumption at each stage of the utility for process related usage. At each stage of the urban water cycle, the user may enter sub-stages representing the different facilities of that particular stage (e.g. different treatment plants, different pump stages or distribution networks).

At the stage level, the energy performance can only be assessed in terms of relative importance of the stage in comparison to the entire water cycle. At sub-stage level, energy performance indicators are calculated to assess if there is a potential to reduce consumption or improve energy production by comparing to benchmark values. These performance indicators (e.g.: standardized pumping energy, treatment energy), when documented at the sub-stage level (i.e.: at the facility level), are then averaged to provide an overview of the overall efficiency of the stage.

3.3.1 Methodology for grid-energy GHG emissions

The GHG emission factor of grid electricity, measures the kilograms (kg) of carbon dioxide (CO_2) emitted per kWh of electricity generated from fossil fuels per IPCC guideline (IPCC, 2006). Renewable sources of electricity such as hydropower, wind, solar and even nuclear, are carbon-free. The emission factors for electricity delivered to customers from a mix of generation sources usually takes into account the average annual contribution of the different sources. Therefore, GHG emissions depend not just on the country, but also on the year and on the urban water industry potentially generating energy from urban water (for instance pumps working as turbines –PATs-, installed into the distribution networks, or in the wastewater treatment plants Combined Heat and Power –CHP- engines running on biogas, and heat pumps). In ECAM, users can apply the mix factor (kg CO_2/kWh) based on, when available, local data provided by the municipalities for electricity used. If that is not the case, the yearly average country default values in the tool should be used Daily time variations of the conversion factor, depending on the fuel source mix (hydroelectric, coal, etc.) are not considered.

3.3.1.1 Energy Benchmarking

As noted previously, the capability of benchmarking various aspects of the various urban water stages exists in the ECAM tool for being able to identify inefficiencies in each stage. *Table 3-7* lists the key energy benchmarking parameters in each stage and their references.

Table 3-7 Energy Benchmarking in ECAM Tool

Stage	Energy Benchmarking Parameter	Units	Code	Reference
Water abstraction	Standardized Energy Consumption	kWh/m3/100m	wsa_KPI_std_nrg_cons	Cabrera, et al., 2014
Water treatment	Energy Consumption Per Treated Water	kWh/m3	wst_KPI_nrg_per_m3	Alegre, et al., 2006
Water distribution	Standardized Energy Consumption	kWh/m3/100m	wsd_KPI_std_nrg_cons	Cabrera, et al., 2014
Wastewater collection	Standardized Energy Consumption	kWh/m3/100m	wwc_KPI_std_nrg_cons	Cabrera, et al., 2014
Wastewater treatment	Energy Consumption Per BOD removed	kWh/kg BOD removed	wwt_KPI_nrg_per_kg	Silva & Rosa, 2014
Wastewater discharge/reuse	Standardized Energy Consumption	kWh/m3/100m	wwd_KPI_std_nrg_cons	Cabrera, et al., 2014

The ranges for good, acceptable, and poor benchmarking values for each of the parameters listed in Table 3-6 can be found in the Annexes E, G, I, M, O, and Q.

3.3.1.2 Pumping Efficiency

Pumping efficiency can be assessed in ECAM at the sub-stage level in Tier B. The intent is to use a tiered approach for assessing pumping efficiency. First the standardized energy consumption benchmarking results, which require less data to obtain, are used to identify where there might be inefficiencies and opportunities to reduce energy consumption and GHG. Field measurements can be obtained for those pumping stations exhibiting poor standardized energy consumption and higher total energy consumption. At a more detailed level, after obtaining measurements such as current and voltage from the field, the data can be then entered into ECAM to calculate the electromechanical efficiency of the pumping units and assess the potential GHG reduction and energy savings from replacing inefficient pumps. The equations used in calculating water power, electromechanical efficiency, energy savings, GHG reduction from new pumps etc. for water abstraction, water distribution, and wastewater collection stages is provided in Annexes E, I, and M, respectively.

3.4 Indirect non-grid energy GHG emissions (Scope 3)

As summarized in *Table 2-1*, the following emissions comprise the Scope 3 GHG emissions included in the ECAM tool:

CH_4, and N_2O emissions from untreated wastewater discharged directly to water bodies (connected and unconnected to sewer):

Untreated wastewater contains COD and nitrogen, which are converted to methane and nitrous oxide in water bodies. Methane is produced from bacteria breaking down the COD settled in the sediment under anaerobic conditions, while nitrous oxide is produced from nitrifying and denitrifying bacteria converting ammonia and nitrate in the water column. These emissions are calculated in the ECAM tool per the IPCC guidelines. For methane emissions, a methane correction factor (MCF) of 0.01 is assumed for discharge to lake, river, or sea and default BOD loading per person for different countries. N_2O emissions are based upon published protein consumption rates per population for all countries. BOD loading and protein consumption data used in ECAM can be found here.

N_2O emissions from effluent discharge in receiving waters:

N_2O can be indirectly (off-site) emitted from WWTPs in receiving waters from the conversion of the nitrogen in the effluent by various nitrifying and denitrifying bacteria cultures. This can be directly related to on-site operations, specifically the nitrogen removal performance of the WWTP, as the emissions are estimated using a default emission factor per IPCC guidelines (IPCC,2006) and the nitrogen discharged in the effluent.

CO_2, CH_4, and N_2O emissions from transport of sludge or water off-site:

These emissions are related to the vehicle fuel consumption in the transport of water (either drinking water or reuse water) or sludge off-site from the WWTP. They can be directly related to performance/operations on-site because the level of sludge dewatering before disposal, for example, will dictate the amount trips taken by sludge hauling trucks, the fuel consumption/combustion, and thus the GHG emissions from the sludge transport.

CH_4, and N_2O emissions from sludge and faecal management:

These emissions are related to the various sludge management options that are available for wastewater utilities. Depending on the method, varying levels of GHG emissions can result and can even result in GHG emissions avoided due to offsetting fertilizer use in the case of land application, and due to carbon sequestration from composting, land filling, and land application. More details on each sludge management options are provided in the methodology section.

The methodology for each of the Scope 3 indirect non-grid energy emission included in ECAM is detailed in the subsequent sections.

3.4.1 Methodology for GHG emissions related to sludge and faecal management

New since version, v2.2 of the ECAM-Tool is the possibility to assess emissions from Sludge Management. The calculations are primarily based on the BEAM-tool (2009) methodology (SYLVIS Environmental, 2009) and include GHG emissions from the following activities:

- Sludge storage (Tier B only)
- Sludge disposal (Tier A and B)
  - Landfilling
  - Land application
  - Incineration
  - Composting
  - Stockpiling
- Sludge transport to disposal site (Tier B only)

The Input Data

The key items that impact the GHG emissions from sludge management are the following:

- Sludge and faecal sludge produced (dry weight)
- Whether sludge or faecal is digested/treated or not
- disposal method

In The ECAM-Tool, the following data is required to estimate the GHG emissions from sludge management at the Tier-A Assessment level:

- Disposal method
- Biogas production (Yes or No)

This is asked for estimating biogas production; however, it is also used for sludge disposal GHG emissions estimates, because if Yes, then tool assumes sludge is digested, and if No, then tool assumes sludge is not digested.

In The ECAM-Tool, the following data is required to estimate the GHG emissions from sludge management at the Tier B level:

- Disposal method (if different in sub-stages)
- Whether sludge is Digested or Non-digested sludge. If Digested, 40% volume reduction is (Tchobanoglous, et al., 2003)
- Wet weight of sludge produced (used to calculate dry weight)
- Whether faecal sludge is treated or not. It gives the type of faecal sludge and its composition (use to calculate dry weight)
- Percentage of emptied containment composition (use to calculate dry weight)
- Number of trips to disposal site
- Distance to disposal site
- Storage time

The computation

First, at the “Initial” Assessment level, the sludge produced is estimated based on default BOD load/person specified, and typical values of total and volatile suspended solids for activated sludge processes. Based upon the sludge produced, which is considered to be the wet weight, the dry weight is calculated based upon 4% solids content (Leeschber et al., 1996). Four percent solids content for sludge can result from a wide range of sludge processing unit operations that can be feasibly expected at wastewater treatment plants around the world (Leeschber et al., 1996). If dewatering by centrifuge or chemical conditioning is used, then 20% solids can be expected; however, it is not used as the default. Of course, the user can estimate the dry weight of sludge based on the actual percent solids and the specific situation, or just the actual dry weight can be entered if this is already known.

The sludge production estimated at the Initial Assessment level is as follows:

Sludge produced (estimated at initial assessment versus actual values at detailed assessment):

$$\begin{aligned}&\text{Sludge produced (wet weight, kg TSS)}\\&\qquad = \text{BOD}_5\text{load ((g/pers)} * 0.001 * \text{Serv. Pop.} * \text{Ap(day)} * 0.55 * 1.176\end{aligned}$$

Where:

- 0.55: ratio of g volatile suspended solids to g of substrate (BOD) removed per (Tchobanoglous et al., 2003)
- 0.1: Assumes 10% of the influent BOD load escapes treatment and leaves the wwtp in the effluent
- 1e-3: Unit conversion factor kg/g
- 1.176: Conversion factor, ratio of total suspended solids to volatile suspended solids (g TSS/ g VSS) in typical activated sludge per (Tchobanoglous, et al., 2003)
- Ap: Assessment period in days

If sludge is digested, then the above value is multiplied by 0.6.

Regarding the dry weight of faecal sludge, if the amount of faecal sludge send to a specific disposal method is unknown this one is calculated on based of fraction of containment emptied, the density of the FS and the content of total solids

$$\text{Faecal sludge produced (wet weight, kg TSS)} = \text{FS emptied } [m^3] * \text{FSdensity } \left(\frac{kg}{m^3}\right) * \%TS$$

Where:

- FS emptied : Volume of faecal sludge emptied from the containment
- FS density : Density of the FS based on the type.(Table 3-5)
- %TS: percentage of total solids based on the type of treated faecal sludge (***Fehler! Verweisquelle konnte nicht gefunden werden.***)

Once dry weight is calculated, the BEAM tool methodology is applied for each of the mentioned sludge management methods below. The exception is stockpiling, which is based upon Majumder et al. (2014) and Sludge storage methane emissions that is based on Daelman, et al. (2014). By clicking on the variables for each method, the equations are described in a description page.

3.4.1.1 Sludge management options

In the following section, the most critical factors for the emissions from sludge management are presented. Where possible, equations have been adopted from the BEAM tool, which is considered a sound and detailed basis for calculations (SYLVIS Environmental, 2009)

Storage

Sludge storage methane emissions are based on Daelman *et al.* (2014), whereby a maximum of 5 percent of the methane potential in the sludge is released with a 20 day or greater detention time, 3% of the methane potential is the sludge is released with a detention time of 5 to 20 days, and zero is released with less than 5 days of storage time. The methane potential is calculated based upon the default BOD load/person and whether the sludge is digested or not.

Composting

Methane (CH_4) emissions: If compost piles are covered or process air is treated in a biofilter, CH_4 emissions are negligible; otherwise, small amounts are possible.

Nitrous oxide (N_2O) emissions: Minimal nitrous oxide emissions from the composting process are possible. Additional emissions may occur after biosolids compost is applied to soil.

If composting air emissions are treated and/or piles are covered, or composting air is released to the atmosphere and compost is > 55% solids, then

$$\text{CH}_4 \text{ emissions (kg/day)} = \text{zero (0)}$$

If composting air is released to the atmosphere and compost is < 55% solids, then

$$\text{CH}_4 \text{ emissions (kg CO}_2\text{ eq)} = \text{sludge mass (kg)} * \text{\% organic C in sludge} * \text{\% VS} * \text{CH}_4 \text{ emissions for uncovered pile} * \text{C to CH}_4 \text{conversion factor} * \text{CMC}$$

Where:

- 56: % of organic carbon in volatile solids
- 51: % of volatile solids in digested sludge
- 70: % of volatile solids in not-digested sludge
- 2.5: % of CH_4 emission for uncovered pile
- 1.3: C to CH_4 conversion factor
- CMC: Conversion factor for CH_4 to CO_2 equivalent (varies from 11 to 34 based on IPCC report year selected)

Nitrous oxide (N_2O) emissions:

If C:N ratio is > 30, or C:N ratio is < 30 and compost is > 55% solids, then

N_2O emissions (kg/day) = zero (0)

If C:N ratio is < 30 and compost is < 55% solids, then

$$\text{N}_2\text{O emissions (kg CO}_2\text{ eq)} = \text{sludge treated (kg)} * \text{\% total N} * \text{N}_2\text{O emissions for low C:N} * \text{N to N}_2\text{O conversion factor (1.57)} * \text{CNC}$$

Where:

- 3: % total N
- 1.5: % N_2O emissions for low C:N
- 1.57: N to N_2O conversion factor
- CNC: Conversion factor for N_2O to CO_2 equivalent – varies from 265 to 310 based on IPCC report year selected

Incineration (combustion)

Methane (CH_4) emissions: CH_4 emissions from combustion are minimal.

$$\mathrm{CH_4\ emissions\ (kg\ CO_2eq) = sludge\ treated\ (kg)\ * 0.0000485\ Kg\ CH_4/}$$
$$\mathrm{dry\ kg\ sludge\ (default\ value, assuming\ 20\%\ solids) * \ CMC}$$

Nitrous oxide (N_2O) emissions: N_2O emissions are the largest concern with combustion of biosolids. They are caused mostly by thermal conversion of nitrogen (N) and by use of urea-based selective non-catalytic reduction (SNCR) emissions control systems.

$$\mathrm{N_2O\ emissions\ (kg\ CO2\ eq)}$$
$$= \mathrm{\%\ of\ total\ N} * \mathrm{mass\ of\ sluge} * (161.3 - 0.140) * (\mathrm{highest\ free\ board\ temp})) * 0.01$$
$$* \mathrm{N\ to\ } N_2\mathrm{O\ conversion} * \mathrm{CNC}$$

Where:

- 3: % total N (this is different form the authors' proposal in BEAM tool, 4)
- 1.57: N to N_2O conversion factor
- CNC: Conversion factor for N_2O to CO_2 equivalent – varies from 265 to 310 based on IPCC report year selected

Land Application

Beam methodology deviates from ECAM methodology at this application. Beam methodology at land application. also includes CO_2 emissions from fossil fuels burned, CO_2 emissions from lime or other alkaline material.

Methane (CH_4) emissions: Methane emissions are possible when biosolids are stored after stabilization and prior to land application. Such emissions are considered under the sludge storage.

Nitrous oxide (N_2O) emissions: N_2O emissions are possible when nitrogen fertilizers, including biosolids, are applied to soils. Emissions are likely greater when biosolids are applied to fine-textured soils and when solids are wetter (< 55% solids). N_2O emissions are also possible during storage.

If the biosolids C:N ratio > 30, then

N_2O (kg/day) = zero (0)

If the biosolids C:N ratio < 30, then

$$\mathrm{N_2O\ emissions\ (kg\ CO_2eq)} = \mathrm{sludge\ mass\ (kg)} * \mathrm{\%\ of\ total\ N} * \mathrm{\%\ of\ sludge\ applied\ on\ fine\ or\ coars\ textured\ soils} * \mathrm{\%\ of\ N\ that\ goes\ to\ N_2O} * \mathrm{N\ to\ N_2O\ conversion} * \mathrm{CNC}$$

Where:

- 3: % of total nitrogen in not-digested sludge
- 4: % of total nitrogen in digested sludge
- 2.3: % of N that goes to N2O from fine-textured soil
- 0.5: % of N that goes to N2O from coarse-textured soil
- 1.57: N to N_2O conversion
- CNC: Conversion factor for N_2O emissions into CO_2 equivalent emissions (varies from 265 to 310 based on IPCC report year selected)

Landfill Disposal

Methane (CH_4) emissions: CH_4 emissions from biosolids placed in a typical landfill are significant and difficult to control. Considerable research has been conducted on landfill methane emissions in general, and refined formulas have been developed and are used in the BEAM. Additional minimal emissions are created when the CH_4 is burned for heat or power.

For fugitive methane emissions from biosolids decomposition in the landfill during the first 3 years after placement:

$$\begin{aligned}\mathrm{CH_4\ emissions\ (kg\ CO_2\ eq)} &= \mathrm{sludge\ mass\ (kg)} * \mathrm{\%VS} * \mathrm{\%\ organic\ C\ in\ VS} * 0.9 * \mathrm{C\ to\ CH_4\ conversion\ factor} \\ &* \mathrm{CH_4\ in\ landfill\ gas} * \mathrm{\%\ decomposed\ in\ first\ 3\ years} * \mathrm{MCFlandfill} * \mathrm{CMC}\end{aligned}$$

Where:

- 56: % of organic carbon in volatile solids
- 51: % of volatile solids in digested sludge
- 70: % of volatile solids in not-digested sludge
- 0.9: model uncertainty factor
- 1.3: C to CH_4 conversion factor
- 50: % of CH_4 in landfill gas
- 80: % DOCf -the decomposable organic fraction of raw wastewater solids
- 69.9: % decomposed in first 3 years
- MCF-landfill (methane correction for anaerobic managed landfills) – 1
- CMC: Conversion factor for CH_4 emissions into CO_2 equivalent emissions (varies from 11 to 34 based on IPCC report year selected)

Nitrous oxide (N_2O) emissions: Landfilled biosolids will likely be anaerobic or close to anaerobic, resulting in potential N_2O emissions.

If C: N ratio is > 30, then

N_2O emissions (kg/day) = zero (0)

If C: N ratio is < 30, then

$$\mathrm{N_2O\ emissions\ (kg\ CO_2\ eq) = sludge\ mass\ (kg)\ *\ \%\ of\ total\ N\ *\ N_2O\ emissions\ for\ low\ C{:}\,N\ *\ N\ to\ N_2O\ conversion\ *\ CNC}$$

Where:

- 3: % of total nitrogen in not-digested sludge
- 4: % of total nitrogen in digested sludge
- 1.5: % of N_2O emissions for low C:N
- 1.57: N to N_2O conversion
- CNC: Conversion factor for N_2O emissions into CO_2 equivalent emissions (varies from 265 to 310 based on IPCC report year selected)

Stockpiling

This part is developed based on Majumder et al. (2014)

Methane (CH_4) emissions: methane emissions from biosolids stockpiles is negligible

Nitrous oxide (N_2O) emissions: N_2O emissions are the main GHG contributors from stockpiling and the GHG emission varies with the age of stockpiles. Very young stockpiles were found to emit large amount of nitrous oxide.

$$\text{kg } CO_2 \text{ eq} = \text{sludge mass (kg)} * 90.3 * 0.001$$

Where:

- 90.3: kg CO_2-e /Mg dry sludge. year
- 0.001: kg to Mg conversion factor

3.4.1.2 Faecal Sludge management options

The ECAM-Tool version 2.2 assess the GHG emissions from reuse/disposal of faecal sludge. The calculations are mainly based on the BEAM-tool (2009) methodology and include GHG emissions from the following activities:

- Faecal Sludge disposal (Tier A and B)
  - Landfilling
  - Land application
  - Dumping
- Faecal Sludge transport to disposal site (Tier B only)

The Input Data

The key items that affect the GHG emissions from sludge management are the following:

- Faecal Sludge produced (dry weight)
- Type of Faecal sludge disposed

In The ECAM-Tool, the following data is required to estimate the GHG emissions from sludge management at the “Initial” Assessment level:

- Disposal method
- Type of Faecal sludge disposed

In The ECAM-Tool, the following data is required to estimate the GHG emissions from sludge management at the “Detailed” Assessment level:

- Dry weight sent to land application
- Type of Faecal sludge disposed
- Dry weight sent to landfilling
- Volume dumped
- Volume of discharged effluent to water body
- Total Nitrogen concentration in the effluent
- Total Nitrogen reused
- Total Phosphorus reused

The computation

In the following section the most critical factors for the emissions from sludge management are presented. Where possible, equations have been adopted from the BEAM methodology, which is considered a sound and detailed basis for calculations.

Land Application

Nitrous oxide (N_2O) emissions: N_2O emissions occur when nitrogen fertilizers, including biosolids, are applied into soils. Emissions are likely greater when biosolids are applied to fine-textured soils and when solids are wetter (< 55% solids).

If the biosolids ratio Carbon-Nitrogen (C:N) is > 30, then

N_2O (kg/day) = zero (0)

If the biosolids C:N ratio < 30, then

$$N_2O \text{ emissions (kg } CO_2 \text{ eq)} = \text{Dry weight sent to land application [kg]} * \text{ \% of total N } * \text{ \% of N that goes to N2O } * 1.57 * \text{CNC}$$

Where:

- % of total N: depends on the type of FS (see Table 3-8)
- 2.3: % of N that goes to N2O from fine-textured soil
- 0.5: % of N that goes to N2O from coarse-textured soil
- 1.57: N to N_2O conversion
- CNC: Conversion factor for N_2O emissions into CO_2 equivalent emissions (varies from 265 to 310

Table 3-8. TS, TVS and TN values for FS from different sources

Type of FS	TS(%)	TVS(%)	TN(%)
Untreated	4.0 [a]	70 [a]	0.24[b]
Treated	22 [c]	40[c]	3[c]
Pit	7 [d]	65[d]	4[e]
Dried Faeces	27 [f]	70[f]	3[f]
Composted	8[g]	80[g]	3[g]
Septic Tanks	2 [h]	60 [h]	0.03 [b]

a-(Seck, et al., 2015)-, b - (Odey, Li, Zhou, & Kalakodio, 2017), c- (Uggetti, Ferrer, Llorens, & García, 2010) d (Semiyaga, Okure, Niwagaba, Nyenje, & Kansiime, 2016) ,e- (Kimuli, et al., 2016).f- (Cofie et al., 2006), g- (Yadav, Tare, & Ahammed, 2012), h- (Klingel, Montangero, Koné, & Strauss, 2002)

GHG emissions avoided from carbon sequestration of land application [kgCO_2e]:

$$\text{GHG emissions avoided from carbon sequestration of land application [kg}CO_2\text{e]} = \text{Dry weight sent to land application [kg]} * 0.25$$

Where:

- 0.25: estimated CO_2 equivalent sequestered kg CO_2eq/dry kg

Landfill Disposal

Methane (CH_4) emissions: CH_4 emissions from biosolids placed in a typical landfill are significant and difficult to control. Considerable research has been conducted on landfill methane emissions in general, and refined formulas have been developed and are used in the BEAM methodology. Additional minimal emissions are created when the CH_4 is burned for heat or power.

For fugitive methane emissions from biosolids decomposition in the landfill during the first 3 years after placement:

$$\begin{aligned} CH_4 \text{ emissions (kg } CO_2 \text{ eq)} \\ &= \text{Dry weight sent to landfilling [kg]} * \%\text{VS in FS} * \% \text{ organic C in VS} * 0.9 \\ &* \text{C to } CH_4 \text{conversion factor} * CH_4 \text{ in landfill gas} * \% \text{ decomposed in first 3 years} \\ &* \text{MCFlandfill} * \text{CMC} \end{aligned}$$

Where:

- 56: % of organic carbon in volatile solids
- % of volatile solids in FS : Depends on type of FS (see Table 3-8)
- 0.9: model uncertainty factor
- 1.3: C to CH_4 conversion factor
- 50: % of CH_4 in landfill gas
- 80: % DOCf -the decomposable organic fraction of raw wastewater solids
- 69.9: % decomposed in first 3 years
- MCF-landfill (methane correction for anaerobic managed landfills) – 1
- CMC: Conversion factor for CH_4 emissions into CO_2 equivalent emissions (varies from 11 to 34 based on IPCC report year selected)

Nitrous oxide (N_2O) emissions: Landfilled biosolids will likely be anaerobic or close to anaerobic, resulting in potential N_2O emissions.

If C:N ratio is > 30, then

N_2O emissions (kg/day) = zero (0)

If C:N ratio is < 30, then

$$N_2O \text{ emissions (kg } CO_2 \text{ eq)} = \text{Dry weight sent to landfilling [kg]} * \% \text{ of total N} * \\ N_2O \text{ emissions for low C:N} * \text{N to } N_2O \text{ conversion} * \text{CNC}$$

Where:

- % of total N: depends on the type of FS (see Table 3-8)
- 1.5: % of N_2O emissions for low C:N
- 1.57: N to N_2O conversion
- CNC: Conversion factor for N_2O emissions into CO_2 equivalent emissions (varies from 265 to 310 based on IPCC report year selected)

GHG emissions avoided from carbon sequestration of landfilling [kgCO2e]:

$$\text{GHG emissions avoided from carbon sequestration of landfilling}[\text{kgCO}_2\text{e}] = \text{Dry weight sent to land application [kg]} * \text{ C to CO}_2 \text{ conversion (3.667)} * \text{\% of organic carbon in volatile solids * \% of volatile solids in FS*0.2}$$

Where:

- 1.57: N to N_2O conversion
- 56: % of organic carbon in volatile solids
- % of volatile solids in FS : Depends on type of FS (see Table 3-8)
- 0.2: 1- DOCf (the decomposable organic fraction of raw wastewater solids=80%)
- C to CO_2 conversion: 3.667

Dumping

- *CH_4 emissions from dumping of faecal sludge [kgCO_2e]*

$$\text{CH}_4 \text{ emissions from dumping of faecal sludge [kgCO}_2\text{e]} = \text{Volumedumped}[\text{m}^3] * \text{BOD conc. of FS [kg/m}^3] * \text{Emission factor for dumped FS receiving water bodies } * \text{CMC}$$

Where:

- Emission factor for dumped FS receiving water bodies: Table 3-9
- BOD conc.of FS [kg/m^3]:
- CMC: Conversion factor for CH4 emissions into CO2 equivalent emissions (varies from 11 to 34 based on IPCC report year selected)

Table 3-9 Methane emission facto for FS receiving bodies (IPCC, 2006)

Emission factor for dumped FS receiving water bodies	CH4 emission factor
Stagnant sewers and anaerobic water bodies [kgCH4/kgBOD]	0.3
Sea and aerobic water bodies [kgCH4/kgBOD]	0.06
Fast flowing and well maintained sewers [kgCH4/kgBOD]	0

N_2O emissions from dumping of faecal sludge [$kgCO_2e$]

$$\mathrm{N_2O\ emissions\ from\ dumping\ of\ faecal\ sludge\ [kgCO_2e]} = \mathrm{Volume\ dumped[m^3]} * 0.005\mathrm{[kg\ N_2O\ /\ kg\ N]} * 1000\ \mathrm{[mg/L]}/1000\ {*}1.57{*}\ \mathrm{CNC}$$

Where:

- 1.57: N to N_2O conversion
- 0.005: N_2O emission factor from effluent [kg N_2O / kg N]
- 1000 mg/L: Total Nitrogen in dumped FS
- 1000: Unit conversion factor
- CNC: Conversion factor for N_2O emissions into CO_2 equivalent emissions (varies from 265 to 310 based on IPCC report year selected)

Urine application

$$\mathrm{GHG\ emissions\ avoided\ [kg\ CO_2e]} = Total\ Nitrogen\ in\ urine\ applied\ [kg] * 1\% * 1.57$$

Where:

- 1%: N_2O-N losses from urine application
- 1.57: N to N_2O conversion

3.4.2 GHG emissions from collected but untreated wastewater

The GHG emissions from untreated wastewater discharge, measured in kg CO_2e (CO_2 kilogram equivalents), are based on:

- Amount of population connected to sewer, but without connection to the wastewater treatment plant, and without onsite treatment
- Nitrogen (for N_2O emissions) and BOD (for CH_4 emissions) content in the wastewater

The Input Data

In The ECAM-Tool, the following data is required to estimate the GHG emissions from untreated wastewater discharge:

The following inputs are required in Population page to determine the nitrogen and BOD load of untreated wastewater based on default protein consumption and BOD loading/person:

1. Resident population within the wastewater utility service area
2. Population connected to sewers
3. Population serviced by wastewater treatment
4. Population with onsite treatment

In Configuration, default values for protein consumption, to determine the nitrogen in the untreated wastewater, and BOD load per person are selected per IPCC guidelines.

The computation

Based on the input data entered in the tool, the following will be computed to estimate the GHG emissions from untreated wastewater discharge that the utility is responsible for. This computation runs in parallel for the nitrogen related content and for the BOD related content.

N_2O emissions from untreated wastewater direct discharge by utility [kgCO_2e] (IPCC, 2006):

$$\mathrm{N_2O\ emissions\ [kg\ CO_2e]} = (\text{Population connected to a sewer system but not to any WWT}) * \text{protein} * \text{days}/365 * 0.16 * 1.1 * 1.25) * 0.005 * (44/28) * \text{CNC}$$

CH_4 emissions from untreated wastewater direct discharge by utility [$kgCO_2e$] (IPCC, 2006):

$$\mathrm{CH_4\ emissions\ [kg\ CO_2e]} = (\mathrm{Population\ connected\ to\ a\ sewer\ system\ but\ not\ to\ any\ WWT}) * (\mathrm{BOD}/1000 * \mathrm{days}) * 0.06) * \mathrm{CMC}$$

Where:

- Serv. Pop.: the number of service population for wastewater (see Figure 4-3)
- Protein: annual per capita protein consumption, kg/person/yr (FAO Statistics Division)
- 0.16: FNPR = fraction of nitrogen in protein, default = 0.16, kg N/kg protein
- 1.1: FNON-CON = factor for non-consumed protein added to the wastewater (1.1 for developed countries)
- 1.25: FIND-COM = factor for industrial and commercial co-discharged protein into the sewer system. (default is 1.25 but use 1 if there are no industrial or commercial connecting without onsite treatment)
- 0.005: Emission Factor Effluent (kg N_20-N/kg N) (Tabled value)
- 44/28: is the conversion of kg N_2O-N into kg N_2O
- 365: Days per year
- 0.06: EFj (kg CH_4/kg BOD) (This value comes from the multiplication of Bo (kg CH_4/kg BOD) (= 0.6) x MCFj (=0.1, for direct discharge into a river, lake or sea)
- CNC: Conversion factor for N_2O emissions into CO_2 equivalent emissions (varies from 265 to 310 based on IPCC report year selected)
- CMC: Conversion factor for CH_4 emissions into CO_2 equivalent emissions (varies from 11 to 34 based on IPCC report year selected)
- BOD: g/person/day (from IPCC guidelines) (Table 3-10)
- 1000: Unit conversion factor

Table 3-10. BOD values in domestic wastewater adapted from (IPCC, 2006)

Estimated BOD_5 values in domestic wastewater for selected regions and countries	
Country/Region	**BOD_5 (g/person/day)**
Africa	37
Egypt	34
Asia, Middle East, Latin America	40
India	34
West Bank and Gaza Strip (Palestine)	50
Japan	42
Brazil	50

Canada, Europe, Russia, Oceania	60
Denmark	62
Germany	62
Italy	60
Sweden	75
Turkey	38
United States	85

3.4.3 GHG emissions from untreated wastewater not connected to sewer network

Based on the input data entered in the tool, the following will be computed to estimate the GHG emissions from untreated wastewater discharge that the utility is not responsible for: this computation runs in parallel for the nitrogen related content and for the BOD related content.

N_2O emissions from untreated wastewater direct discharge not serviced by utility [kgCO_2e] (IPCC, 2006):

$$\begin{aligned} \mathrm{N_2O\ emissions\ [kg\ CO_2e]} &= (\mathrm{Resident\ population} - \mathrm{population\ connected\ to\ a\ sewer}) * \mathrm{protein} * \mathrm{days}/365 \\ &* 0.16 * 1.1 * 1.25) * 0.005 * (44/28) * \mathrm{CNC} \end{aligned}$$

CH_4 emissions from untreated wastewater direct discharge not serviced by utility [kgCO_2e] (IPCC, 2006):

$$\mathrm{CH_4\ emissions[kg\ CO_2e]} = (\mathrm{Resident\ population} - \mathrm{population\ connected\ to\ a\ sewer}) * (\mathrm{BOD}/1000 * \mathrm{days}) * 0.06) * \mathrm{CMC}$$

Where:

- Protein: annual per capita protein consumption, kg/person/yr.
- 16: FNPR = fraction of nitrogen in protein, default = 0.16, kg N/kg protein
- 1.1: FNON-CON = factor for non-consumed protein added to the wastewater (1.1 for developed countries)
- 1.25: FIND-COM = factor for industrial and commercial co-discharged protein into the sewer system. (default is 1.25 but use 1 if there are no industrial or commercial connecting without onsite treatment)
- 0.005: Emission Factor Effluent (kg N_20-N/kg N) (Tabled value)
- 44/28: is the conversion of kg N_2O-N into kg N_2O
- 365: Days per year
- 0.06: EFj (kg CH_4/kg BOD) (This value comes from the multiplication of Bo (kg CH_4/kg BOD) (= 0.6) x MCFj (=0.1, for direct discharge into a river, lake or sea)
- CNC: Conversion factor for N_2O emissions into CO_2 equivalent emissions (varies from 265 to 310 based on IPCC report year selected)
- CMC: Conversion factor for CH_4 emissions into CO_2 equivalent emissions (varies from 11 to 34 based on IPCC report year selected)
- BOD: g/person/day (from IPCC guidelines) (Table 3-10)
- 1000: Unit conversion factor

3.4.4 GHG emissions from truck transport of water, sludge or faecal sudge

The method for estimating CO_2, CH_4, and N_2O emissions from on-site stationary combustion, such as from engine generators and drives, will be based upon the IPCC guidelines (2006), Volume 2 (Energy), Chapter 3: Mobile Combustion. For estimating CO_2 emissions, Equation 3.2.1 from the IPCC guidelines is applied, which is based upon the fuel consumed and a default emission factor based on fuel type. For estimating CH_4 and N_2O emissions, Equation 3.2.3 in the IPCC guidelines will be applied, which is based upon the fuel consumed and fuel type.

The GHG emissions from truck transport of water and/or sludge, measured in kg CO_2e (CO_2 kilogram equivalents), are determined by two factors:

- Engine Fuel Type (Diesel, Petrol or Natural Gas)
- Volume of fuel consumed

There are many different factors contributing to this volume of fuel consumed (road quality, driver, age of the vehicle and level of maintenance etc.).

The Input Data

In the ECAM Tool, the following data is required to estimate the GHG emissions from truck transport:

- The engine fuel type is to be selected by a drop-down menu, where the user can select the fuel type. By default, the assumed fuel is Diesel.
- Volume of fuel used (for drinking water and water reuse only).
- The number of trips to the disposal site (for sludge only)
- The distance to the disposal in km of driving (for sludge only - one way).

For sludge, since the trucks are normally owned by a private hauler and not owned by the utility, the ECAM Tool assumes an average consumption of 25 L/100 km (0.25 L/km). For drinking water and water reuse, since it is normally the utility's responsibility to deliver water, the volume of fuel used is requested since the utility normally tracks this information as part of its operating costs. However, if the fuel consumption is not tracked, it can be estimated based upon the same 25 L/100 km consumption factor, the distance to cover each trip, and the number of trips.

This information is requested only at the "Detailed Assessment level."

The computation

Based on the input data entered in the tool, the following intermediate values will be computed to estimate the GHG emissions from on-site engines to be used in the Performance Indicators:

The energy content in the volume of fuel consumed, based on the following expression (IPCC, 2006):

$$\text{Energy Fuel Cons (Assumed diesel)}[\text{TJ}] = \text{Number of trips to disposal site} * 2 \text{ (round trip)} * \text{km to disposal site} * \text{ average fuel consumption per km} * \text{Fuel density} * \text{NCV}/1{,}000{,}000$$

Where:

- 1,000,000: For units conversion
- NCV: Net Calorific Values [TJ/Gg] (43 for Diesel) Fuel Density (FD) and Net Calorific Values (NCV) factors are related with the type of fuel and there are tabled values from the IPCC guidelines (Table 3-1).

$$\text{Emissions from vehicle engines [ws, ww]} = \text{Energy fuel consumed} * (\text{EFCO2} + \text{EFN2O x CNC}) + \text{EFCH4} * \text{CMC})$$

Where:

- EF-CO_2: Emission factor of CO_2 for the chosen fuel
- EF-N_2O: Emission factor of N_2O for the chosen fuel
- EF-CH_4: Emission factor of CH_4 for the chosen fuel
- CNC: Conversion factor for N_2O emissions into CO_2 equivalent emissions (varies from 265 to 310 based on IPCC report year selected)
- CMC: Conversion factor for CH_4 emissions into CO_2 equivalent emissions (varies from 11 to 34 based on IPCC report year selected)

Table 3-11 Fuel Properties

	Fuel density [kg/L]	EF CO_2(kg/TJ)	EF CH_4(kg/TJ)	EFN_2O (kg/TJ)	NCV (TJ/Gg)
Gasoline/Petrol	0.74	69 300	3.8	1.9	44.3
Gas/Diesel Oil	0.84	74 100	3.9	3.9	43
Natural Gas	0.75 [kg/m^3]	56 100	92	0.2	48

3.4.5 GHG emissions from treated effluent discharge

The methodology to be followed for estimating N_2O emissions from receiving waters off-site due to wastewater effluent is based upon IPCC guidelines (2006), Volume 5 (Wastes), Chapter 6: Wastewater Treatment and Discharge. Specifically, Equation 6.7 of the guidelines will be used, which is based upon the nitrogen in the effluent and a default N_2O emission factor (0.005 kg N2O-N / kg N). The uncertainty of this emission factor is rather high, as the possible range of values per IPCC is 0.0005 – 0.25 kg N_2O-N / kg N. However, as previously mentioned, this indirect GHG emission source can be directly related to the performance of the WWTP (nitrogen removal); therefore, it provides a means of monitoring performance versus estimated GHG emissions reductions.

The GHG emissions from treated effluent discharge, measured in kg CO_2e (CO_2 kilogram equivalents), are determined by one factor:

- Nitrogen load of the effluent from the wastewater treatment plant.
- Nitrogen load of the effluent from the faecal sludge treatment

Whether they have, specific nitrogen limits or not, most WWTPs monitor the nitrogen in the effluent.

The Input Data

In The ECAM-Tool, the following data is required to estimate the GHG emissions from treated effluent discharged at both the Initial and Detailed Assessment levels:

- Average total nitrogen concentration in the effluent limit.

The computation

Based on the input data entered in the tool, the following will be computed to estimate the GHG emissions from untreated effluent discharge to be used in the Performance Indicators:

$$\mathrm{N_2O\ Emissions\ [kg\ CO_2e] = [Average\ nitrogen\ concentration\ in\ the\ effluent\ (mg/L)} * \mathrm{(vol\ of\ treated\ wastewater\ ((m^3))/1000)} * 0.005 * (44/28)] * \mathrm{CNC}$$

$$\mathrm{N_2O\ Emissions\ \ Faecal\ Sllludge\ [kg\ CO_2e] = [Average\ nitrogen\ concentration\ in\ the\ effluent\ Faecal\ Sludge\ (mg/L)} * \mathrm{(vol\ of\ treated\ wastewater\ ((m^3))/1000)} * 0.005 * (44/28)] * \mathrm{CNC}$$

Where:

- 1000: conversion of units
- 0.005: Effluent (kg N_20-N/kg N) N_2O emission factor
- (44/28): is for the conversion of kg N_2O-N into kg N_2O
- CNC: Conversion factor for N_2O emissions into CO_2 equivalent emissions (varies from 265 to 310 based on IPCC report year selected)

3.5 GHG emission offset from Water Reuse, Nutrient Recovery, and Carbon Sequestration

In the following section the emissions offsets from the water reuse, nutrient recovery, and carbon sequestration are presented. Where possible, equations have been adopted from the BEAM tool, which is considered a sound and detailed basis for calculations (SYLVIS Environmental, 2009)

3.5.1 Fertiliser GHG emission avoided for Nitrogen due to water reuse / nutrient recovery

The Input Data

In The ECAM-Tool, the total Nitrogen recovered from either water reuse, nutrient recovery from the process at WWTP and/or from land application is required to estimate the GHG emissions avoided.

The computation

Based on the input data entered in the tool, the following will be computed to estimate the GHG emissions offset from nitrogen recovery:

$$\mathrm{CO_2\ Equivalent\ avoided\ [kg\ CO2e] = Total\ N\ reused\ or\ recycled\ (kg)} * 4$$

3.5.2 Fertiliser GHG emission avoided for Phosphorus due to water reuse / nutrient recovery

The Input Data

In The ECAM-Tool, the total Phosphorus recovered from either water reuse, nutrient recovery from the process at WWTP and/or from land application is required to estimate the GHG emissions avoided.

The computation

Based on the input data entered in the tool, the following will be computed to estimate the GHG emissions offset from water reused/recycled:

$$\mathrm{CO_2\ Equivalent\ avoided\ [kg\ CO_2e] = Total\ P\ reused\ or\ recycled\ (kg/m^3)} * 2$$

Where:

4: conversion factor (kgCO_2/kg N)

2: conversion factor (kgCO_2/kg P)

3.5.3 Carbon Sequestration from Sludge Management

Depending on the disposal method either composting or land application or land filling of sludge, following carbon offsets can be achieved. In case the users select none of the above it will be 0.

The input data

In the ECAM/tool, following data inputs are required to calculate the carbon sequestration from sludge disposal. The dry weight of the Sludge composted, dry weigh of the sludge or faecal sludge sent to land application, dry weight of sludge or faecal sludge sent to land filling.

The computation

Based on the input data entered in the tool, the following will be computed to offsets from carbon sequestration

a. Carbon sequestration from composting

$$\mathrm{CO_2eq.\,sequestered\ (Kg/assessment\ period)} = \mathrm{Dry\ weightof(\ Sludge/FaecalSludge)\ composted\ (kg/assessment\ period)} * 0.25$$

b. Carbon sequestration from land application

$$\mathrm{CO_2eq.\,sequestered\ (Kg/assessment\ period)} = \mathrm{Dry\ weightof\ (\ Sludge/FaecalSludge)\ sent\ to\ land\ application\ (kg\ /assessment\ period)} * 0.25$$

c. Carbon sequestration from land filling

$$\mathrm{CO_2eq.\,sequestered\ (Kg/day)} = \mathrm{Dry\ (\ Sludge/FaecalSludge)\ (kg/day)} * \%\ \mathrm{VS} * 0.56 * 0.2 * 3.667$$

Where:

- 0.25: CO_2 equivalent sequestered (Kg CO_2eq/dry Kg sludge)
- %VS: % Volatile Solidfs (= 51% if sludge digested, 70% if sludge not digested). For Faecal Sludge values from the Table 3-8)
- 0.56: % of organic carbon in volatile solids
- 0.2: the undecomposable organic fraction of raw wastewater = (1-DOC_f), where DOC_f is the decomposable organic fraction of raw wastewater = 80%

3.5.4 GHG emission avoided due to reuse displacing potable water

GHG emissions will be avoided from water reuse displacing potable water use because of the reduction in energy consumption during abstraction, treatment and distribution stage.

The input data

In the ECAM/tool, following data inputs are required to calculate offsets from the energy savings. Energy consumption during abstraction, treatment and distribution stages and the volume of the reused water displacing potable water.

The computation

Based on the input data entered in the tool, the following will be computed during different stages

$$
\begin{aligned}
&\mathrm{CO_2\ Equivalent\ avoided\ [kg\ CO_2e]} \\
&\qquad = \text{Energy consumption per abstratced water (Kwh/m}^3\text{)} \\
&\qquad * \text{Volume of treated effluent water reused (m}^3\text{)}
\end{aligned}
$$

$$
\begin{aligned}
&\mathrm{CO_2\ Equivalent\ avoided\ [kg\ CO_2e]} \\
&\qquad = \text{Energy consumption per treated water (Kwh/m3)} \\
&\qquad * \text{Volume of treated effluent water reused (m}^3\text{)} \\
&\qquad * \text{Energy conversion factor into carbon equivalents}
\end{aligned}
$$

$$\begin{aligned}&CO_2 \text{ Equivalent avoided [kg } CO_2e]\\&\quad = \text{Energy consumption per volume injected to distribution } (Kwh/m^3)\\&\quad * \text{Volume of treated effluent water reused } (m^3)\\&\quad * \text{Energy conversion factor into carbon equivalents}\end{aligned}$$

3.6 Performance indicators and methodology

The typical Performance Indicators (PIs) to be used in the project are based upon the IWA PI frameworks that have been broadly and successfully used worldwide (Cabrera *et al.,* 2011).

A performance indicator is a measure of the efficiency and effectiveness related to specific issues of the delivery of the services by an undertaking. A PI can be dimensionless (-, %) or intensive (e.g. kWh/m^3).

There are 3 types of Performance indicators:

1. Key performance indicators (kPIs). Provide global picture of stage's performance – energy or GHG.
2. Context PIs. Provide context information about the stage (e.g. sludge quality is related to energy consumption)
3. Service level PIs. Provide more information on service level. Limited number of key quality of service indicators that need to be taken into account when interpreting monitoring results of direct and indirect emissions. For instance, emissions per m^3 of treated water may increase if the level of treatment increases; emissions per m^3 of authorized consumption may also increase if there were insufficient pressure in the baseline and the situation is fixed during the course of the project. If these aspects were not included in the assessment system, improvement measures might appear to have not worked. The same rational reversely applies for tracing decreases in the levels of service

Interpreting performance indicators and benchmarks

Two examples are provided below on how energy performance outcomes can be interpreted. Both examples correspond to water pressurized transport (pumping stages):

- The energy required to elevate 1 m^3 one hundred meters (or, to increment its pressure into 9.81 bar), is exactly 0.2725 kWh/m^3. Assuming a global inefficiency (mainly pump and electric motor drive), of 0.70, a reasonable value is 0.4 kWh/m^3. If water is pumped in a well, an elevation of 100 m and the calculated value of the indicator results in 0.70 kWh/m^3, it is evident that there is room for improvement.

- At the distribution stage the evaluation is a bit more complex because inefficiencies can be due to not just only the poor performances of the pumping station, but also due to leaks, pipe friction or other losses such as, for instance, pressure break tanks. As before, indicators to measure the ideal (theoretical) and the real global efficiencies (this last one to be determined based on specifics of the utility) are required to calculate the difference (that is to say, the improvement margin).

When significant differences between the measure performance and the benchmark value are observed, an energy audit to understand the origin of the inefficiencies must be activated. Overall, to assess the system's performance at each stage, indicators are required. When possible, IWA indicators are used and, when necessary, complemented with other metrics.

Important: *Users should always analyse the performance indicators and benchmarks applied cautiously, keeping in mind the specific characteristics of the system lay-out and operating conditions as well as taking into account the quality of input data and potential uncertainties involved (section 3.8).*

3.7 Uncertainty Analysis

ECAM aims to provide an accurate picture of the emissions of a utility. However, users should be aware that results are impacted by the quality of input data and uncertainties that are inherent to the calculation methods and default factors applied. This section provides further information about typical uncertainties that may affect the outcomes of the energy and carbon emissions assessments.

Fossil fuels

Emission factors uncertainty: The carbon content of fossil fuels is used to determine the emission factors from these sources and it has a physical constraint on the magnitude of uncertainty, as a consequence the uncertainties for CO_2 emissions from fossil fuels combustion is relatively low. There may be differences in the uncertainties based on the type of the fuel. On the other hand, emission factors for CH_4 and particularly N_2O are highly uncertain. This could be attributed to lack of appropriate measurements and subsequent generalization, uncertainty in measurements, or limited knowledge about the emission generating process. As uncertainties are rarely known, they are usually obtained from indirect sources or by means of expert judgements (IPCC, 2006)

Activity data uncertainty: Generally, the uncertainty in activity data is the result of systematic and random errors. The uncertainty resulting from the two errors combined could be up to ± 10percent for countries with less well-developed energy data system (IPCC, 2006).

Emissions from the road transportation, such as the emissions from sludge transport, roughly consists of 97 percent CO_2, 2 to 3 percent N_2O and the rest to be CH_4. As a consequence, the effect of higher uncertainty related with N_2O and Ch_4 are dominated by the large CO_2 part. For more detailed explanations including uncertainties related with emission factor and activity uncertainty, the reader is referred to IPCC chapter 3.

Wastewater

The range for the default uncertainty for methane emission factors and activity data of domestic wastewater is presented in *Table 3-12*. Certain parameters such as the extent to which wastewater treated in latrines, septic tanks or removed by sewer is very uncertain (IPCC, 2006):

Table 3-12. Default uncertainty ranges for domestic wastewater (adopted from IPCC, 2006)

Parameter	Uncertainty Range
Emission Factor	
Maximum CH_4 producing capacity (B_o)	± 30%
Fraction treated anaerobically (MCF)	The MCF is technology dependent. See Table 6.3. Thus the uncertainty range is also technology dependent. The uncertainty range should be determined by expert judgement, bearing in mind that MCF is a fraction and must be between 0 and 1. Suggested ranges are provided below. Untreated systems and latrines, ± 50% Lagoons, poorly managed treatment plants± 30% Centralized well managed plant, digester, reactor, ± 10%
Activity Data	
Human population (P)	± 5%
BOD per person	± 30%
Fraction of population income group (U)	Good data on urbanization are available, however, the distinction between urban high income and urban low income may have to be based on expert judgment. ± 15%
Degree of utilization of treatment/discharge pathway or system for each income group (Ti,j)	Can be as low as ± 3% for countries that have good records and only one or two systems. Can be ± 50% for an individual method/pathway. Verify that total Ti,j = 100%

Correction factor for additional industrial BOD discharged into sewers (I)	For uncollected, the uncertainty is zero %. For collected the uncertainty is ± 20%

According to the IPCC (2006) there is a large uncertainty related with the default emission factors for N_2O from effluent. The range of uncertainty for N_2O emission factors that is based on expert judgement is presented in Table 3-7.

Table 3-13 Default uncertainty ranges for domestic wastewater (adopted from IPCC, 2006)

Parameter	Definition	Default value	Range
Emission Factor			
$EF_{EFFLUENT}$	Emission factor, (kg N_2O-N/kg –N)	0.005	0.0005-0.25
EF_{PLANT}	Emission factor, (g N_2O/person/year)	3.2	2-8
Activity Data			
P	Number of people in country	Country-specific	± 10 %
Protein	Annual per capita protein consumption	Country-specific	± 10 %
FNRP	Fraction of nitrogen in protein (kg N/kg protein)	0.16	0.15-0.17
T_{PLANT}	Degree of utilization of large WWT plants	Country-specific	± 20 %
$F_{NON-CON}$	Factor to adjust for non-consumed protein	1.1 for countries with no garbage disposals, 1.4 for countries with garbage disposals	1.0-1.5
$F_{IND-CON}$	Factor to allow for co-discharge of industrial nitrogen into sewers. For countries with significant fish processing plants, this factor may be higher. Expert judgment is recommended.	1.25	1.0-1.5

4 Guidance scenarios

In this part of the guide explanations are given for some key-inputs required in ECAM tool. This chapter also provides suggestions on how to use ECAM for various system lay-outs and for specific scenarios.

4.1 Population

In ECAM tool, the type of population data required to assess utilities could be generally classified in two: population number used for assessing GHG emissions and energy performance related with water supply and population related to wastewater.

Under

4.1.1 Water supply

Resident population: Number of permanent residents within the drinking water utility area of service, regardless of whether they are served or not by the utility.

Serviced population: Serviced population is referred to the number of inhabitants, within the area of service managed by the utility, which are connected to the distribution system and are receiving the service as of the reference date.

4.1.2 Wastewater

Resident population: Number of permanent residents within the geographical area that the wastewater utility can serve, regardless of whether they are serviced or not by the utility with wastewater treatment.

Population connected to sewers: Number of permanent residents within the wastewater utility service area, which are connected to the sewer system as of the reference date.

Serviced population: Serviced population refers to the number of permanent residents within the wastewater utility service area, whose wastewater is receiving treatment in a central wastewater treatment plant.

Population with onsite treatment: refers to the number of permanent residents within the wastewater utility service area that are not connected to sewers and have onsite treatment of their wastewater as opposed to treatment at a central wastewater treatment plant.

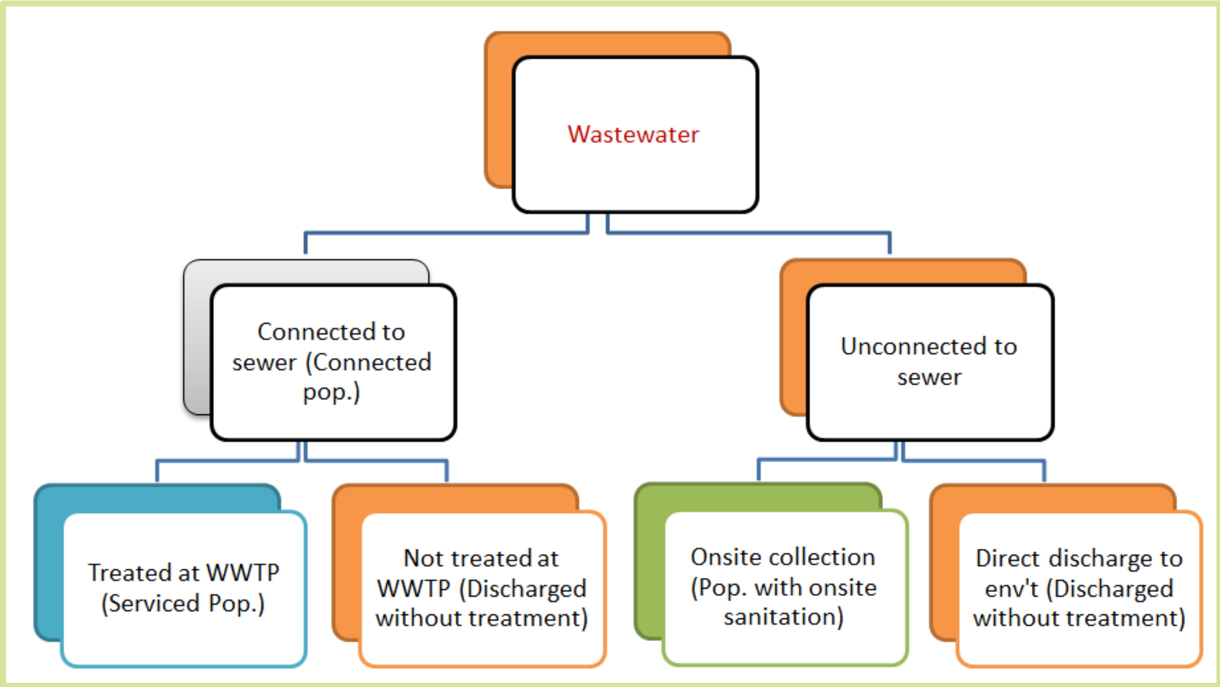

Figure 4-1 population classification for wastewater

The following decision trees illustrate the approach that should be followed in entering population data in ECAM.

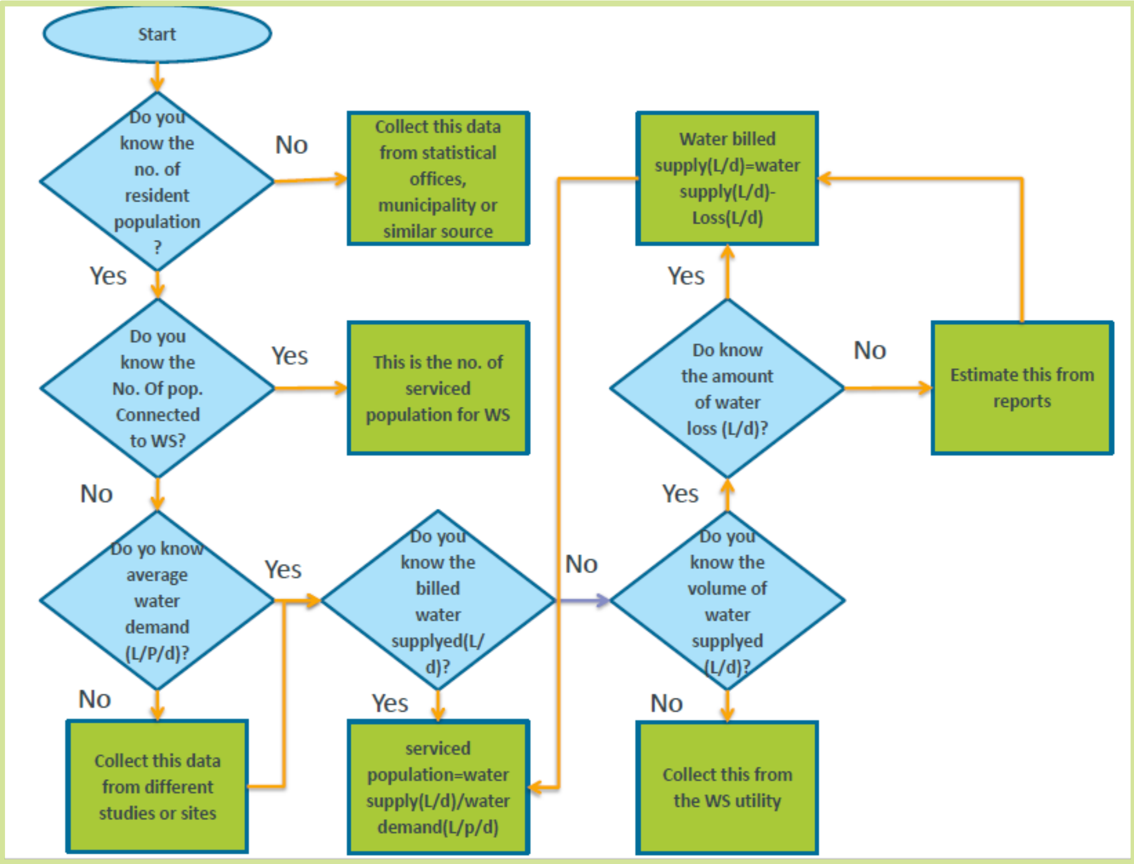

Figure 4-2 Decision tree Serviced population in water supply

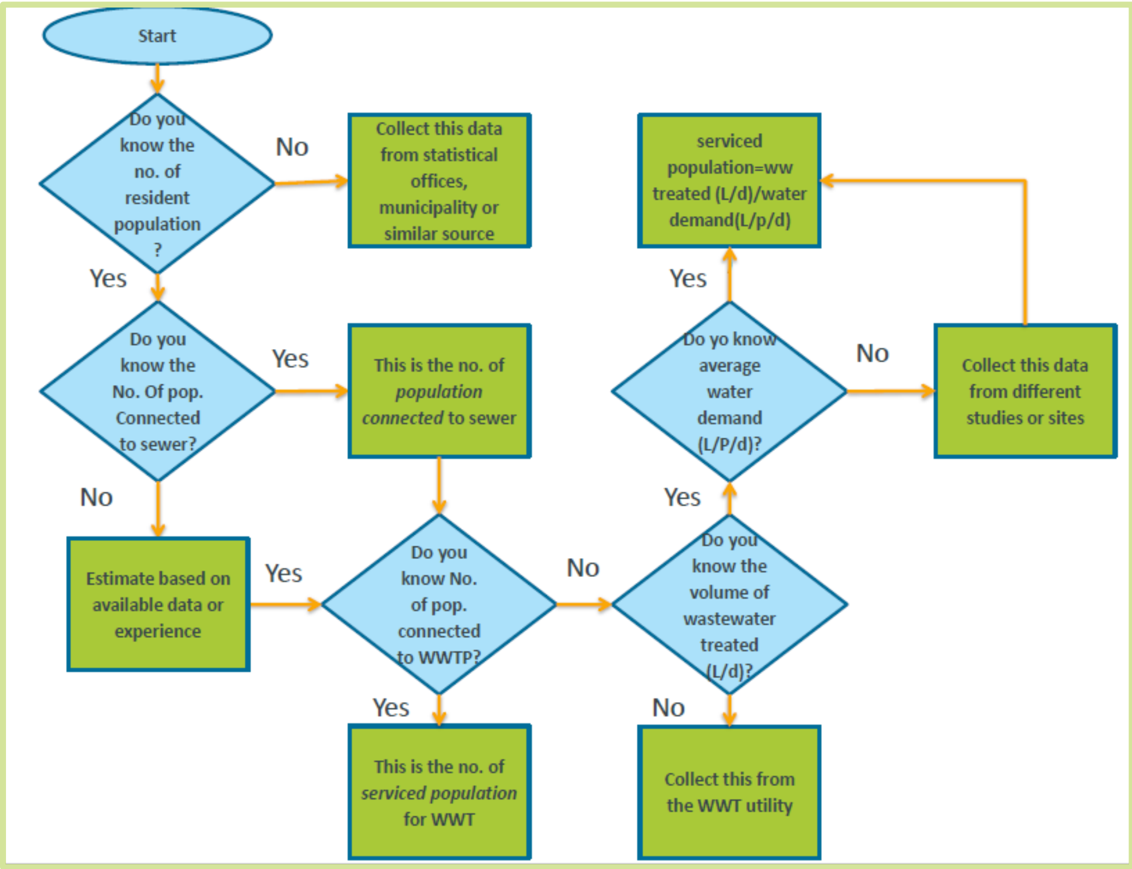

Figure 4-3 Decision tree for Serviced population in wastewater treatment

4.2 Wet weather and dry weather flow

Dry weather flow is the average daily influent flow to a wastewater treatment plant during a dry period/non-rainy season. The wet weather flow is the average daily influent flow during wet-weather days, days in which there was rain.

Infiltrations and inflow in the wastewater system- Significant energy consumption may be caused by water entering the drainage networks due to cross connections with the storm water systems or to rainwater or groundwater infiltration. In ECAM, by looking at dry weather and wet weather flows, rain-derived infiltration and inflow (I/I) can easily be estimated and used to see GHG benefits of reducing this I/I.

4.3 Soil typology for sludge application

N_2O emissions are possible when nitrogen fertilizers, including biosolids, are applied to soils. Emissions are likely greater when biosolids are applied to fine-textured soils and when solids are wetter (< 55% solids). N_2O emissions are also possible during storage.

N_2O are increased when available (mineral) nitrogen (N) is in a low oxygen (O) or anaerobic matrix. Fine-textured soils and moisture promote these conditions. For this reason, the BEAM outputs a higher level of N_2O emissions if the soil is > 30% clay (fine-textured). (SYLVIS Environmental, 2009)

In case of uncertainty about the class of soil, whether it is fine or coarse texture, the user is recommended to take a conservative approach and select fine-textured soil until such a time the soil type can be confirmed. This will prevent an underestimation of GHG emissions.

4.4 Water reuse

In ECAM, water reuse is considered as follows:

In the wastewater discharge / reuse stage, the amount of wastewater that is reused is entered, including the amount displacing potable water. This quantifies the amount of GHG (N_2O) avoided by not discharging the treated effluent to a receiving water body, and the amount GHG (grid-energy) avoided from having to abstract, treat, and distribute less drinking water. For example, if the utility is considering to reuse wastewater and displacing potable water use for non-potable purposes (i.e. using drinking water to irrigate), the impact of this is quantified based upon the kWh/m^3 in the water supply abstraction/treatment/distribution stages, plus the N_2O emissions from effluent discharge in the Wastewater Discharge/Reuse stage.

4.5 Multiple wastewater treatment processes

4.5.1 Two or more treatment processes in series

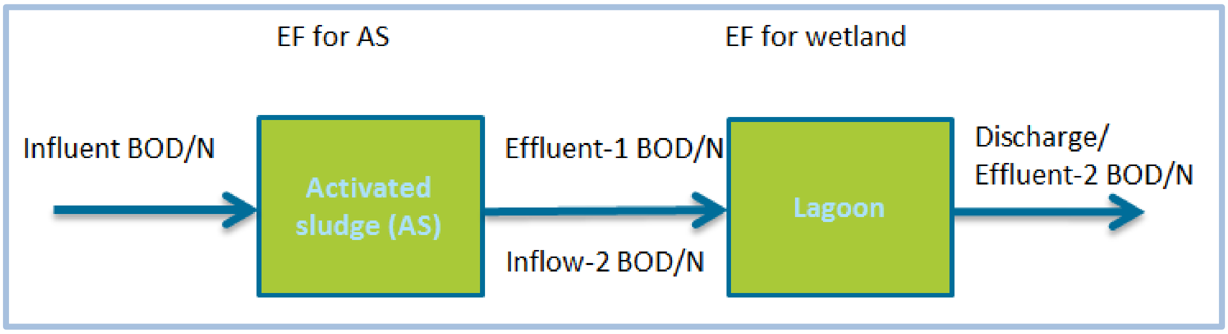

Figure 4-4. Two separate treatment processes in series

If the utility has two or more wastewater treatment technologies in series, as presented in *Figure 4-4*, the following considerations has to be taken in to account while using ECAM. Each treatment technology has to be assessed independently and the GHG emission and energy consumption has to be calculated independently and the two results summation gives the total for the utility. The following inputs need caution while filling out.

- *BOD:* the BOD for the first treatment in the line is the same as the inflow, but the influent BOD load to the next treatment technology must be the effluent BOD load of the preceding treatment, as long as the inflow to the system is only from the outflow of the preceding technology.
  For example, in *Figure 4-4*, the BOD inflow load to lagoon is the same as the effluent of AS.
- *Nitrous oxide from treatment:* the calculation used in ECAM tool considers nitrous oxide emission based on serviced population for all advanced treatment technologies. So, the nitrous oxide emission from treatment system in series should be calculated only once based on serviced population.
- *Storage time for sludge:* If there is sludge from the treatment systems in series, the time sludge is stored before further treatment or transporting to disposal, should not be added.
  For example, in *Figure 4-4*, the sludge from AS is different form the sludge form lagoon in many ways. So sludge management assessment has to be done independently for each case.
- *Number of trips to sludge disposal site/ Distance to sludge disposal site:* if the sludge is transported to the same site from the same source location, the number of trips/distance to

disposal site can be summed and it could be addressed as a single system. But, if the sludge from one technology, for example AS is transported to location 1 and the sludge from the next treatment, in this example lagoon, is transported to location 2, do not sum-up the trips/distance to get the total number of trips/total distance covered, but assess each independently and the GHG emissions can be added to get the overall condition of the utility.

- *Sludge type disposed of:* Even if assessing both digested and undigested sludge is possible with ECAM, the tool does not compute both at the same time. So, if there is a sludge part that is taken in to digester before disposal and there is another part that is disposed without digestion, each of this needs to be assessed independently.

4.5.2 Two or more treatments in parallel or different locations

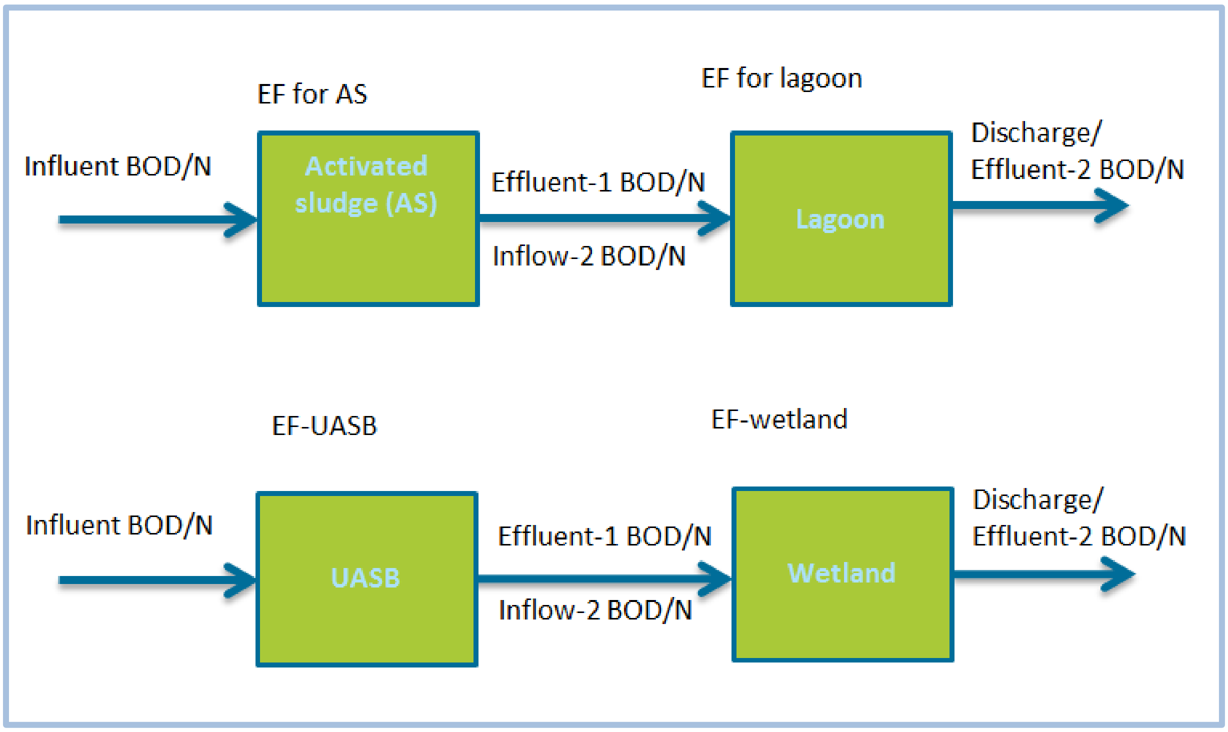

Figure 4-5 Two separate treatment processes/facilities in parallel

If the utility has two or more wastewater treatment plants that receive independent inflows or located at different locations, the assessment must be done totally separately. If there is a need to assess the overall performance indicators for the entire utility, care must be taken, and the results should not be directly summed.

Inputs

- *BOD:* the influent BOD for treatment technologies/plants in parallel or located in different locations is the same as the inflow to their respective location/part.

  For example, in *Figure 4-5*, the BOD for AS inflow is different from the inflow to the UASB.

  In case if there are more treatment technologies in series at two different locations or parallel systems, as shown in *Figure 4-5*, the series parts for each location need to be considered as presented in section 4.5.1 and then the parallel systems can be computed.
- *Nitrous oxide from treatment:* the calculation used in ECAM tool considers nitrous oxide emission based on serviced population for all advanced treatment technologies. So, the nitrous oxide emission from treatment system in parallel or located in different locations has to be calculated separately for each based on their respective serviced population number.
- *Storage time for sludge:* for sludge from the treatment systems in parallel, the time sludge is stored before further treatment or transporting to disposal, should not be added.
- *Number of trips to sludge disposal site/ Distance to sludge disposal site:* if the sludge is transported to the same site from the same source location, the number of trips/distance to disposal site can be summed and it could be addressed as a single system. But, if the sludge from one location is transported to location 1 and the sludge from the other facility is transported to location 2, do not sum-up the trips/distance to get the total number of trips/total distance covered, but assess each independently and the total GHG emissions can be added to get the overall condition of the utility.
- *Sludge type disposed of:* Even if assessing both digested and undigested sludge is possible with ECAM, the tool does not compute both at the same time. So, if there is a sludge part that is taken in to digester before disposal and there is another part that is disposed without digestion, each of this needs to be assessed independently using two different ECAM files.
- *Fluidized bed furnace temperature:* if there are two or more incinerators each has to be assessed independently. Do not sum the temperature. To get the total GHG from incineration, add the results for each incinerator.

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6 Annex

All inputs and outputs included in ECAM v2.2

Note: Inputs/outputs and formulas may have been updated since printing. For latest, you can always check them directly in ECAM and can click on a variable (hyperlinked) to see detailed information on the variable including formula, and other variables depending on the specific variable.

Annex A Energy Outputs

Code	Name	Type	Formula	Unit	Description	
ws_nrg_cons	Water energy consumption (Abstraction+Treatment+Distribution)	Output	wsa_nrg_cons + wst_nrg_cons + wsd_nrg_cons	kWh	Electric energy consumption including both from the grid and self-produced, for the water stages, by the undertaking during the entire assessment period	WS
wsg_KPI_nrg_x_ye	Water energy consumption per year	Output	wsg_KPI_nrg_cons/Years	kWh/year	Water energy consumption per year	WS
wsg_KPI_nrg_x_ys	Water energy consumption per year per person	Output	wsg_KPI_nrg_x_ye/ws_serv_pop	kWh/year/person	Water energy consumption per year per person	WS
wsg_KPI_nrg_x_m3	Water energy consumption per authorized consumption	Output	wsg_KPI_nrg_cons/wsd_auth_con	kWh/m3	Water energy consumption per authorized consumption	WS
wsg_KPI_std_nrg_	Water average standardized energy consumption of all pumping substages	Output	(wsa_KPI_std_nrg_cons + wsd_KPI_std_nrg_cons)/2	kWh/m3/100	Average energy consumption per pumping water per head in the drinking water system	WS
ws_SL_nrg_cost	Energy costs percentage	Output	100 * ws_nrg_cost/ws_run_cost	%	Proportion of the utility energy costs referred to the total running costs related to urban drinking water system related to urban drinking water system	WS

Annex A Energy Outputs

Code	Name	Type	Formula	Unit	Description	
ww_nrg_cons	Energy consumed from the grid (Collection+Treatment+Discharge) (Collection+Treatment+Discharge)	Output	wwc_nrg_cons + wwt_nrg_cons + wwd_nrg_cons	kWh	Total electric energy consumed from the grid related to wastewater management within the service area managed by the undertaking during the entire assessment period	WW
wwg_KPI_nrg_x_ye	Wastewater energy consumption per year	Output	wwg_KPI_nrg_cons/Years	kWh/year	Wastewater energy consumption per year	WW
wwg_KPI_nrg_x_ys	Wastewater energy consumption per year per person	Output	wwg_KPI_nrg_x_ye/ww_serv_pop	kWh/year/person	Wastewater energy consumption per year per person	WW
wwt_KPI_nrg_per_kg	Wastewater energy consumption per BOD removed	Output	wwt_nrg_cons/c_wwt_bod_rmvd	kWh/kg	Total energy consumed in the wastewater system per BOD5 removed	WW
wwg_KPI_std_nrg_	Wastewater average standardized energy consumption of all pumping substages	Output	(wwc_KPI_std_nrg_cons + wwd_KPI_std_nrg_cons)/2	kWh/m3/100	Average energy consumption per pumping water per head in the wastewater system	WW
wwg_KPI_nrg_perc	Wastewater energy cost percentage of total running cost	Output	100 * wwg_KPI_nrg_cons/wwg_KPI_nrg_cons	%	Wastewater energy cost percentage of total running cost	WW
ww_SL_nrg_cost	Energy costs percentage	Output	100* ww_nrg_cost/ww_run_cost	%	Proportion of the utility energy costs referred to the total running costs	WW

Annex B Tier A - Water supply – Inputs

Code	Name	Type	Formula	Unit	Description
ws_resi_pop	Resident population	Input	--	People	Number of permanent residents within the water utility area of service
ws_serv_pop	Serviced population	Input	--	People	Serviced population is referred to the number of inhabitants, within the area of service managed by the utility, which are connected to the distribution system and are receiving the service
ws_nrg_cost	Energy costs	Input	--	Currency Unit	Costs from electric energy consumption for the entire water supply utility, based on the electricity bill during the entire assessment period
ws_run_cost	Total running costs	Input	--	Currency Unit	Total operations and maintenance net costs and internal manpower net costs (i.e. not including the capitalised cost of self-constructed assets) related to water supply within the service area managed by the undertaking during the entire assessment period

Annex C Tier A - Water supply – Outputs

Code	Name	Type	Formula	Unit	Description
ws_nrg_cons	Energy consumed from the grid (Abstraction+Treatment+Distribution)	Input/Output	wsa_nrg_cons + wst_nrg_cons + wsd_nrg_cons	kWh	Total energy consumed from the grid for the entire water supply utility, based on the electricity bill during the entire assessment period
ws_vol_fuel	Volume of fuel consumed(engines)	Input/Output	wsa_vol_fuel + wst_vol_fuel + wsd_vol_fuel	L	Volume of fuel consumed (engines)
ws_SL_serv_pop	Serviced population in Water Supply	Output	100 * ws_serv_pop/ws_resi_pop	%	Serviced population
ws_SL_nrg_cost	Energy costs percentage	Output	100 * ws_nrg_cost/ws_run_cost	%	Proportion of the utility energy costs referred to the total running costs related to urban drinking water system
ws_SL_auth_con	Authorized consumption per person per day	Output	1000 * wsd_auth_con/ws_serv_pop/Days	L/serv.pop./day	Volume of authorized consumption per serviced person in the service area managed by the undertaking divided by the duration of the assessment period
ws_SL_auc_emis	GHG emissions related to water consumption	Output	ws_KPI_GHG-ws_SL_nrw_emis	kg CO_2	GHG emissions related to water consumption
wsa_KPI_GHG	Total GHG Water Abstraction	Output	wsa_KPI_GHG_elec + wsa_KPI_GHG_fuel	kg CO_2e	Total GHG Water Abstraction
wst_KPI_GHG	Total GHG Water Treatment	Output	wst_KPI_GHG_elec + wst_KPI_GHG_fuel	kg CO_2eq	Total GHG Water Treatment

wsd_KPI_GHG	Total GHG Water Distribution	Output	wsd_KPI_GHG_elec + wsd_KPI_GHG_fuel + wsd_KPI_GHG_trck	kg CO_2eq	Total GHG Water Distribution
ws_KPI_GHG	Total GHG Water Supply	Output	wsa_KPI_GHG + wst_KPI_GHG + wsd_KPI_GHG	kg CO_2 eq	GHG Emissions from non-electricity and electricity consumption

Annex D Detailed GHG assessment – Water Abstraction - Inputs

Code	Name	Type	Formula	Unit	Description
wsa_nrg_cons	Energy consumed from the grid	Input	--	kWh	Electric energy consumption including both from the grid and self-produced, for the water abstraction unit, by the undertaking during the entire assessment period
wsa_vol_conv	Volume of abstracted water	Input	--	m^3	Sum of the volume of water abstracted (gravity or pumped) in the water abstraction unit that are the responsibility of the undertaking, during the assessment period
wsa_fuel_typ	Fuel type	Input	--	Fuel type	Fuel type
wsa_vol_fuel	Volume of fuel consumed	Input	--	L	Volume of fuel consumed
wsa_nrg_pump	Energy consumed from the grid (pumping)	Input	--	kWh	Electric energy consumption for pumping
wsa_vol_pump	Volume pumped	Input	--	m^3	Volume of water pumped in each water abstraction unit that are the responsibility of the undertaking, during the assessment period
wsa_pmp_head	Pumping head	Input	--	m	Head at which the water is pumped in each water abstraction unit that are the responsibility of the undertaking, during the assessment period
wsa_pmp_type	Type of pump	Input	--	Pump type	Pump type

wsa_pmp_size	Size of pump (kW)	Input	--	Pump size	Pump size kW
wsa_sta_head	Static head	Input	--	m	Static head
wsa_main_len	Mains length	Input	--	km	Total transmission and distribution mains length (there are not service connections at the abstraction and conveyance stage)
wsa_pmp_flow	Measured pump flow	Input	--	L/s	Measured pump flow
wsa_pmp_volt	Measured pump voltage	Input	--	V	Measured pump voltage
wsa_pmp_amps	Measured pump current	Input	--	A	Measured pump current
wsa_pmp_pf	Power Factor	Input	--	--	Power Factor
wsa_pmp_exff	Expected electromechanical efficiency of new pump	Input	--	%	Expected electromechanical efficiency of new pump

Annex E Detailed GHG assessment – Water Abstraction - Outputs

Code	**Name**	**Type**	**Formula**	**Unit**	**Description(*_Reference values_)**
wsa_nrg_per_abs_watr	Energy consumption per abstracted water	Output	wsa_nrg_cons/wsa_vol_conv	kWh/m^3	Energy consumption per abstracted water
wsa_KPI_GHG_elec	Electricity	Output	wsa_nrg_cons * conv_kwh_co2	kg CO_2e	Electricity
wsa_KPI_GHG	Total GHG Water Abstraction	Output	wsa_KPI_GHG_elec + wsa_KPI_GHG_fuel	kg CO_2e	Total GHG Water Abstraction

Annex E Detailed GHG assessment – Water Abstraction - Outputs

Code	Name	Type	Formula	Unit	Description(**Reference values*)
wsa_KPI_GHG_fuel	Fuel engines (total emissions)	Output	wsa_KPI_GHG_fuel_co2 + wsa_KPI_GHG_fuel_n2o + wsa_KPI_GHG_fuel_ch4	kg CO_2e	Fuel engines (total emissions)
wsa_nrg_per_pmp_watr	Energy consumed per pumped water		wsa_nrg_pump/wsa_vol_pump	kWh/m3	Energy consumed per pumped water
wsa_KPI_std_nrg_cons*	Standardized energy consumption	Output	wsa_nrg_pump/(wsa_vol_pump * wsa_pmp_head/100)	kWh/m^3/100m	Standardized energy consumption *If pmp_type is "Submersible")* *if(pmp_size=="5.6 - 15.7 kW")* *SEC >= 0.7877)"Unsatisfactory";0.7877 > SEC > 0.5013)"Acceptable"; SEC <= 0.5013)"Good";* *pmp_size=="15.7 - 38 kW")* *SEC >= 0.5866)="Unsatisfactory";(0.5866 > SEC > 0.4447)="Acceptable"; SEC <= 0.4447)="Good";* *pmp_size=="39 - 96 kW")* *SEC >= 0.4837)= "Unsatisfactory";0.4837 > SEC > 0.4115)="Acceptable"; SEC <= 0.4115)="Good";* *(pmp_size=="> 96 kW")* *(SEC >= 0.4673= "Unsatisfactory";0.4673 > SEC > 0.4054= "Acceptable"; SEC <= 0.4054= "Good";else "Out of range";* *If pmp_type is External* *(pmp_size=="5.6 - 15.7 kW")* *(SEC >= 0.5302="Unsatisfactory";(0.5302 > SEC > 0.3322= "Acceptable"; SEC <= 0.3322= "Good"; else if(pmp_size=="15.7 - 38 kW")* *SEC >= 0.4923= "Unsatisfactory";if (0.4923 > SEC > 0.3169= "Acceptable"; SEC <= 0.3169= "Good";*

Annex E Detailed GHG assessment – Water Abstraction - Outputs

Code	Name	Type	Formula	Unit	Description(*Reference values)
					if(pmp_size=="39 - 96 kW") SEC >= 0.4595= "Unsatisfactory";0.4595 > SEC > 0.3080= "Acceptable"; SEC <= 0.3080= "Good"; else if(pmp_size=="> 96 kW") SEC >= 0.4308= "Unsatisfactory";0.4308 > SEC > 0.3080= "Acceptable"; SEC <= 0.3080= "Good"; return "Out of range"
wsa_KPI_un_head_loss*	Unit head loss	Output	1000 * (wsa_pmp_head-wsa_sta_head)/wsa_main_len	m/km	Unit energy friction loss in the conveyance system *Good: UHL ≤ 2* *Acceptable: 2 < UHL ≤ 4* *Unsatisfactory: UHL > 4*
c_wsa_pmp_pw	Calculated water power	Output	wsa_pmp_flow * wsa_pmp_head * ct_gravit/1000	kWh	Calculated water power
wsa_KPI_nrg_elec_eff	Electromechanical efficiency of existing pump	Output	100 * c_wsa_pmp_pw/(wsa_pmp_volt * wsa_pmp_amps * Math.sqrt(3) * wsa_pmp_pf/1000)	%	Electromechanical efficiency of existing pump
wsa_KPI_std_nrg_newp	Estimated standardized energy consumption of new pump	Output	wsa_KPI_nrg_elec_eff/wsa_pmp_exff * wsa_KPI_std_nrg_cons	kWh/m^3/100m	Estimated standardized energy consumption of new pump
wsa_KPI_nrg_cons_new	Energy consumption with expected new pump efficiency	Output	wsa_KPI_nrg_elec_eff/wsa_pmp_exff * wsa_nrg_pump	kWh	Energy consumption with expected new pump efficiency
wsa_KPI_nrg_estm_sav	Estimated electricity savings	Output	wsa_nrg_cons-wsa_KPI_nrg_cons_new	kWh	Estimated electricity savings

Annex E Detailed GHG assessment – Water Abstraction - Outputs

Code	Name	Type	Formula	Unit	Description(**Reference values*)
wsa_KPI_ghg_estm_red	Estimated GHG reduction per assessment period	Output	conv_kwh_co2 * wsa_KPI_nrg_estm_sav	kg CO_2 eq	Estimated GHG reduction per assessment period

Annex F Detailed GHG assessment -Water Treatment - Inputs

Code	Name	Type	Formula	Unit	Description
wst_nrg_cons	Energy consumed from the grid	Input	--	kWh	Energy consumed during the assessment period by each urban water treatment plant managed by the undertaking
wst_vol_trea	Volume of treated water	Input	--	m^3	Sum of the volume of water treated by WTPs that are the responsibility of the water undertaking, during the assessment period
wst_mass_slu	Sludge produced in WTPs	Input	--	kg	Sludge produced during the assessment period by each urban water treatment plant managed by the undertaking
wst_treatmen	Treatment type	Input	--	Technology	Treatment type
wst_fuel_typ	Fuel type	Input	--	Fuel type	Fuel type
wst_vol_fuel	Volume of fuel consumed	Input	--	L	Volume of fuel consumed
wst_nrg_pump	Energy consumed from the grid (pumping)	Input	--	kWh	Energy consumed from the grid (pumping)
wst_vol_pump	Volume pumped	Input	--	m^3	Volume pumped

wst_pmp_head	Pump head	Input	--	m	Pump head
wst_tst_carr	Percent of quality tests in compliance	Input	--	%	Number of treated water tests carried out during the assessment period
wst_trea_cap	Treatment capacity	Input	--	m^3	The treatment capacity of each WTP or on site system facility that are the responsibility of the wastewater undertaking, during the assessment period

Annex G Detailed GHG assessment -Water Treatment – Outputs

Code	Name	Type	Formula	Unit	Description(*Reference values*)
wst_KPI_nrg_per_m3*	Energy consumption per treated water	Output	wst_nrg_cons/wst_vol_trea	kWh/m^3	Unit energy consumption per treated water in water treatment plants ***WTP > 5000 m^3/d** - Good: ECT ≤ 0.025; Acceptable: 0.025 < ECT ≤ 0.04; Unsatisfactory: ECT > 0.04* ***WTP <= 5000 m^3/d** - Good: ECT ≤ 0.04; Acceptable: 0.04 < ECT ≤ 0.055; Unsatisfactory: ECT > 0.055* ***WTP with Pre-ox > 5000 m^3/d** - Good: ECT ≤ 0.055; Acceptable: 0.055 < ECT ≤ 0.07; Unsatisfactory: ECT > 0.07* ***WTP with Pre-ox <= 5000 m^3/d** - Good: ECT ≤ 0.07; Acceptable: 0.07 < ECT ≤ 0.085; Unsatisfactory: ECT > 0.085* ***WTP (with raw and treated water pumping)** - Good: ECT ≤ 0.4; Acceptable: 0.4 < ECT ≤ 0.5; Unsatisfactory: ECT > 0.5*

Annex G Detailed GHG assessment -Water Treatment – Outputs

Code	Name	Type	Formula	Unit	Description(**Reference values*)
wst_KPI_slu_per_m3*	Sludge production per treated water	Output	wst_mass_slu/wst_vol_trea	kg/m^3	Unit sludge production per treated water in water treatment plants *Good: SPT ≤ 0.06* *Acceptable: 0.06 < SPT ≤ 0.10* *Unsatisfactory: SPT > 0.10*
wst_KPI_GHG_elec	Electricity	Output	wst_nrg_cons * conv_kwh_co2	kg CO_2e	GHG emissions from electricity
wst_KPI_GHG	Total GHG Water Treatment	Output	wst_KPI_GHG_elec + wst_KPI_GHG_fuel	kg CO_2e	Total GHG Water Treatment
wst_KPI_GHG_fuel	Fuel engines (total emissions)	Output	wst_KPI_GHG_fuel_co2 + wst_KPI_GHG_fuel_n2o + wst_KPI_GHG_fuel_ch4	kg CO_2e	Fuel engines (total emissions)
wst_KPI_std_nrg_cons	Standardized energy consumption pumping	Output	wst_nrg_pump/(wst_vol_pump * wst_pmp_head/100)	$kWh/m^3/100m$	Standardized energy consumption pumping
wst_KPI_capac_util	Capacity utilization	Output	100 * wst_vol_trea/wst_trea_cap	%	Percentage of treatment capacity utilized *Good: 90 ≤ tE4 ≤ 70* *Acceptable: 100 ≤ tE4 < 90 and 70 < tE4 ≤ 50* *Unsatisfactory: tE4 > 100 and tE4 < 50*

Annex G Detailed GHG assessment -Water Treatment – Outputs

Code	Name	Type	Formula	Unit	Description(***Reference values***)
wst_KPI_tst_carr	Percent of quality tests in compliance	Output	wst_tst_carr	%	Percent of quality tests in compliance

Annex H Detailed GHG assessment – Water Distribution Inputs

Code	Name	Type	Formula	Unit	Description
wsd_nrg_cons	Energy consumed from the grid	Input	--	kWh	Electric energy consumption including both from the grid and self-produced, for water distribution during the entire assessment period
wsd_vol_dist	Volume of water injected to distribution	Input	--	m^3	The water volume entering the distribution system from the water treatment or directly from abstraction during the assessment period
wsd_fuel_typ	Fuel type (Engines)	Input	--	Fuel type	Fuel type (Engines)
wsd_vol_fuel	Volume of fuel consumed (Engines)	Input	--	L	Volume of fuel consumed (Engines)
wsd_auth_con	Volume of authorized consumption	Input	--	m^3	Sum of the volume of metered and/or non-metered water that, during the assessment period, is taken by registered customers, by the water supplier itself, or by others who are implicitly or explicitly authorised to do so by the water supplier, for residential, commercial, industrial or public purposes. It includes water exported
wsd_bill_con	Volume of billed authorized consumption	Input	--	m^3	Authorized consumption, which are billed and generate revenue (also known as revenue water). It is equal to billed metered consumption plus Billed Unmetered Consumption
wsd_trck_typ	Fuel type (Trucks)	Input	--	Fuel type	Fuel type (Trucks)
wsd_vol_trck	Volume of fuel consumed (Trucks)	Input	--	L	Volume of fuel consumed (Trucks)
wsd_deli_pts	Delivery points with adequate pressure	Input	--	number	Number of delivery points that receive and are likely to receive pressure equal to or above the guaranteed or declared target level at the peak demand hour (but not when demand is abnormal).

Annex H Detailed GHG assessment – Water Distribution Inputs

Code	Name	Type	Formula	Unit	Description
wsd_ser_cons	Number of service connections	Input	--	number	Total number of service connections, at the reference date
wsd_time_pre	Time system is pressurised	Input	--	hours/day	Amount of time of the year the system is pressurised
wsd_min_pres	Minimum pressure to be supplied at the distribution nodes	Input	--	m	According the standards, a minimum pressure must be provided to the consumers (20 - 30 m) , for each water distribution unit
wsd_hi_no_el	Highest node elevation	Input	--	m asl	Is the elevation of the highest node of the network, for each water distribution unit
wsd_lo_no_el	Lowest node elevation of the stage	Input	--	m asl	Is the elevation of the lowest node of the stage, for each water distribution unit
wsd_av_no_el	Average nodes elevation	Input	--	m asl	The average elevation of the network. If necessary it could be calculated as sum of lowest and the highest node elevation of the network divided by two, for each water distribution unit
wsd_wt_el_no	Water table elevation node	Input	--	m	It is the elevation of the water table to calculate the natural energy provided to the system, for each water distribution unit
wsd_nrg_pump	Energy consumed from the grid (pumping)	Input	--	kWh	Electric energy consumption for pumping
wsd_vol_pump	Distributed water pumped	Input	--	m^3	Volume of water in the drinking water distribution system which requires pumping, for each distribution unit
wsd_pmp_head	Pump head	Input	--	m	Pump head
wsd_pmp_size	Size of pump (kW)	Input	--	Pump size	Pump size kW
wsd_sta_head	Static head	Input	--	m	Static head
wsd_main_len	Mains length	Input	--	km	Total transmission and distribution mains length (service connections not included), for each water distribution unit at the reference date
wsd_pmp_flow	Measured pump flow	Input	--	L/s	Measured pump flow

Annex H Detailed GHG assessment – Water Distribution Inputs

Code	Name	Type	Formula	Unit	Description
wsd_pmp_volt	Measured pump voltage	Input	--	V	Measured pump voltage
wsd_pmp_amps	Measured pump current	Input	--	A	Measured pump current
wsd_pmp_pf	Power Factor	Input	--	--	Power Factor
wsd_pmp_exff	Expected electromechanical efficiency of new pump	Input	--	%	Expected electromechanical efficiency of new pump

Annex I Detailed GHG assessment – Water Distribution Outputs

Code	Name	Type	Formula	Unit	Description(**Reference values*)
wsd_KPI_nrg_per_vd	Energy consumption per volume injected to distribution	Output	wsd_nrg_cons/wsd_vol_dist	kWh/m3	Unit energy consumption per water injected to distribution
wsd_KPI_GHG_elec	Electricity	Output	wsd_nrg_cons * conv_kwh_co2	kg CO_2e	GHG emissions from electricity
wsd_KPI_GHG	Total GHG Water Distribution	Output	wsd_KPI_GHG_elec + wsd_KPI_GHG_fuel + wsd_KPI_GHG_trck	kg CO_2e	Total GHG Water Distribution
wsd_KPI_GHG_fuel	Fuel engines (total emissions)	Output	wsd_KPI_GHG_fuel_co2 + wsd_KPI_GHG_fuel_n2o + wsd_KPI_GHG_fuel_ch4	kg CO_2e	Fuel engines (total emissions)
wsd_SL_water_loss	Water losses	Output	100 * (wsd_vol_dist-wsd_auth_con)/wsd_vol_dist	%	Water losses include: unauthorized consumption + Customer meter inaccuracies and data handling errors + leakage in transmission and distribution mains + storage leaks and overflows from water storage tanks + service connections leaks up to the meter. See non revenue water table
wsd_SL_nr_water	Non-revenue water	Output	100 * (wsd_vol_dist-wsd_bill_con)/wsd_vol_dist	%	Non revenue water includes: water losses + unbilled authorized consumption. See non revenue water table
wsd_KPI_nrg_per_m3	Energy consumption per authorized consumption	Output	wsd_nrg_cons/wsd_auth_con	kWh/m^3	Unit energy consumption per authorized consumption in water distribution
wsa_SL_GHG_nrw	GHG in Abstraction due to water losses	Output	(wsa_KPI_GHG * (wsd_vol_dist - wsd_auth_con) / wsa_vol_conv)	kgCO_2eq	GHG in Abstraction due to water losses

Annex I Detailed GHG assessment – Water Distribution Outputs

Code	Name	Type	Formula	Unit	Description(**Reference values*)
wst_SL_GHG_nrw	GHG in Treatment due to water losses	Output	(wst_KPI_GHG * (wsd_vol_dist - wsd_auth_con) / wst_vol_trea)	$kgCO_2eq$	GHG in Treatment due to water losses
wsd_SL_GHG_nrw	GHG in Distribution due to water losses	Output	(wsd_KPI_GHG * (wsd_vol_dist - wsd_auth_con) / wsd_vol_dist)	$kgCO_2eq$	GHG in Distribution due to water losses
wsd_SL_ghg_attr	Total GHG attributable to water losses	Output	wsa_SL_GHG_nrw + wst_SL_GHG_nrw + wsd_SL_GHG_nrw	$kgCO_2eq$	Total GHG attributable to water losses
wsd_KPI_GHG_trck	Fuel (Trucks)	Output	wsd_KPI_GHG_trck_co2 + wsd_KPI_GHG_trck_n2o + wsd_KPI_GHG_trck_ch4	kg CO_2e	Fuel (Trucks)
wsd_SL_pres_ade	Percentage of supply pressure adequacy	Output	100 * wsd_deli_pts/wsd_ser_cons	%	Percentage of delivery points (one per service connection) that receive and are likely to receive adequate pressure
wsd_SL_cont_sup	Continuity of supply	Output	100 * wsd_time_pre/24	%	Percentage of delivery points (one per service connection) that receive and are likely to receive adequate pressure
c_wsd_nrg_topo	Topographic energy supplied to the system	Output	ct_gravit * wsd_vol_dist * (wsd_hi_no_el-wsd_av_no_el)/3600000	kWh	This is the energy supplied to the system because its irregular topography
c_wsd_nrg_natu	Natural energy provided (gravity energy from supply to distribution)	Output	ct_gravit * wsd_vol_dist * (wsd_wt_el_no-wsd_lo_no_el)/3600000	kWh	Sum of natural energy provided for all the input reservoirs and tanks of the stage. Intermediate tanks are not considered.
c_wsd_nrg_mini	Minimum required energy for the system to operate	Output	ct_gravit * wsd_auth_con * (wsd_min_pres + wsd_av_no_el-wsd_lo_no_el)/3600000	kWh	This energy takes into account the node consumption elevation plus the minimum pressure required by the users

Annex I Detailed GHG assessment – Water Distribution Outputs

Code	Name	Type	Formula	Unit	Description(*Reference values*)
	by users (theoretical)				
c_wsd_nrg_supp	Total supplied energy to the network (natural plus shaft), real system	Output	wsd_nrg_cons + c_wsd_nrg_natu	kWh	The energy provided to a system can be natural and shaft (pumping energy). With the provided expression the energy is precisely calculated
wsd_KPI_nrg_efficien*	Global water distribution energy efficiency	Output	100 * c_wsd_nrg_mini/c_wsd_nrg_supp	%	Integrate all system distribution inefficiencies (pumps, friction, leaks and others). Compliments, giving a more complete information **wsd_KPI_std_nrg_cons** *Good: GDE ≥ 80 – PTE* *Acceptable: 80-dE5 > GDE ≥ 70- PTE* *Unsatisfactory: GDE < 70 – PTE (Cabrera, et al., 2014)*
wsd_KPI_nrg_topgraph	Percentage of topographic energy	Output	100 * c_wsd_nrg_topo/c_wsd_nrg_supp	%	Percentage of energy provided to the system due to the terrain topography *Flat: PTE ≤ 15* *Medium: 15 < PTE ≤ 30* *Hilly: PTE > 30 (Cabrera et al., 2014)*
wsd_KPI_std_nrg_cons*	Standardized Energy Consumption	Output	wsd_nrg_pump/(wsd_vol_pump * wsd_pmp_head/100)	$kWh/m^3/$ 100m	Energy consumption per pumping water per head *Good: 0.2725 ≤ SEC ≤ 0.40* *Acceptable: 0.40 < SEC ≤ 0.54* *Unsatisfactory: SEC > 0.54 (Cabrera, et al., 2014)*
wsd_KPI_un_head_loss*	Unit head loss	Output	1000 * (wsd_pmp_head-wsd_sta_head)/wsd_main_len	m/km	Unit energy friction loss in the conveyance system

Annex I Detailed GHG assessment – Water Distribution Outputs

Code	Name	Type	Formula	Unit	Description(**Reference values*)
					Good: UHL ≤ 2 Acceptable: 2 < UHL ≤ 4 Unsatisfactory: UHL > 4 (Alegre, et al., 2006)
wsd_KPI_water_losses*	Non-revenue water per mains length	Output	Math.max(0,1000 * (wsd_vol_dist-wsd_auth_con)/(wsd_main_len))/Years	m^3/km	Total water losses (apparent and real), expressed in terms of annual volume lost per mains length *Good: NRM ≤ 6 , Acceptable: 6 < NRM ≤ 12, Unsatisfactory: NRM > 12 (Alegre, et al., 2006)*
c_wsd_pmp_pw	Calculated water power	Output	wsd_pmp_flow * wsd_pmp_head * ct_gravit/1000	kW	Calculated water power
wsd_KPI_nrg_elec_eff	Electromechanical efficiency of existing pump	Output	100 * c_wsd_pmp_pw/(wsd_pmp_volt * wsd_pmp_amps * Math.sqrt(3) * wsd_pmp_pf/1000)	%	Electromechanical efficiency of existing pump
wsd_KPI_std_nrg_newp	Standardized energy consumption of new pump	Output	wsd_KPI_nrg_elec_eff/wsd_pmp_exff * wsd_KPI_std_nrg_cons	kWh/m^3/ 100m	Standardized energy consumption of new pump
wsd_KPI_nrg_cons_new	Energy consumption with expected new pump efficiency	Output	wsd_KPI_nrg_elec_eff/wsd_pmp_exff * wsd_nrg_pump	kWh	Energy consumption with expected new pump efficiency
wsd_KPI_nrg_estm_sav	Estimated electricity savings	Output	wsd_nrg_cons-wsd_KPI_nrg_cons_new	kWh	Estimated electricity savings
wsd_KPI_ghg_estm_red	Estimated GHG reduction per assessment period	Output	conv_kwh_co2 * wsd_KPI_nrg_estm_sav	kg CO_2 eq	Estimated GHG reduction per assessment period

Annex J Wastewater – Tier A - Inputs

Code	Name	Type	Formula	Unit	Description
ww_resi_pop	Resident population	Input	--	People	Number of permanent residents within the area of service for wastewater services managed by the undertaking (whether they are connected or not) , at the reference date
ww_conn_pop	Population connected to sewers	Input	--	People	Number of permanent residents within the service area managed by the undertaking which are connected to the sewer system, at the reference date
ww_serv_pop	Serviced population	Input	--	People	Serviced population is referred to the number of inhabitants (or inhabitant equivalents), within the area of service managed by the utility, which are connected to a sewer system and which wastewater are receiving treatment in a WWTP.
ww_onsi_pop	Population with onsite treatment	Input	--	People	Population with onsite treatment
ww_nrg_cost	Energy costs	Input	--	Currency unit	Costs from electric energy consumption for the entire wastewater utility, based on the electricity bill during the entire assessment period.
ww_run_cost	Total running costs	Input	--	USDCurrency unit	Total operations and maintenance net costs and internal manpower net costs (i.e. not including the capitalised cost of self-constructed assets) related to wastewater management within the service area managed by the undertaking during the entire assessment period

Annex K Wastewater – Tier A - Outputs

Code	Name	Type	Formula	Unit	Description
ww_KPI_GHG_unt	Untreated wastewater	Output	ww_KPI_GHG_unt_ch4 + ww_KPI_GHG_unt_n2o	kg CO2e	GHG emissions in CO2 eq from untreated wastewater
wwc_KPI_GHG	Total GHG Wastewater Collection	Output	wwc_KPI_GHG_elec + wwc_KPI_GHG_fuel	kg CO_2e	Total GHG Wastewater Collection
wwt_KPI_GHG	Total GHG Wastewater Treatment	Output	wwt_KPI_GHG_elec + wwt_KPI_GHG_fuel + wwt_KPI_GHG_tre + wwt_KPI_GHG_dig_fuel + wwt_KPI_GHG_biog + wwt_KPI_GHG_slu	kg CO_2e	Total GHG Wastewater Treatment
wwd_KPI_GHG	Total GHG Wastewater Discharge/Reuse	Output	wwd_KPI_GHG	kg CO_2e	Total GHG Wastewater Discharge/Reuse
ww_KPI_GHG	Total GHG Wastewater	Output	wwc_KPI_GHG + wwt_KPI_GHG + wwd_KPI_GHG	kg CO_2	GHG Emissions from non-electricity and electricity consumption
ww_SL_serv_pop	Resident population serviced with Wastewater Treatment	Output	100 * ww_serv_pop/ww_resi_pop	%	Percentage of the resident population that are connected to the sewer systems and which wastewater is treated by the undertaking
ww_SL_treat_m3	Collected wastewater treated	Output	100 * ww_serv_pop/ww_conn_pop	%	Percentage of the collected sewage prior to dilution or overflows in the sewer system that are treated in wastewater treatment plants
ww_SL_nrg_cost	Energy costs percentage	Output	100 * ww_nrg_cost/ww_run_cost	%	Proportion of the utility energy costs referred to the total running costs

ww_nrg_cons	Energy consumed from the grid (Collection+Treatment +Discharge)	Output	wwc_nrg_cons + wwt_nrg_cons + wwd_nrg_cons	kWh	Total electric energy consumed from the grid related to wastewater management within the service area managed by the undertaking during the entire assessment period
ww_vol_fuel	Volume of fuel consumed	Output	wwc_vol_fuel + wwt_vol_fuel + wwt_fuel_dig + wwd_vol_fuel	L	Volume of fuel consumed
ww_SL_ghg_unc	Uncollected wastewater	Output	ww_SL_ghg_unc_ch4 + ww_SL_ghg_unc_n2o		GHG emissions from uncollected wastewater
ww_GHG_avoided	Total GHG emissions avoided		wwt_SL_GHG_avoided + wwt_wr_C_seq_slu + wwd_wr_GHG_avo_d + wwd_SL_ghg_non + wwd_wr_GHG_avo + fst_SL_GHG_avoided + fsr_ghg_avoided_reuse + fsr_ghg_avoided_land +		Total GHG emissions avoided
ww_SL_vol_pday	Treated wastewater per person per day	Output	1000 * wwt_vol_trea/ww_serv_pop/Days	L/serv.pop./day	Volume of treated wastewater per serviced person in the service area managed by the undertaking divided by the duration of the assessment period

Annex L Detailed GHG assessment – Wastewater Collection - Inputs

Code	Name	Type	Formula	Unit	Description
wwc_nrg_cons	Energy consumed from the grid	Input	--	kWh	Energy consumed during the assessment period by each pumping station for conveying wastewater to treatment managed by the undertaking
wwc_vol_conv	Volume of wastewater conveyed to treatment	Input	--	m^3	Collected wastewater, corresponding to the volume of domestic, commercial and industrial outputs to the sewer system which reaches the treatment plant or an outfall during the assessment period (pumped or not). At sub-stage level, if the volume is pumped, only enter in this line if it is pumping directly to the plant or the discharge. In case of multiple stage pumping do not include the volume in this line. This input should equal value reported in global assessment for volume wastewater treated by default.
ww_ch4_efac_unt	CH4 emission factor (untreated wastewater)	Input	--	kgCH4/kgBOD	CH4 emission factor (untreated wastewater)
ww_ch4_efac_unc	CH4 emission factor (uncollected wastewater)	Input	--	kgCH4/kgBOD	CH_4 emission factor (uncollected wastewater)
wwc_fuel_typ	Fuel type	Input		Fuel type	Fuel type
wwc_vol_fuel	Volume of fuel consumed	Input	--	L	Volume of fuel consumed
wwc_wet_flow	Average daily wet weather flow	Input	--	m^3/day	Average daily wet weather flow

Annex L Detailed GHG assessment – Wastewater Collection - Inputs

wwc_dry_flow	Average daily dry weather flow	Input	--	m^3/day	Average daily dry weather flow
wwc_rain_day	Number of rain days	Input	--	day	Number of rain days during the assessment period
wwc_nrg_pump	Energy consumed from the grid (pumping)	Input	--	kWh	Energy consumed from the grid (pumping)
wwc_vol_pump	Volume of pumped wastewater	Input	--	m^3	Volume of pumped wastewater
wwc_pmp_head	Pump head	Input	--	m	Pump head
wwc_sta_head	Static head	Input	--	m	Static head
wwc_coll_len	Collector length	Input	--	km	Collector length
wwc_pmp_flow	Measured pump flow	Input	--	L/s	Measured pump flow
wwc_pmp_volt	Measured pump voltage	Input	--	V	Measured pump voltage
wwc_pmp_amps	Measured pump current	Input	--	A	Measured pump current
wwc_pmp_pf	Power Factor	Input	--	--	Power Factor
wwc_bod_pday	BOD_5 per person per day	Input	--	g/person/day	This represents the average Biochemical oxygen demand (BOD_5) that each resident connected to the sewer system eliminates in the wastewater produced every day. The default value is provided after selection of country. This default value shall be adjusted if local studies provide more accurate estimates. The default values provided by the tool are based on the IPCC data, which typically represent the country average. Hence, due to the variability between different areas within a country, it is recommended to use actual measured values for the system whenever possible to obtain the most accurate results.
wwc_prot_con	Annual protein consumption per capita	Input	--	kg/person/year	Protein consumption per capita per year. The default value is provided after selection of country. If you have a specific factor that applies to your region you can provide. The default values provided by the tool are based on the FAO Statistics Division, which typically represent the country average. Hence, due to

Annex L Detailed GHG assessment – Wastewater Collection - Inputs

					the variability between different areas within a country, it is recommended to use actual measured values for the system whenever possible to obtain the most accurate results.
wwc_pmp_exff	Expected electromechanical efficiency of new pump	Input	--	%	Expected electromechanical efficiency of new pump

Annex M Detailed GHG assessment – Wastewater Collection - Outputs

Code	Name	Type	Formula	Unit	Description (**Reference values*)
wwc_SL_conn_pop	Population connected to sewer	Output	100 * ww_conn_pop/ww_resi_pop	%	Population connected to sewer
wwc_KPI_nrg_per_m3	Energy consumption per wastewater conveyed to treatment	Output	wwc_nrg_cons/wwc_vol_conv	kWh/m^3	Amount of energy consumed to bring 1 m^3 of wastewater from the sources to the wastewater treatment plant
wwc_KPI_GHG_elec	Electricity	Output	wwc_nrg_cons * conv_kwh_co2	kg CO_2e	GHG from electricity
wwc_KPI_GHG	Total GHG Wastewater Collection	Output	wwc_KPI_GHG_elec + wwc_KPI_GHG_fuel	kg CO_2e	Total GHG Wastewater Collection

Annex M Detailed GHG assessment – Wastewater Collection - Outputs

Code	Name	Type	Formula	Unit	Description (**Reference values*)
wwc_KPI_GHG_fuel	Fuel engines (total emissions)	Output	wwc_KPI_GHG_fuel_co2 + wwc_KPI_GHG_fuel_n2o + wwc_KPI_GHG_fuel_ch4	kg CO_2e	Fuel engines (total emissions)
c_wwc_vol_infl	Infiltration and inflow volume	Output	wwc_rain_day/86400 * (wwc_wet_flow-wwc_dry_flow)	m^3	Infiltration and inflow volume
wwc_SL_GHG_ii	From Infiltration and Inflow	Output	wwc_KPI_nrg_per_m3 * c_wwc_vol_infl * conv_kwh_co2	kg CO_2eq	From Infiltration and Inflow
wwc_SL_fratio	Wet weather flow to dry weather flow ratio	Output	wwc_wet_flow/wwc_dry_flow	-	Wet weather flow to dry weather flow ratio
wwc_SL_GHG_inf	GHG in wastewater collection due to infiltration/inflow	Output	wwc_KPI_GHG_elec * c_wwc_vol_infl / wwc_vol_conv	kg CO_2e	GHG in wastewater collection due to infiltration/inflow
wwt_SL_GHG_inf	GHG in wastewater treatment due to infiltration/inflow	Output	wwt_KPI_GHG_elec * c_wwc_vol_infl / wwc_vol_conv	kg CO_2e	GHG in wastewater treatment due to infiltration/inflow
wwd_SL_GHG_inf	GHG in wastewater discharge/reuse due to infiltration/inflow	Output	wwd_KPI_GHG_elec * c_wwc_vol_infl / wwc_vol_conv	kg CO_2e	GHG in wastewater discharge/reuse due to infiltration/inflow
wwc_SL_inf_emis	Total GHG emissions attributable to infiltration/inflow	Output	wwc_SL_GHG_inf + wwt_SL_GHG_inf + wwd_SL_GHG_inf	kg CO2e	Total GHG emissions attributable to infiltration/inflow
wwc_KPI_std_nrg_cons*	Standardized Energy Consumption	Output	wwc_nrg_pump/(wwc_vol_pump * wwc_pmp_head/100)	$kWh/m^3/100m$	Percentage of energy consumed in wastewater collection with regards to the Total energy consumed from the grid and self-produced in the water and wastewater systems

Annex M Detailed GHG assessment – Wastewater Collection - Outputs

Code	Name	Type	Formula	Unit	Description (**Reference values*)
					Good: 0.2725 ≤ SEC ≤ 0.45 *Acceptable: 0.45 < SEC ≤ 0.68* *Unsatisfactory: SEC > 0.68*
wwc_KPI_un_head_loss	Unit head loss	Output	1000 * (wwc_pmp_head-wwc_sta_head)/wwc_coll_len	m/km	Unit energy friction loss in the conveyance system
c_wwc_pmp_pw	Calculated water power	Output	wwc_pmp_flow * wwc_pmp_head * ct_gravit/10000	kW	Calculated water power
wwc_KPI_nrg_elec_eff	Electromechanical efficiency of existing pump	Output	100 * c_wwc_pmp_pw/(wwc_pmp_volt * wwc_pmp_amps * Math.sqrt(3) * wwc_pmp_pf/1000)	%	Electromechanical efficiency of existing pump
ww_SL_treat_m3	Collected wastewater treated	Output	100 * (ww_serv_pop/ww_conn_pop)	%	Percentage of the collected sewage prior to dilution or overflows in the sewer system that are treated in wastewater treatment plants
wwc_SL_ghg_unc_ch4	CH_4 from uncollected wastewater	Output	(ww_resi_pop-ww_conn_pop) * wwc_bod_pday/1000 * Days * 0.3 * ct_ch4_eq;	kg CO_2e	CH_4 from uncollected wastewater. 0.3 is kgCH_4/kgBOD
wwc_SL_ghg_unc_n2o	N_2O from uncollected wastewater	Output	(ww_resi_pop-ww_conn_pop) * wwc_prot_con * Years * ct_fra_np * ct_fac_nc * ct_fac_ic * ct_ef_eff * ct_n2o_co * ct_n2o_eq;	kg CO_2e	N_2O from uncollected wastewater
wwc_SL_ghg_unc	CO_2eq from uncollected wastewater	Output	wwc_SL_ghg_unc_ch4 + wwc_SL_ghg_unc_n2o	kg CO_2e	CO_2eq from uncollected wastewater
wwc_SL_ghg_ons_ch4	CH_4 from onsite treatment	Output	ww_onsi_pop * wwc_bod_pday/1000 * Days * 0.3 * ct_ch4_eq	kg CO_2e	CH4 from onsite treatment

Annex M Detailed GHG assessment – Wastewater Collection - Outputs

Code	Name	Type	Formula	Unit	Description (**Reference values*)
wwc_SL_ghg_ons_n2o	N_2O from onsite treatment	Output	ww_onsi_pop * wwc_prot_con * Years * ct_fra_np * ct_fac_nc * ct_fac_ic * ct_ef_eff * ct_n2o_co * ct_n2o_eq	kg CO_2e	N2O from onsite treatment
wwc_SL_ghg_ons	CO_2eq from onsite treatment	Output	wwc_SL_ghg_ons_ch4 + wwc_SL_ghg_ons_n2o	kg CO_2e	CO2eq from onsite treatment
wwc_KPI_std_nrg_newp	Standardized energy consumption of new pump	Output	wwc_KPI_nrg_elec_eff/wwc_pmp_exff * wwc_KPI_std_nrg_cons	$kWh/m_3/100m$	Standardized energy consumption of new pump
wwc_KPI_nrg_cons_new	Energy consumption with expected new pump efficiency	Output	wwc_vol_pump * wwc_KPI_std_nrg_newp/100 * wwc_pmp_head	kWh	Energy consumption with expected new pump efficiency
wwc_KPI_nrg_estm_sav	Estimated electricity savings	Output	wwc_nrg_cons-wwc_KPI_nrg_cons_new	kWh	Estimated electricity savings
wwc_KPI_ghg_estm_red	Estimated GHG reduction per assessment period	Output	conv_kwh_co2 * wwc_KPI_nrg_estm_sav	kg CO_2 eq	Estimated GHG reduction per assessment period
wwc_KPI_GHG_unt_ch4	CH_4 from untreated wastewater	Output	(ww_conn_pop-ww_serv_pop) * wwc_bod_pday/1000 * Days * ct_ch4_ef * ct_ch4_eq	kg CO_2e	CH_4 from untreated wastewater
wwc_KPI_GHG_unt_n2o	N_2O from untreated wastewater	Output	(ww_conn_pop-ww_serv_pop) * wwc_prot_con * Years * ct_fra_np * ct_fac_nc * ct_fac_ic * ct_ef_eff * ct_n2o_co * ct_n2o_eq	kg CO_2e	N_2O from untreated wastewater

Annex N Detailed GHG assessment – Wastewater Treatment - Inputs

Code	Name	Type	Formula	Unit	Description
wwt_type_tre	Type of treatment	Input	--	Technology	Type of treatment
wwt_ch4_efac	CH_4 emission factor	Input	--	$kgCH_4/kgBOD$	Methane emission factor of selected biological wastewater aerobic treatment processes. Activated Sludge - Well managed:0 Activated Sludge - Minor poorly aerated zones:0.06 Activated Sludge - Some aerated zones:0.12 Activated Sludge - Not well managed:0.18 Aerated Lagoon: 0.18 Anaerobic Lagoon <2m depth: 0.12 Anaerobic Lagoon >2m depth: 0.48 Anaerobic Lagoon covered: 0.00 //MISSING VALUE Trickling Filter: 0.036 UASB - CH4 recovery not considered: 0.48 UASB - CH4 recovery considered: 0.3 Wetlands - Surface flow:0.24 Wetlands - Horizontal subsurface flow:0.06 Wetlands - Vertical subsurface flow:0.006
wwt_bod_infl	Influent BOD_5 load	Input	--	kg	BOD_5 load entering the WWTP during the assessment period. It can be estimated by multiplying the average BOD concentration in the influent by the volume entering the plant. If this is done daily and summed over the duration of the assessment period the value will be most accurate
wwt_bod_effl	Effluent BOD_5 load	Input	--	kg	BOD_5 load at the effluent of the WWTP during the assessment period. It can be estimated by multiplying the average BOD5 concentration in the effluent

Annex N Detailed GHG assessment – Wastewater Treatment - Inputs

Code	Name	Type	Formula	Unit	Description
					by the effluent volume the plant. If this is done daily and summed over the duration of the assessment period the value will be most accurate
wwt_bod_slud	BOD removed as sludge	Input	--	kg	BOD removed from the wastewater though the process of removing primary or secondary sludge from the aerobic treatment process. This value is used to estimate the Methane emissions from poorly aerated biological treatment of wastewater
c_wwt_bod_rmvd	BOD5 mass removed	Input	--	kg	This is calculated from the difference in BOD mass from the influent with BOD mass from the effluent over the assessment period.
wwt_fuel_typ	Fuel type (Engines)	Input	--	Fuel type	Fuel type (Engines)
wwt_vol_fuel	Volume of fuel consumed	Input	--	L	Volume of fuel consumed
wwt_biog_pro	Biogas produced	Input	--	m^3	Biogas produced during the assessment period by each wastewater treatment plant managed by the undertaking
wwt_biog_fla	Biogas flared	Input	--	m^3	Biogas flared is calculated with the difference between biogas produced minus biogas valorised. If biogas produced is 0 (unknown), biogas flared is estimated using ww_serv_pop*bod_pday*ct_bod_kg*ct_biog_g*Days/1000

Annex N Detailed GHG assessment – Wastewater Treatment - Inputs

Code	Name	Type	Formula	Unit	Description
wwt_dige_typ	Fuel type (for digestor)	Input	--	Fuel type	Fuel type (for digestor)
wwt_fuel_dig	Fuel consumed for the digester	Input	--	L	Fuel consumed for the digester
wwt_biog_val	Biogas valorised as heat and/or electricity	Input	--	m^3	Biogas valorised in the treatment plant to heat the digesters or the building and/or to run a Co-generator to generate heat and electricity
wwt_nrg_biog	Electrical energy produced from biogas valorization	Input	--	kWh	Energy produced from biogas valorisation during the assessment period by each wastewater treatment plant managed by the undertaking
wwt_trea_cap	Treatment capacity	Input	--	m^3	Treatment capacity of each WWTP that are the responsibility of the wastewater undertaking, during the assessment period
wwt_tst_cmpl	Number of water quality tests complying	Input	--	number	Number of tests in each wastewater treatment plant that comply with discharge consents during the assessment period
wwt_tst_cond	Number of water quality tests conducted	Input	--	number	Number of tests carried out in each treated wastewater treatment plant during the assessment period
wwt_nrg_pump	Energy consumed from	Input	--	kWh	Energy consumed from the grid (pumping)

Annex N Detailed GHG assessment – Wastewater Treatment - Inputs

Code	Name	Type	Formula	Unit	Description
	the grid (pumping)				
wwt_pmp_head	Pump head	Input	--	m	Pump head
c_wwt_nrg_biog	Total energy content of biogas valorized	Input/output	-	kWh	Sum of energy content of biogas used in a cogenerator or a boiler during the assessment period by all wastewater treatment plants managed by the undertaking
wwt_mass_slu	Sludge produced in WWTPs (total weight)	Input	--	kg	Sludge produced during the assessment period by each wastewater treatment plant managed by the undertaking
wwt_dryw_slu	Dry weight in sludge produced	Input	--	kg	Average of dry total weight of sludge produced as dry weight during the assessment period by each wastewater treatment plant managed by the undertaking. If sludge is processed with centrifuges or chemicals, a good estimation is 20% of Sludge produced in WWTP (total weight)
wwt_slu_disp	Sludge type disposed of	Input	--	Sludge type disposed of	Sludge type disposed
wwt_mass_slu_sto	Sludge stored (dry weight)	Input	--	kg	Amount of sludge that is stored prior to disposal (dry weight)
wwt_time_slu_sto	Storage time	Input	--	day	Time interval the sludge is stored for before being sent to disposal

Annex N Detailed GHG assessment – Wastewater Treatment - Inputs

Code	Name	Type	Formula	Unit	Description
Methane potential	Methane potential	Input/output	--	kg CH4	Maximum methane emission potential for sludge stored
wwt_mass_slu_comp	Sludge composted (dry weight)	Input	--	kg	Amount of sludge that is sent to composting (dry weight)
wwt_mass_slu_inc	Sludge incinerated (dry weight)	Input	--	kg	Amount of sludge that is sent to incineration (dry weight)
wwt_temp_inc	Fluidized Bed Reactor Temperature	Input	--	K	Incineration temperature
wwt_mass_slu_app	Sludge sent to land application (dry weight)	Input	--	kg	Amount of sludge that is sent to land application (dry weight)
wwt_soil_typ	Soil typology	Input	--	Soil type	Soil typology the sludge is applied on
wwt_mass_slu_land	Sludge sent to landfilling (dry weight)	Input	--	kg	Amount of sludge that is sent to landfilling (dry weight)
wwt_slu_type	Disposal type	Input	--	Disposal type	Disposal type

Annex N Detailed GHG assessment – Wastewater Treatment - Inputs

Code	Name	Type	Formula	Unit	Description
wwt_mass_slu_stock	Sludge stockpiled (dry weight)	Input	--	kg	Amount of sludge that is stockpiled (dry weight)
wwt_trck_typ	Fuel type (Trucks)	Input	--	Fuel type	Fuel type (Trucks)
c_wwt_nrg_biog	Total energy content of biogas valorized	Input/output	--	kWh	Sum of energy content of biogas used in a cogenerator or a boiler during the assessment period by all wastewater treatment plants managed by the undertaking
wwt_vol_tslu	Volume of fuel consumed (trucks)	Input	--	L	Volume of fuel consumed (trucks)
wwt_GHG_tre_n2o	N2O emissions from treatment process correction factor	Input	-	kg	ECAM uses a generic emissions factor from IPCC to calculate N2O emissions. If you have more accurate values of N2O emissions you can add the positive or negative difference to calculated value to adapt the result.

Annex O Detailed GHG assessment – Wastewater Treatment - Outputs

Code	Name	Type	Formula	Unit	Description(*Reference values*)
c_wwt_bod_rmvd	BOD5 mass removed	Output	wwt_bod_infl-wwt_bod_effl	kg	This is calculated from the difference in BOD mass from the influent with BOD mass from the effluent over the assessment period.
wwt_KPI_nrg_per_m3	Energy consumption per treated wastewater	Output	wwt_nrg_cons/wwt_vol_trea	kWh/m^3	Energy consumption per treated wastewater ***TF or aerated lagoons*** ***-*** *Good: ECTWW ≤ 0.185 + 1127/ TW;Acceptable: 0.185 + 1127/TW < ECTWW < 0.231 + 1409/TW; Unsatisfactory: ECTWW ≥ 0.231 + 1409/TW* ***AS*** *- Good: ECTWW ≤ 0.280 + 1192/TW;* *-Acceptable: 0.280 + 1192/TW < ECTWW < 0.350 + 1490/TW; Unsatisfactory: ECTWW ≥ 0.350 + 1490/TW* ***AS + C/F*** *- Good: ECTWW ≤ 0.325 + 1384/TW; Acceptable: 0.325 + 1384/TW < ECTWW < 0.406 + 1730/TW;* *-Unsatisfactory: ECTWW ≥ 0.406 + 1730/TW* ***AS w/ nitrification + C/F*** *- Good: ECTWW ≤ 0.424 + 1362/TW; Acceptable: 0.424 + 1362/TW < ECTWW < 0.530 + 1703/TW; Unsatisfactory: ECTWW ≥ 0.530 + 1703/TW* *note: TW = Treated wastewater (m3/d)*
wwt_KPI_nrg_per_kg*	Energy consumption per BOD_5 mass removed	Output	wwt_nrg_cons/c_wwt_bod_rmvd	kWh/Kg BOD removed	Unit energy consumption per BOD mass removed in wastewater treatment plant(*ECMR*) *Good: ECMR ≤ 2* *Acceptable: 2 < ECMR ≤ 10* *Unsatisfactory: ECMR > 10*
ww_SL_vol_pday	Treated wastewater per person per day	Output	1000 * wwt_vol_trea/wwt_serv_pop/Days	L/serv.pop./day	Volume of treated wastewater per serviced person in the service area managed by the undertaking divided by the duration of the assessment period

Annex O Detailed GHG assessment – Wastewater Treatment - Outputs

Code	Name	Type	Formula	Unit	Description(**Reference values*)
wwt_KPI_GHG_elec	Electricity	Output	wwt_nrg_cons * conv_kwh_co2	kg CO_2eq	GHG emissions from electricity
wwt_KPI_GHG_tre_ch4	CH_4 from treatment process	Output	(wwt_bod_infl-wwt_bod_slud-wwt_bod_effl) * wwt_ch4_efac * ct_ch4_eq	kg CO_2eq	Methane (CO_2eq) emitted in wastewater treatment plants
wwt_KPI_GHG_tre_n2o	N_2O from treatment process	Output	ActiveStages.wasteTre * wwt_serv_pop * ct_fac_ic * ct_n2o_efp * Years * 1e-3 * ct_n2o_eq + wwt_GHG_tre_n2o	kg CO_2eq	N_2O (CO_2 eq) emitted in wastewater treatment plants. Eq 6.9 2006 IPCC Guidelines for National Greenhouse Gas Inventories
wwt_KPI_GHG_tre	Treatment process	Output	wwt_KPI_GHG_tre_ch4 + wwt_KPI_GHG_tre_n2o	kg CO2eq	From treatment process (CH4+N2O)
wwt_KPI_GHG	Total GHG Wastewater Treatment		wwt_KPI_GHG_elec + wwt_KPI_GHG_fuel + wwt_KPI_GHG_tre + wwt_KPI_GHG_dig_fuel + wwt_KPI_GHG_biog + wwt_KPI_GHG_slu;	kg CO2eq	Total GHG Wastewater Treatment
wwt_KPI_GHG_fuel	Fuel engines (total emissions)	Output	wwt_KPI_GHG_fuel_co2 + wwt_KPI_GHG_fuel_n2o + wwt_KPI_GHG_fuel_ch4	kg CO_2e	Direct CO_2e emitted from on-site engines in wastewater stages based upon sum of CO_2, CH_4 and N_2O emission from stationary combustion
wwt_KPI_biog_x_bod	Biogas produced per mass removed	Output	wwt_biog_pro/c_wwt_bod_rmvd	Nm^3/kg	Unit energy production per treated wastewater in wastewater treatment plants
wwt_KPI_GHG_dig_fuel	Fuel employed for digester	Output	wwt_KPI_GHG_dig_fuel_co2 + wwt_KPI_GHG_dig_fuel_n2o + wwt_KPI_GHG_dig_fuel_ch4	kg CO_2eq	Amount of CO_2 eq emissions due to fuel employed for digester (CO_2+N_2O+CH_4)
wwt_KPI_GHG_biog	Biogas	Output	(wwt_biog_pro-wwt_biog_val-wwt_biog_fla + wwt_biog_fla *	kg CO_2eq	GHG emissions from biogas

Annex O Detailed GHG assessment – Wastewater Treatment - Outputs

Code	Name	Type	Formula	Unit	Description(*Reference values*)
			ct_ch4_lo/100) * wwt_ch4_biog/100 * ct_ch4_m3 * ct_ch4_eq		
c_wwt_nrg_biog	Total energy content of biogas valorized	Output	wwt_biog_val * wwt_ch4_biog/100 * ct_ch4_nrg	kWh	Sum of energy content of biogas used in a cogenerator or a boiler during the assessment period by all wastewater treatment plants managed by the undertaking
wwt_KPI_nrg_biogas	Energy production per treated wastewater	Output	wwt_nrg_biog/wwt_vol_trea	kWh/m^3	Energy production from biogas valorization per volume of treated wastewater *Good: EPMR ≥ 0.0009 BOD_5* *Acceptable: 0.0009 BOD_5 > EPMR ≥ 0.0007 BOD_5* *Unsatisfactory: EPMR < 0.0007 BOD_5* *<u>note:</u> BOD_5 = influent BOD (mg/L)*
wwt_KPI_nrg_x_biog	Electrical energy produced per total available energy in biogas	Output	100 * wwt_nrg_biog/c_wwt_nrg_biog	%	Unit biogas produced per BOD mass removed in wastewater treatment plants *EEEB <15%= Unsatisfactory* *15 to 25% = acceptable* *EEEB >25%= good*
wwt_SL_GHG_avoided	GHG emissions avoided due to biogas valorization	Output	wwt_nrg_biog * conv_kwh_co2	kg CO2eq	GHG emissions avoided due to biogas valorization
wwt_KPI_capac_util	Capacity utilization	Output	100 * wwt_vol_trea/wwt_trea_cap	%	Percentage of dry weight of sludge that comes out from the WWTP to disposal *Good: 95 ≤ CUWT ≤ 70* *Acceptable:100 ≤ CUWT < 95 and 70 < CUWT ≤ 50*

Annex O Detailed GHG assessment – Wastewater Treatment - Outputs

Code	Name	Type	Formula	Unit	Description(*Reference values*)
					Unsatisfactory: CUWT > 100 and CUWT < 50
wwt_SL_qual_com	Percentage of quality compliance	Output	100 * wwt_tst_cmpl/wwt_tst_cond	%	Percentage of water quality tests carried out in wastewater treatment plants that comply with discharge consents
wwt_KPI_nrg_per_pump	Energy consumption for wastewater pumping to treatment	Output	wwt_nrg_pump/wwt_vol_pump	kWh/m^3	Energy consumption for wastewater pumping to treatment
wwt_KPI_std_nrg_cons	Standardized Energy Consumption pumping	Output	(wwt_nrg_pump)/(wwt_vol_pump * wwt_pmp_head/100)	$kWh/m^3/100m$	Standardized Energy Consumption pumping
wwt_KPI_sludg_prod	Sludge production (total weight)	Output	wwt_mass_slu/wwt_vol_trea	kg/m^3	Sludge production per treated wastewater *Good : SP ≤ 0.8* *Acceptable: 0.8 < SP ≤ 1.5* *Unsatisfactory: SP > 1.5*
wwt_KPI_dry_sludge	Dry weight in sludge production	Output	100 * wwt_dryw_slu/wwt_mass_slu	% DW	Unit sludge production per treated wastewater in wastewater treatment plants(*DSP*) *Good: DSP ≥ 20* *Acceptable: 20 < DSP ≤ 12* *Unsatisfactory: DSP < 12*
wwt_KPI_GHG_slu	Sludge management	Output	wwt_KPI_ghg_sto_co2eq + wwt_KPI_ghg_comp_co2eq + wwt_KPI_ghg_inc_co2eq +	kg CO_2 eq	GHG emissions from sludge management operations (storing, composting, incineration, land application, landfilling, stockpiling and truck transport)

Annex O Detailed GHG assessment – Wastewater Treatment - Outputs

Code	Name	Type	Formula	Unit	Description(*Reference values*)
			wwt_KPI_ghg_app_co2eq + wwt_KPI_ghg_land_co2eq + wwt_KPI_ghg_stock_co2eq + wwt_KPI_ghg_tsludge + 0		
wwt_wr_C_seq_slu	GHG emissions avoided due to carbon sequestration from sludge management	Output	wwt_slu_comp_C_seq + wwt_slu_app_C_seq + wwt_slu_land_C_seq;	kg CO2e	GHG emissions avoided due to carbon sequestration from sludge management

c_wwt_ch4_pot	Methane potential	Inout/Output	if(sludge_type=="Non-digested"){
			wwt_mass_slu_sto * 0.65 * 0.70 * 0.56 * (4/3)
			}else if(sludge_type=="Digested"){
			wwt_mass_slu_sto * 0.65 * 0.51 * 0.56 * (4/3)
			}else{0}
				kg CH_4	Maximum methane emission potential for sludge stored

wwt_slu_storage_ch4	CH_4 emissions due to sludge storage	Output	f=0;# 'f' is 3% or 5% of methane potential depending on time sludge is stored if(5 * day < wwt_time_slu_sto && wwt_time_slu_sto < 20 * day) {f=0.03} else if(wwt_time_slu_sto >= 20 * day) {f=0.05} f * c_wwt_ch4_pot * ct_ch4_eq;	kg CO_2 eq	Amount of CH4 emissions due to sludge storage

Annex O Detailed GHG assessment – Wastewater Treatment - Outputs

Code	Name	Type	Formula	Unit	Description(**Reference values*)
wwt_KPI_ghg_sto_co2eq	Total CO2 eq from sludge storage	Output	wwt_slu_storage_ch4	kg CO_2 eq	Amount of CO2,eq emissions related to sludge storage
wwt_slu_composting_ch4	CH_4 emissions due to sludge composting	Output	sludge_type=="Non-digested") {wwt_mass_slu_comp * 0.56 * 0.7 * 0.56 * 0.7 * wwt_mass_slu_comp * 0.025 * 1.3 * ct_ch4_eq} else if(sludge_type=="Digested") {wwt_mass_slu_comp * 0.56 * 0.51 * 0.025 * 1.3 * ct_ch4_eq} else{0}	kg CO_2 eq	Amount of CH_4 emissions due to sludge composting
wwt_slu_composting_n2o	N_2O emissions due to sludge composted	Output	wwt_mass_slu_comp * 0.03 * 0.015 * ct_n2o_co * ct_n2o_eq	kg CO_2 eq	Amount of N_2O emissions due to sludge composted
wwt_KPI_ghg_comp_co2eq	Total CO_2,eq emissions due to sludge composted	Output	wwt_slu_composting_ch4 + wwt_slu_composting_n2o	kg CO_2 eq	Amount of CO_2,eq emissions due to sludge composted
wwt_slu_comp_C_seq	GHG emissions avoided due to carbon sequestration	Output	wwt_mass_slu_comp * ct_C_seqst	kg CO_2 eq	GHG emissions avoided due to carbon sequestration in sludge composting

Annex O Detailed GHG assessment – Wastewater Treatment - Outputs

Code	Name	Type	Formula	Unit	Description(*Reference values*)
	in sludge composting				
wwt_slu_inciner_ch4	CH_4 emissions due to sludge incinerated	Output	(4.85/1e5) * wwt_mass_slu_inc * ct_ch4_eq	kg CO_2 eq	Amount of CH_4 emissions due to sludge incinerated

wwt_slu_inciner_n2o	N_2O emissions due to sludge incinerated	Output	if(wwt_temp_inc > 1152)
			{0}
			else
			{0.03 * wwt_mass_slu_inc * (161.3-0.14 * Math.max(1023,wwt_temp_inc)) * 0.01 * 1.57 * ct_n2o_eq}
				kg CO_2 eq	Amount of N_2O emissions due to sludge incinerated

wwt_KPI_ghg_inc_co2eq	Total CO2,eq emissions due to sludge incineration	Output	wwt_slu_inciner_ch4 + wwt_slu_inciner_n2o	kg CO_2 eq	Amount of CO2,eq emissions due to sludge incineration

wwt_slu_landapp_n2o	N_2O emissions due to sludge for land application	Output	if(sludge_type=="Non-digested")
			if(soil_type=="Fine-Textured" & ratio_CN < 30){wwt_mass_slu_app * 0.03 * 0.023 * 44/28 * ct_n2o_eq}
			if(soil_type=="Coarse-Textured" & ratio_CN < 30){wwt_mass_slu_app * 0.03 * 0.005 * 44/28 * ct_n2o_eq}
				kg CO_2 eq	Amount of N_2O emissions due to sludge applied to land

Annex O Detailed GHG assessment – Wastewater Treatment - Outputs

Code	Name	Type	Formula	Unit	Description(**Reference values*)
			if(sludge_type=="Digested") if(soil_type=="Fine-Textured" & ratio_CN < 30){wwt_mass_slu_app * 0.04 * 0.023 * 44/28 * ct_n2o_eq} if(soil_type=="Coarse-Textured" & ratio_CN < 30){wwt_mass_slu_app * 0.04 * 0.005 * 44/28 * ct_n2o_eq} else{0}		
wwt_KPI_ghg_app_co2eq	Total CO_2,eq emissions due to land application of sludge	Output	wwt_slu_landapp_n2o	kg CO_2 eq	Amount of CO_2,eq emissions due to land application of sludge
wwt_slu_app_C_seq	GHG emissions avoided due to carbon sequestration in sludge land application	Output	wwt_mass_slu_app * ct_C_seqst	kg CO2 eq	GHG emissions avoided due to carbon sequestration in sludge land application
wwt_slu_landfill_ch4	CH_4 emissions due to sludge for landfilling	Output	if(sludge_type="Non-digested"){ wwt_mass_slu_land * 0.56 * 0.70 * 0.9 * 1.3 * 0.5 * 0.8 * 0.69 * ct_ch4_eq else if(sludge_type="Digested"){	kg CO_2 eq	Amount of CH_4 emissions due to sludge applied to landfill

Annex O Detailed GHG assessment – Wastewater Treatment - Outputs

Code	Name	Type	Formula	Unit	Description(*Reference values*)
			wwt_mass_slu_land * 0.56 * 0.51 * 0.9 * 1.3 * 0.5 * 0.8 * 0.70 * ct_ch4_eq else{0}		
wwt_slu_landfill_n2o	N_2O emissions due to sludge for landfilling	Output	if(ratio_CN>30) {0} else if(sludge_type="Non-digested") { wwt_mass_slu_land * 0.03 * 0.015 * 1.57 * ct_n2o_eq if(sludge_type="Digested") {wwt_mass_slu_land * 0.04 * 0.015 * 1.57 * ct_n2o_eq	kg CO_2 eq	Amount of N_2O emissions due to sludge applied to landfill
wwt_KPI_ghg_land_co2eq	Total CO_2,eq emissions due to landfilling of sludge	Output	wwt_slu_landfill_ch4 + wwt_slu_landfill_n2o if(sludge_type=="Landfill (flaring)"){ 0.02 * (wwt_slu_landfill_ch4 + wwt_slu_landfill_n2o) if(sludge_type=="Landfill (with gas recovery)") {0}	kg CO_2 eq	Amount of CO_2,eq emissions due to landfilling of sludge
wwt_slu_land_C_seq	GHG emissions avoided due to carbon sequestration		sludge_type=Tables.find('wwt_slu_disp', wwt_slu_disp); VS = (sludge_type=="Digested")? 0.51:0.70; wwt_mass_slu_land * (VS) * (0.56) * (0.2) * (44/12);	kg CO_2 eq	GHG emissions avoided due to carbon sequestration in sludge landfilling

Annex O Detailed GHG assessment – Wastewater Treatment - Outputs

Code	Name	Type	Formula	Unit	Description(**Reference values*)
	in sludge landfilling				
wwt_KPI_ghg_stock_co2eq	Total CO_2,eq emissions due to sludge stockpiling	Output	wwt_mass_slu_stock * 90.3 * 1e-3	kg CO_2 eq	Amount of CO_2,eq emissions due to sludge stockpiling. Emissions due to stockpiling only refer to the first year
wwt_KPI_ghg_tsludge	Sludge transport	Output	wwt_KPI_ghg_tsludge_co2 + wwt_KPI_ghg_tsludge_n2o + wwt_KPI_ghg_tsludge_ch4	kg CO_2 eq	Indirect CO_2e emitted from sludge transport off-site. Based upon sum of CO_2, CH_4 and N_2O emission from mobile combustion. The fuel consumption is calculated assuming 2 times distance to disposal site (round tryp) time the number of trips times an average diesel consumption of 25 L per 100 km
wwt_KPI_std_elec_eff	Calculated existing electromechanical efficiency of current pump	Output	100 * 0.2725/wwt_KPI_std_nrg_cons	%	Calculated existing electromechanical efficiency of current pump

Annex P Detailed GHG assessment – Wastewater Discharge/Reuse - Inputs

Code	Name	Type	Formula	Unit	Description
wwd_nrg_cons	Energy consumed from the grid	Input	--	kWh	Sum of energy consumed (from the grid or self-produced) during the assessment period by all each pumping stations for discharged wastewater managed by the undertaking
wwd_vol_disc	Volume of discharged wastewater to water body	Input	--	m^3	Volume of wastewater discharged by each wastewater treatment plant that are the responsibility of the undertaking, during the assessment period. This includes all the wastewater collected, whether it is conveyed to treatment or discharged untreated
wwd_bod_effl	Effluent BOD load	Input	-	kg	Effluent BOD load
wwd_n2o_effl	Total Nitrogen concentration in the effluent	Input	--	mg/L	Total Nitrogen concentration in the effluent during the assessment period
wwd_ch4_efac	CH_4 emission factor	Input	-	mg/L	CH_4 emission factor
wwd_vol_nonp	Volume of reused effluent	Input	--	m^3	Volume of reused effluent

Annex P Detailed GHG assessment – Wastewater Discharge/Reuse - Inputs

Code	Name	Type	Formula	Unit	Description
wwd_fuel_typ	Fuel type	Input	--	Fuel type	Fuel type
wwd_vol_fuel	Volume of fuel consumed	Input	--	L	Volume of fuel consumed
wwd_trck_typ	Fuel type (Trucks)	Input	--	Fuel type	Fuel type (Trucks)
wwd_vol_trck	Volume of fuel consumed (Trucks)	Input	--	L	Volume of fuel consumed (Trucks)
wwd_nrg_pump	Energy consumed from the grid (pumping)	Input	--	kWh	Electric energy consumption for pumping
wwd_vol_pump	Pumped volume	Input	--	m^3	Pumped volume
wwd_pmp_head	Head pumped against	Input	--	m	Head pumped against
wwd_wr_N_rec	Total Nitrogen recovered	Input	--	kg	Total Nitrogen recovered from ww treatment and/or water reuse, and displacing fertilizer
wwd_wr_P_rec	Total Phosphorus recovered	Input	--	kg	Total Phosphorus recovered from ww treatment and/or water reuse, and displacing fertilizer
wwd_wr_adnrg	Additional energy consumption	Input	--	kWh	Additional energy consumption for reuse treatment and/or pumping

Annex P Detailed GHG assessment – Wastewater Discharge/Reuse - Inputs

Code	Name	Type	Formula	Unit	Description
wwd_wr_vol_d	Volume of reused water displacing potable water	Input	--	m^3	Volume of reused water displacing potable water
wwd_reus_typ	Type of reuse	Input	--	Discharge/Reuse type	Type of reuse/discharge

Annex Q Detailed GHG assessment – Wastewater Discharge/Reuse - Outputs

Code	Name	Type	Formula	Unit	Description (**Reference values*)
wwd_KPI_nrg_per_m3	Energy consumption per discharged/reused wastewater	Output	wwd_nrg_cons/wwd_vol_disc	kWh/m^3	Unit energy consumption per discharged water
wwd_KPI_GHG_elec	Electricity	Output	wwd_nrg_cons * conv_kwh_co2	kg CO_2eq	GHG from electricity
wwd_KPI_GHG_tre	Effluent discharge	Output	wwd_KPI_GHG_tre_ch4 + wwd_KPI_GHG_tre_n2o	kg CO2eq	Effluent discharge

Annex Q Detailed GHG assessment – Wastewater Discharge/Reuse - Outputs

Code	Name	Type	Formula	Unit	Description (**Reference values*)
wwd_total_m3	Total volume discharged and reused effluent	Output	wwd_vol_disc + wwd_vol_nonp	m^3	Total volume discharged and reused effluent
wwd_KPI_GHG	Total GHG Wastewater Discharge /Reuse	Output	wwd_KPI_GHG_elec + wwd_KPI_GHG_fuel + wwd_KPI_GHG_trck + wwd_KPI_GHG_tre	kg CO_2e	Total GHG Wastewater Discharge/Reuse
wwd_KPI_GHG_fuel	Fuel engines (total emissions)	Output	wwd_KPI_GHG_fuel_co2 + wwd_KPI_GHG_fuel_n2o + wwd_KPI_GHG_fuel_ch4	kg CO_2e	Fuel engines (total emissions)
wwd_KPI_GHG_trck	Truck transport	Output	wwd_KPI_GHG_trck_co2 + wwd_KPI_GHG_trck_n2o + wwd_KPI_GHG_trck_ch4	kg CO_2e	Truck transport
wwd_KPI_std_nrg_cons*	Standardized energy consumption	Output	(wwd_nrg_pump)/(wwd_vol_pump * wwd_pmp_head/100)	kWh/m^3/100m	Percentage of energy consumed in wastewater discharged with regards to the Total energy consumed from the grid and self produced in the water and wastewater systems(*SEC*) *Good: 0.2725 ≤ SEC ≤ 0.40* *Acceptable: 0.40 < SEC ≤ 0.54* *Unsatisfactory: SEC > 0.54*
wwd_SL_ghg_non	GHG emissions avoided due to	Output	wwd_n2o_effl/1000 * wwd_vol_nonp * ct_n2o_eq * ct_ef_eff * ct_n2o_co	kg CO_2e	GHG emissions avoided due to water reuse eliminating discharge to water body

Annex Q Detailed GHG assessment – Wastewater Discharge/Reuse - Outputs

Code	Name	Type	Formula	Unit	Description (**Reference values*)
	water reuse eliminating discharge to receiving waters				
wwd_wr_GHG_avo_N	GHG emissions avoided due to Nitrogen reuse	Output	wwd_wr_N_rec * ct_cr_forN	kg CO2e	GHG emissions avoided due to Nitrogen reuse displacing synthetic fertilizer
wwd_wr_GHG_avo_P	GHG emissions avoided due to Phosphorus reuse	Output	wwd_wr_P_rec * ct_cr_forP	kg CO2e	GHG emissions avoided due to Phosphorus reuse displacing synthetic fertilizer
wwd_wr_GHG_avo	GHG emissions avoided due to nutrient reuse displacing synthetic fertilizer	Output	wwd_wr_GHG_avo_N + wwd_wr_GHG_avo_P	kg CO2e	GHG emissions avoided due to nutrient reuse displacing synthetic fertilizer
wwd_wr_GHG_avo_d	GHG emissions avoided due to reuse displacing potable water use	Output	wwd_wr_nrg_sav * conv_kwh_co2	kg CO2e	GHG emissions avoided due to reuse displacing potable water use
wwd_wr_nrg_sav	Net electricity savings due to reuse displacing potable water	Output	wwd_wr_vol_d * (wsa_nrg_per_abs_watr + wst_KPI_nrg_per_m3 + wsd_KPI_nrg_per_vd)-wwd_wr_adnrg	kWh	Net electricity savings due to reuse displacing potable water

Annex Q Detailed GHG assessment – Wastewater Discharge/Reuse - Outputs

Code	Name	Type	Formula	Unit	Description (**Reference values*)
wwd_KPI_GHG_tre_n2o	Indirect GHG from discharge to water body	Output	wwd_n2o_effl/1000 * wwd_vol_disc * ct_n2o_eq * ct_ef_eff * ct_n2o_co	kg CO_2e	Indirect CO2e emitted in receiving waters due to nitrogen in wastewater effluent. Based upon nitrogen in the WWTP effluent multiplied by default emission factor

*Performance indicators with reference values under the description

Annex R Tier A – Faecal Sludge Management – Inputs

Code	Name	Type	Formula	Unit	Description
fs_resi_pop	Resident population	Input	--	People	Resident population (FSM)
fs_onsi_pop	Population with onsite treatment	Input	--	People	Population with onsite treatment
fs_vol_trck	Volume of fuel consumed (transport)	Input/output	fsc_vol_trck + fst_vol_trck + fsr_vol_trck	L	Volume of fuel consumed (transport)
fsc_cont_emp	Containments emptied	Input	--	&	Fraction of produced faecal sludge that is emptied from containments during the assessment period. If only partial emptying is done it should be reflected in the fraction.

Annex S Detailed GHG assessment – Containment Faecal Sludge Management – Inputs

Code	Name	Type	Formula	Unit	Description
fsc_bod_infl	Influent BOD load	Input	--	kg	BOD load entering the containment before any treatment. It can be estimated from the population
fsc_ch4_efac	CH_4 emission factor	Input	--	$kgCH_4/kgBOD$	Methane emission factor for the containment technology of faecal sludge
fsc_cont_emp	Containments emptied	Input	--	%	Fraction of produced faecal sludge that is emptied from containments during the assessment period. If only partial emptying is done, it should be reflected in the fraction.
fsc_fdensity	Faecal sludge density	Input	--	kg/m^3	Faecal sludge density
fsc_fslu_emp	Faecal sludge emptied	Input/Output	ct_fs_prod * fs_onsi_pop * Days/fsc_fdensity * fsc_cont_emp/100	m^3	Volume of faecal sludge emptied from the containment
fsc_bod_rmvd	BOD removed as faecal sludge	Input/Output	fsc_fslu_emp * fsc_bod_conc_fs	kg	Total BOD that is removed from the containment technology. It can be estimated from the volume or the mass of FS emptied and standard BOD content.
fsc_nrg_cons	Energy consumed from the grid	Input	--	kWh	Energy consumed from the grid
fsc_trck_typ	Fuel type	Input	--	--	Fuel type (trucks)
fsc_vol_trck	Volume of fuel consumed (trucks)	Input	--	L	Volume of fuel consumed (trucks)

Annex T Detailed GHG assessment – Containment Faecal Sludge Management – Outputs

Code	Name	Type	Formula	Unit	Description
fsc_KPI_GHG_elec	Electricity	Output	fsc_nrg_cons * conv_kwh_co2	kg CO_2e	GHG Electricity
fsc_KPI_GHG_cont	Methane emissions	Output	(fsc_bod_infl-fsc_bod_rmvd) * fsc_ch4_efac * ct_ch4_eq	kg CO_2e	GHG Transport
fsc_KPI_GHG_trck	Transport	Output	fsc_KPI_GHG_trck_co2 + fsc_KPI_GHG_trck_n2o + fsc_KPI_GHG_trck_ch4	kg CO_2e	GHG Transport
fsc_bod_rmvd	Total GHG Faecal Sludge Containment	Output	fsc_KPI_GHG_elec + fsc_KPI_GHG_cont + fsc_KPI_GHG_trck	kg CO_2e	Total GHG in FSM Containment

Annex U Detailed GHG assessment – Treatment Faecal Sludge Management – Inputs

Code	Name	Type	Formula	Unit	Description
fst_nrg_cons	Energy consumed from the grid	Input	--	kWh	Energy consumed from the grid
fst_ch4_efac	CH_4 emission factor	Input	--	$kgCH_4/kgBOD$	Methane emission factor for the treatment technology of faecal sludge
fst_bod_infl	Influent BOD load	Input	--	kg	BOD loading entering the treatment
fsc_fslu_emp	Effluent BOD load	Input/Output	0.10 * fst_bod_infl	kg	BOD load at the effluent of the treatment
fst_bod_slud	BOD removed with excess sludge	Input	--	kg	BOD removed with excess sludge from the treatment process.
fst_trck_typ	Fuel type	Input	--	--	Fuel type (trucks)
fst_vol_trck	Volume of fuel consumed (trucks)	Input	--	L	Volume of fuel consumed (trucks)
fst_biog_pro	Biogas produced	Input	--	m^3	Biogas produced during the assessment period by each faecal sludge treatment plant managed by the undertaking
fst_biog_val	Biogas valorized	Input	--	m^3	Biogas valorized in the treatment plant, for example to heat the digesters or the building and/or to run a Co-generator to generate heat and electricity
fst_biog_fla	Biogas flared	Input	--	m^3	Biogas flared refers to the biogas that is combusted by flare gas systems without electricity or heat valorisation

Annex U Detailed GHG assessment – Treatment Faecal Sludge Management – Inputs

fst_ch4_biog	Percentage of methane in biogas	Input	--	%	Percentage of methane in biogas
fst_nrg_biog	Electrical energy produced from biogas valorization	Input	--	kWh	Electrical energy produced from biogas valorization

Annex V Detailed GHG assessment – Treatment Faecal Sludge Management – Outputs

Code	**Name**	**Type**	**Formula**	**Unit**	**Description**
fst_KPI_GHG_elec	Electricity	Output	fst_nrg_cons * conv_kwh_co2	kg CO_2e	GHG emissions from electricity use
fst_KPI_GHG_tre_ch4	CH_4 from treatment process	Output	(fst_bod_infl-fst_bod_slud-fst_bod_effl) * fst_ch4_efac * ct_ch4_eq	kg CO_2e	Methane (CO2 eq) emitted in wastewater treatment plants
fst_KPI_GHG_tre_n2o	N_2O from treatment process	Output	--	kg CO_2e	N2O (CO2 eq) emitted in wastewater treatment plants. Eq 6.9 2006 IPCC Guidelines for National Greenhouse Gas Inventories
fst_KPI_GHG_tre	Treatment process	Output	fst_KPI_GHG_tre_ch4 + fst_KPI_GHG_tre_n2o;	kg CO_2e	GHG emissions from treatment process (CH_4+N_2O)
fst_KPI_GHG	Total GHG in Faecal Sludge Treatment	Output	fst_KPI_GHG_elec + fst_KPI_GHG_trck + fst_KPI_GHG_biog +	kg CO_2e	Total GHG Faecal sludge Treatment

Annex V Detailed GHG assessment – Treatment Faecal Sludge Management – Outputs

			fst_KPI_GHG_fuel + fst_KPI_GHG_tre		
fst_KPI_GHG_trck	Transport	Output	fst_KPI_GHG_trck_co2 + fst_KPI_GHG_trck_n2o + fst_KPI_GHG_trck_ch4	kg CO_2e	Transport
fst_KPI_GHG_biog	Biogas	Output	fst_biog_pro-fst_biog_val-fst_biog_fla + fst_biog_fla * ct_ch4_lo/100) * fst_ch4_biog/100 * ct_ch4_m3 * ct_ch4_eq	kg CO_2e	GHG emissions from biogas
fst_SL_GHG_avoided	GHG emissions avoided due to biogas valorization	Output	fst_nrg_biog * conv_kwh_co2	kg CO_2e	GHG emissions avoided due to biogas valorisation

Annex W Detailed GHG assessment –Reuse/Disposal Faecal Sludge Management – Inputs

Code	Name	Type	Formula	Unit	Description
fsr_nrg_cons	Energy consumed from the grid	Input	--	kWh	Energy consumed from the grid
fsr_vol_disc	Volume of discharged effluent to water body	Input	--	m^3	Volume of discharged effluent to water body
fsr_n2o_effl	Total Nitrogen load in the effluent uent BOD load	Input	--	mg/L	Total Nitrogen load in the effluent
fsr_bod_effl	Effluent BOD load	Input	--	kg	Effluent BOD load
fsr_ch4_efac	CH_4 emission factor	Input	--	$kgCH_4/kgBOD$	CH_4 emission factor (effluent discharge)
fsr_trck_typ	Fuel type	Input	--	--	Fuel type (trucks)
fsr_vol_trck	Volume of fuel consumed	Input	--	L	Volume of fuel consumed (trucks)
fsr_fslu_typ_lf	Type of faecal sludge disposed	Input	--	Type of FS	Type of faecal sludge disposed
fsr_mass_landfil	Dry weight sent to landfill	Input/output	fsc_fslu_emp * fsc_fdensity * total_solids	kg	Dry weight sent to landfill
fsr_lf_N_cont	Total Nitrogen (% of dry weight)	Input	--	%	Total Nitrogen (% of dry weight)

Annex W Detailed GHG assessment –Reuse/Disposal Faecal Sludge Management – Inputs

fsr_lf_TVS	Total Volatile Solids (% of dry weight)	Input	--	%	Total Volatile Solids (% of dry weight)
fsr_disp_typ	Landfill type	Input	--	Disposal type	Type of the landfilling
fsr_fslu_typ_la	Type of faecal sludge disposed	Input	--	Type of FS	Type of (faecal) sludge sent to land application
fsr_mass_landapp	Dry weight sent to land application	Input/output	fsc_fslu_emp * fsc_fdensity * total_solids	kg	Amount of (faecal) sludge that is sent to land application (dry weight)
fsr_la_N_cont	Total Nitrogen (% of dry weight)	Input	--	%	Total Nitrogen (% of dry weight)
fsr_soil_typ	Soil type	Input	--	Soil type	Soil typology the sludge is applied on. Note: if you don't know the soil typology, leave it as 'Fine-textured'
fsr_vol_dumping	Volume dumped	Input/output	fsc_fslu_emp	m^3	The volume of faecal sludge dumped
fsr_ch4_efac_dumping	CH_4 emission factor	Input	--	$kgCH_4/kgBOD$	Methane emission factor for faecal sludge dumping
fsr_bod_conc_fs	BOD concentration of faecal sludge	Input	--	kg/m^3	BOD concentration of faecal sludge
fsr_N_urine	Total Nitrogen in urine applied to land	Input	--	kg	Total Nitrogen in urine applied to land
fsr_reused_N	Total Nitrogen reused that displaces synthetic fertilizer	Input	--	kg	Total Nitrogen reused that displaces synthetic fertilizer
fsr_reused_P	Total Phosphorus reused that displaces synthetic fertilizer	Input	--	kg	Total Phosphorus reused that displaces synthetic fertilizer

Annex X Detailed GHG assessment – Treatment Faecal Sludge Management – Outputs

Code	Name	Type	Formula	Unit	Description
fsr_KPI_GHG_elec	Electricity	Output	fsr_nrg_cons * conv_kwh_co2	kg CO_2e	GHG emissions from electricity use
fsr_KPI_GHG	Total emissions Faecal Sludge Reuse/Disposal	Output	fsr_KPI_GHG_elec + fsr_KPI_GHG_fuel + fsr_KPI_GHG_trck + fsr_KPI_GHG_landapp + fsr_KPI_GHG_landfil + fsr_KPI_GHG_dumping + fsr_KPI_GHG_tre + fsr_KPI_GHG_urine	kg CO_2e	Total emissions Faecal Sludge Reuse/Disposal
fsr_ghg_avoided_land	GHG emissions avoided due to carbon sequestration	Output	fsr_ghg_avoided_landapp + fsr_ghg_avoided_landfil	kg CO_2e	GHG emissions avoided due to carbon sequestration
fsr_KPI_GHG_tre	Effluent discharge	Output	fsr_KPI_GHG_tre_ch4 + fsr_KPI_GHG_tre_n2o	kg CO_2e	Effluent discharge
fsr_KPI_GHG_trck	Transport	Output	fsr_KPI_GHG_trck_co2 + fsr_KPI_GHG_trck_n2o + fsr_KPI_GHG_trck_ch4	kg CO_2e	Transport
fsr_KPI_GHG_landfil_ch4	Landfilling (CH_4)		fsr_mass_landfil * fsr_lf_TVS/100 * ct_oc_vs * ct_DOCfra/100 * ct_lf_unc * ct_ch4_C * ct_ch4_lf/100 * ct_d3y_lf/100 * ct_ch4_eq;	kg CO_2e	Amount of CO2,eq emissions due to CH4 emission from (faecal) sludge applied to landfill

Annex X Detailed GHG assessment – Treatment Faecal Sludge Management – Outputs

fsr_KPI_GHG_landfil_n2o	Landfilling (N_2O)	Output	fsr_mass_landfil * fsr_lf_N_cont/100 * ct_n2o_lf/100 * ct_n2o_co * ct_n2o_eq	kg CO_2e	Amount of CO2,eq emissions due to N_2O emission from (faecal) sludge applied to landfill
fsr_KPI_GHG_landfil	Landfilling	Output	fsr_KPI_GHG_landfil_n2o + fsr_KPI_GHG_landfil_ch4	kg CO_2e	Total GHG from (faecal) sludge sent to landfilling
fsr_ghg_avoided_landfil	GHG emissions avoided from carbon sequestration of landfilling	Output	fsr_mass_landfil * TVS * ct_oc_vs * ct_u_org_f * ct_co2_C;	kg CO_2e	GHG emissions avoided from carbon sequestration of landfilling
fsr_KPI_GHG_landapp	Land Application	Output	fsr_mass_landapp * fsr_la_N_cont/100 * N_transformed_to_N2O * ct_n2o_co * ct_n2o_eq	kg CO_2e	Amount of CO_2,eq emissions due to N_2O emission from faecal sludge sent to land application
fsr_ghg_avoided_landapp	GHG emissions avoided from carbon sequestration of land application	Output	fsr_mass_landapp * ct_C_seqst	kg CO_2e	GHG emissions avoided from carbon sequestration of land application
fsr_KPI_GHG_dumping_ch4	Dumping (CH_4)	Output	fsr_vol_dumping * fsr_bod_conc_fs * fsr_ch4_efac_dumping * ct_ch4_eq	kg CO_2e	Amount of CO_2,eq emissions due to CH_4 emission from (faecal) sludge dumped
fsr_KPI_GHG_dumping_n2o	Dumping (N_2O)	Output	fsr_vol_dumping * fsr_n2o_effl * ct_ef_eff * ct_n2o_co * ct_n2o_eq	kg CO_2e	Amount of CO_2,eq emissions due to N_2O emission from (faecal) sludge dumped
fsr_KPI_GHG_dumping	Dumping	Output	fsr_KPI_GHG_dumping_n2o + fsr_KPI_GHG_dumping_ch4	kg CO_2e	Total GHG missions due to (faecal) sludge dumping

Annex X Detailed GHG assessment – Treatment Faecal Sludge Management – Outputs

fsr_KPI_GHG_urine	Urine application	Output	fsr_N_urine * ct_n2o_co * 0.01	kg CO_2e	Amount of CO_2,eq emissions due to N_2O emission from land application of urine
fsr_ghg_avoided_reuse_N	GHG emissions avoided due to Nitrogen reuse	Output	fsr_reused_N * ct_cr_forN	kg CO_2e	GHG emissions avoided due to Nitrogen reuse
fsr_ghg_avoided_reuse_P	GHG emissions avoided due to Phosphorus reuse	Output	fsr_reused_P * ct_cr_forP	kg CO_2e	Amount of CO2,eq emissions avoided due to Phosphorus reuse
fsr_ghg_avoided_reuse	GHG emissions avoided due to nutrient reused displacing synthetic fertilizer	Output	fsr_ghg_avoided_reuse_N + fsr_ghg_avoided_reuse_P	kg CO2e	Amount of CO2,eq emissions avoided due to nutrients reused displacing synthetic fertilizer

Annex Y Useful links

General References	General data bases or guidelines used. IPCC Greenhouse Gas Inventories 1996. First edition in which is based the 2006 Guidelines. (*http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.html*) International Energy Agency *http://www.iea.org/* World Coal Association (Source of energy values, NCV's etc.). (*https://www.worldcoal.org/*)
Benchmarking	*http://www.iwapublishing.com/books/9781843391982/benchmarking-water-services* *http://www.iwawaterwiki.org/xwiki/bin/view/Articles/TheNewIWABenchmarkingFramework* (ISBN13: 9781843391982; eISBN: 9781780400877)
CO_2 EQUIVALENTS	CLIMATE CHANGE 2013 The Physical Science Basis. (*http://www.climatechange2013.org*) (*http://www.ipcc.ch/report/ar5/wg1/*)
Emissions from Sludge management	*http://www.ccme.ca/files/Resources/waste/biosolids/beam_final_report_1432.pdf*
SDG-6	*http://www.undp.org/content/undp/en/home/sustainable-development-goals/goal-6-clean-water-and-sanitation/targets/*
SDG-11	*http://www.undp.org/content/undp/en/home/sustainable-development-goals/goal-11-sustainable-cities-and-communities/targets/*
Supplied Water categories	*http://www.pacificwater.org/_resources/article/files/IWA%20Standard%20Water%20Balance_Water%20Loss%20Task%20Force%20Article%202.pdf*

Published by:

www.wacclim.org

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This project is part of the International Climate Initiative (IKI):
www.international-climate-initiative.com/en

Status
December 2018

The Water and Wastewater Companies for Climate Mitigation (WaCCliM) project, is a joint initiative between the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and the International Water Association (IWA). This project is part of the International Climate Initiative (IKI). The German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) supports this initiative on the basis of a decision adopted by the German Bundestag.

On behalf of:

Federal Ministry
for the Environment, Nature Conservation
and Nuclear Safety

of the Federal Republic of Germany

Implemented by:

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

the international water association