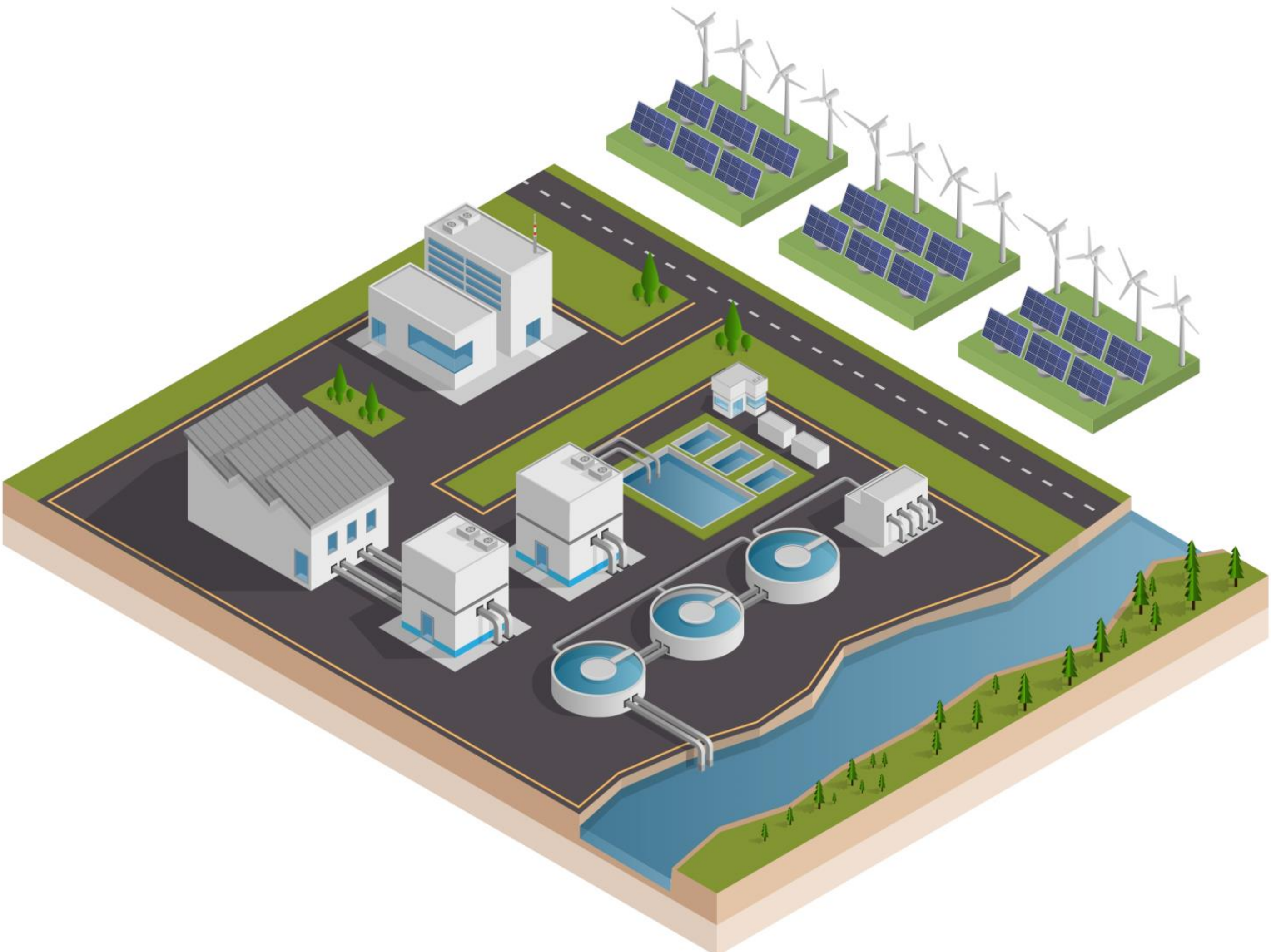
Water and Wastewater Companies for Climate Mitigation

WaCCliM

Methodology for Establishing Baseline Scenarios

in the Urban Water Sector with ECAM



IUWA - Institut für Umweltwirtschaftsanalysen Heidelberg e.V.
Sha Xia · Michael Seyboth · Kevin Fleckenstein · Sophie Gindele

Water and Wastewater Companies for Climate Mitigation – WaCCliM
Adriana Noelia Veizaga Campero · Elaine Cheung

Table of Contents

List of Figures

List of Tables

List of Abbreviations

2030 WRG 2030 Water Resources Group

BAU Business-as-usual

BMU [GER] Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

BOD Biochemical Oxygen Demand

CAGR Compound Annual Growth Rate

CH_4 Methane

CO_2 Carbon dioxide

ECAM Energy Performance and Carbon Emissions Assessment and Monitoring

EDGAR [EU] Emissions Database for Global Atmospheric Research

EF Emission Factor

EPA [US] Environmental Protection Agency

GHG Greenhouse Gas

GWh Gigawatt-hours

GWP Global Warming Potential

IBNET International Benchmarking Network for Water and Sanitation Utilities

IEA International Energy Agency

IKI International Climate Initiative

IMF International Monetary Fund

IPCC Intergovernmental Panel on Climate Change

IWA International Water Association

JMP Joint Monitoring Programme for Water Supply, Sanitation and Hygiene

kWh kilowatt-hour

MRV Measuring, Reporting, and Verification

Mtoe Million tonnes of oil equivalent

N_2O Nitrous oxide

NEPCO [JOR] National Electric Power Company

NRW Non-Revenue Water

OECD Organisation for Economic Co-operation and Development

PEIGE Tool of Projecting ECAM Inputs for GHG Emissions as BAU Scenarios

PPI Producer Price Index

SDG Sustainable Development Goal

TN Total Nitrogen

TOW Total Organics in Wastewater

TWh Terawatt-hours

UN United Nations

UNDESA United Nations Department of Economic and Social Affairs

UNDP United Nations Development Programme

UNESCAP United Nationations Economic and Social Commission for Asia and the Pacific

UNICEF United Nations Children's Fund

UNSD United Nations Statistics Division

WaCCliM Water and Wastewater Companies for Climate Mitigation

WASH drinking water, sanitation and hygiene

WHO World Health Organisation

WWAP World Water Assessment Programme

WWTP Wastewater Treatment Plant

WWU Water and Wastewater Utility

Summary

Climate change poses significant risks to the water and wastewater services provided in human settlements. At the same time, these also hold enormous potential for mitigating climate change. As water is transferred across the urban water cycle to meet the various demands of society, greenhouse gas (GHG) emissions are released directly during the biological degradation of organics in wastewater and indirectly through energy consumption. With the aim of enabling companies, institutions and government agencies to identify reduction potentials, this methodology outlines the path for establishing the business-as-usual (BAU) emission scenarios water and wastewater utilities could exhibit in the mid-term if the current management and practices were to continue.

Based on the physical and biochemical characteristics of the emission pathways in the urban water cycle, key parameters can be identified that determine the direction and magnitude of the variation of GHG emissions. They are primarily the parameters associated with the range of anthropogenic activities that release the emissions. Impacted by various socio-economic and technological drivers, these parameters evolve over time and can be projected based on the trend derived from studies of international and national databases, journal papers, reports and policy documents, which are presented in this methodology.

The approach is created on the basis of the "Energy Performance and Carbon Emissions Assessment and Monitoring" (ECAM) tool of the international project "Water and Wastewater Companies for Climate Mitigation (WaCCliM)". Based on the projected future values of the key parameters, the variables that are necessary to be inputted into ECAM – the ECAM inputs – for the computation of GHG emissions can be quantified for a certain point of time. This step will be facilitated by the "Tool of Projecting ECAM Inputs for GHG Emissions as BAU Scenarios (PEIGE)" in Excel format, which automatically calculates future values once users have entered the required input values.

Applying the established modelling for BAU scenario projections, the pilot utilities of the WaCCliM project demonstrate various aspects of mitigation potentials. The optimisation of energy efficiency and biogas recovery, the promotion of water conservation and the improvement of the wastewater services in the quantity and quality are associated with the most substantial benefits in terms of mitigating climate risks, improving financial performance and implementing the Sustainable Development Goals.

Introduction

Introduction

The water sector is facing enormous challenges. To satisfy soaring demands from the growing number of inhabitants and economic activities, the water industry in many countries is struggling with declining water availability. The pressure caused by population growth, urbanisation, and industrialisation is exacerbated by the various impacts of climate change, which are increasingly observed across the globe [IPCC, 2014a].

At the same time, water and wastewater utilities (WWUs) are also contributors to climate change, estimated to be responsible for 3%-7% of a country's total greenhouse gas (GHG) emissions [IWA, 2015]. In light of stronger water consumption needs in the future, continuing the present trajectory will push the emission level even higher, aggravating the magnitude of expected climate impacts and water stress.

As a guideline for water professionals and decision-makers, this document shall illustrate the steps to establish baseline scenarios of GHG emission development in the urban water cycle, which would arise in the future if no action was taken. The approach is created on the basis of the version 2.2 of the "Energy Performance and Carbon Emissions Assessment and Monitoring" (ECAM) tool of the international project "Water and Wastewater Companies for Climate Mitigation (WaCCliM)", funded through the International Climate Initiative (IKI) of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU).

As the very first of its kind, ECAM allows for a holistic approach of the urban water cycle to drive GHG emission reduction in utilities, even those with limited data availability. It is designed to assess the carbon emissions that WWUs can control and prepares them for future reporting needs for climate mitigation.

Using the ECAM tool, this methodology takes a further step in developing the capabilities of GHG measuring, reporting, and verification (MRV). By identifying the evolution of GHG emissions in the business-as-usual (BAU) condition, it facilitates the exploration of reduction potentials as well as the evaluation of the success of mitigation efforts.

To achieve these objectives, the methodology is organised in simple steps as follows:

- ***Step 1*** outlines the framework of the study, including the examined system of the urban water cycle, the relevant GHGs and their emission pathways.
- ***Step 2*** analyses the driving factors behind the key parameters determining the direction and scope of the development of baseline emissions in the system considered.
- ***Step 3*** describes the collection of data and the projection of the key ECAM inputs based on the effects of driving factors.
- ***Step 4*** explains the calculation pathways of BAU emission scenarios with the ECAM tool.

The approaches quantifying GHG emissions embedded in the ECAM tool and this document are developed in accordance with the 2006 Guidelines for National GHG Inventions of the Intergovernmental Panel on Climate Change (IPCC) [2006].

Baseline emission scenarios

A baseline scenario related to GHG emissions is a reference situation describing an actual or assumed future trajectory of the evolution of GHG emissions in the absence of climate change abatement actions. It shows the level of emissions in the coming decades without intervention measures specifically addressing climate change. Baseline scenarios are established to identify emission reduction potentials of a particular action and the associated costs.

Baseline scenarios are developed under various assumptions of demographic and macroeconomic change, technological development and penetration, resource intensity, climate change impacts and many other aspects. Depending on the assumptions about future events in these areas, the results of baseline scenario concepts could deviate greatly from each other. According to the IPCC [2001], the literature differentiates between several concepts of baselines, including:

- Business-as-usual (BAU) baseline, which assumes that future development trends follow those of the past – i.e. the "no policy change" scenario
- Efficient baseline, which implies the efficient utilisation of all resources

The occurrence of the efficient baseline has the prerequisite of adequately functioning markets that internalise environmental costs to promote the wide-ranging dissemination and application of efficiency-enhancing technologies. This condition is not usually fulfilled in developing and emerging countries, meaning that such techniques are often combined with high investment and operation costs and are not favoured on a large scale [IPCC, 2001]. As such, this methodology applies the concept of BAU scenarios for the estimation of the annual GHG emissions in the urban water cycle.

Methodology development

Methodology development

Step 1: Definition of boundaries and time horizon

In order to explore the future quantity of GHGs released in the urban water cycle as baselines, the first step is to identify the fundamental framework within which the envisaged methodology is developed. To fulfil this task, this step sets the boundary and elements of the urban water cycle considered in this study. Sources and pathways of GHG emissions released in the system, mainly carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), will be then briefly outlined. Finally, the option and time horizon adopted for baseline scenarios must be defined.

Step 2: Identification of the key parameters and driving factors that affect the GHG emission trajectory

To establish baseline scenarios in the urban water cycle, it is necessary to track the essential terms that evolve and characterise the tendency and magnitude of GHG emission variations. These are primarily the parameters associated with the range of anthropogenic activities that release the emissions. In this step, the key parameters and the driving factors behind the key parameters will be introduced and analysed in the context of the global trend. This step varies and adjusts according to each local context and the time frame decided for the scenario establishment.

Step 3: Data collection & projection

Data must be collected preferably from water utilities. To facilitate this step, a tool to Project ECAM Inputs for GHG Emissions as BAU Scenarios (PEIGE) was developed, which projects data based on fixed BAU trends analysed in step 2, nevertheless, the tool should be adjusted and fit to local or utility BAU trends.

Step 4: Development of BAU scenarios using ECAM

Once the data are projected, these will be the input source in ECAM to determine the GHG emissions in any desired time frame. This will then outline the trajectory of GHG emissions to be considered as the BAU scenario.

Figure 1. *Steps to develop BAU scenarios*

Step 1: System boundaries & time horizon

Step 1: System boundaries & time horizon

1.1. System boundary of the urban water cycle

Water moves through the natural hydrologic cycle in the Earth's physical system. In human settlements, water is used intensively to meet the diversified demands of society. Being significantly modified by anthropogenic impacts, water circulation in urban areas covers a broad scope of pathways and components within the natural and human systems as well as between the two [Marsalek et al., 2006].

In studies about anthropogenic GHG emissions resulting from the urban water cycle, the part of human-dominated water circulation is of central interest. It includes water supply, drainage, wastewater collection and management, as well as the beneficial uses of receiving waters [Marsalek et al., 2006].

Along this chain of water conveyance, WWUs play an essential role, interlinking natural water bodies and consumers of human society. Raw water is extracted, purified and distributed to meet end-users' consumption needs without risks to health. Wastewater – or the used water – is collected and treated to minimise impacts on the environment before it is returned to natural waters. During these processes, GHG emissions are released, mainly through energy consumption and biochemical treatment.

In accordance with ECAM, this methodology considers the urban water cycle in a narrow sense, referring to the typical public water and wastewater services[1], especially in urban areas. Six sub-stages, i.e. the abstraction, treatment, and distribution of potable water, as well as the collection, treatment and discharge of wastewater, are examined in detail for the evaluation of associated GHG emissions.

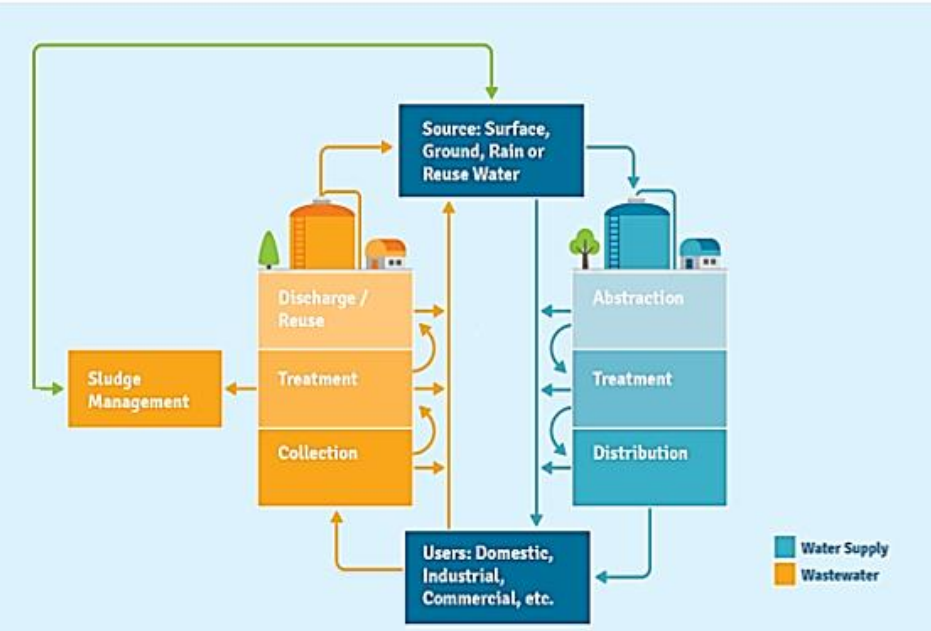


Figure 2. *System boundary.*

Source: Modified from ECAM Methodology Version 2.0.

[1] In the context of public water and wastewater services, domestic water/wastewater and municipal water/wastewater are the most widely used terms that are comparable to each other in many cases. Domestic water/wastewater refers to services supplied to households for drinking, cooking, cleaning, and sanitation. Municipal water/wastewater includes all that is connected to the public distribution network, including households, shops, services, some urban industries, some urban agriculture, etc. FAO (2016), *glossary*.

1.2. Pathways of GHG emissions in the urban water cycle

The main GHGs emitted in the urban water cycle include CO_2, CH_4, and N_2O. Compared regarding the global warming potentials (GWP)[2] over the 100-year horizon, CO_2 accounts for the majority of the overall GHG emissions from the urban water cycle. However, CH_4 and N_2O also contribute significantly due to their high GWP of 34 and 298 CO_2-equivalents respectively [IPCC, 2014a], although they are released in a much smaller quantity. Whereas CO_2 emissions are all attributed to energy consumption, CH_4 and N_2O emissions are produced primarily during biological processes in the wastewater section. Therefore, the pathways of GHG emissions in the urban water cycle can be divided into energy-related and non energy-related sources.

Energy-related emissions

Energy consumption is a significant source of GHG emissions in the urban water cycle. Energy is necessary for WWUs to empower their facilities, especially for pumping and treatment. The associated fossil fuel combustion results in indirect or direct emissions of GHGs, mainly CO_2, depending on whether the energy is transmitted from the public electricity grid or generated by on-site engines. In those WWUs where water distribution and wastewater discharge take place by truck transport instead of by pipelines and drainage networks, emissions are released through fossil fuel combustion of vehicles. If the distribution and discharge are accomplished via gravity, no energy is needed. For better focusing, this methodology concentrates on energy-related emissions resulting from electricity consumption.

According to the International Energy Agency (IEA) [2016c], the global water and wastewater sector, including serving households, agriculture and industry, consumed around 120 million tonnes of oil equivalent (Mtoe) in 2014. 60% was attributed to electricity, equalling 820 terawatt-hours (TWh), or around 4% of the global electricity demand. The electric power was mainly consumed for water extraction (40%), wastewater collection and treatment (25%), and water distribution (20%). Moreover, there is an apparent disparity between low/middle-income and high-income countries: 42% of the water-related electricity was used for wastewater treatment in industrialised nations, whereas the share was much smaller in developing and emerging economies due to the lower degree of wastewater treatment.

Non-energy related emissions

Non-energy related emissions are primarily CH_4 and N_2O, which are produced during the collection, treatment and discharge of wastewater. According to the EU Emissions Database for Global Atmospheric Research (EDGAR), the wastewater sector, including treated and untreated sewage from all sources, contributes approximately 11% of the total global methane release as well as 4% of global N_2O emissions [Janssens-Maenhout et al., 2017; JRC & PBL, 2016].

In wastewater treatment plants (WWTPs), methane is emitted through the anaerobic decomposition of organic material. The anaerobic digestion of the primary sludge may be a substantial emitting source if the emitted CH_4 is not flared or recovered. N_2O emissions are associated with the degradation of nitrogen components through microbial processes such as nitrification and denitrification, which takes place in sewers and treatment plants as well as in discharged effluents. Both gases can be further emitted in the handling and disposal of digested sludge, which is, however, not considered in the present document. Also excluded from the assessment are the CH_4 and N_2O emissions in sewers due to the deficiency of appropriate methodologies according to the IPCC. Moreover, CO_2 emissions from biological wastewater treatment are not examined, either, as they are defined as biogenic and not considered in the IPCC 2006 Guidelines.

In countries with inadequate infrastructure, the use or discharge of untreated wastewater can lead to significant CH_4 and N_2O emissions and adverse impacts on public health and the environment. Due to the possibility to convert methane to valuable energy, tackling untreated wastewater can realise remarkable potentials of climate mitigation and the improvement of utilities' energy and operation security. To highlight the possibilities, ECAM and the present methodology also examine these uncontrolled emissions, despite their being produced partly outside the boundary of WWUs.

The ECAM tool categorises the emission pathways described above into three scopes consistent with the IPCC standard. Scope 1 summarises all direct emissions from sources that are owned or controlled by the WWUs. Scope 2 refers to indirect emissions owing to the generation of purchased electricity consumed by the WWUs. Scope 3 covers other indirect emissions released as consequences of the activities of the WWUs, but from sources not owned or controlled by them. *Annex A* presents an overview of GHG emissions considered in this guideline.

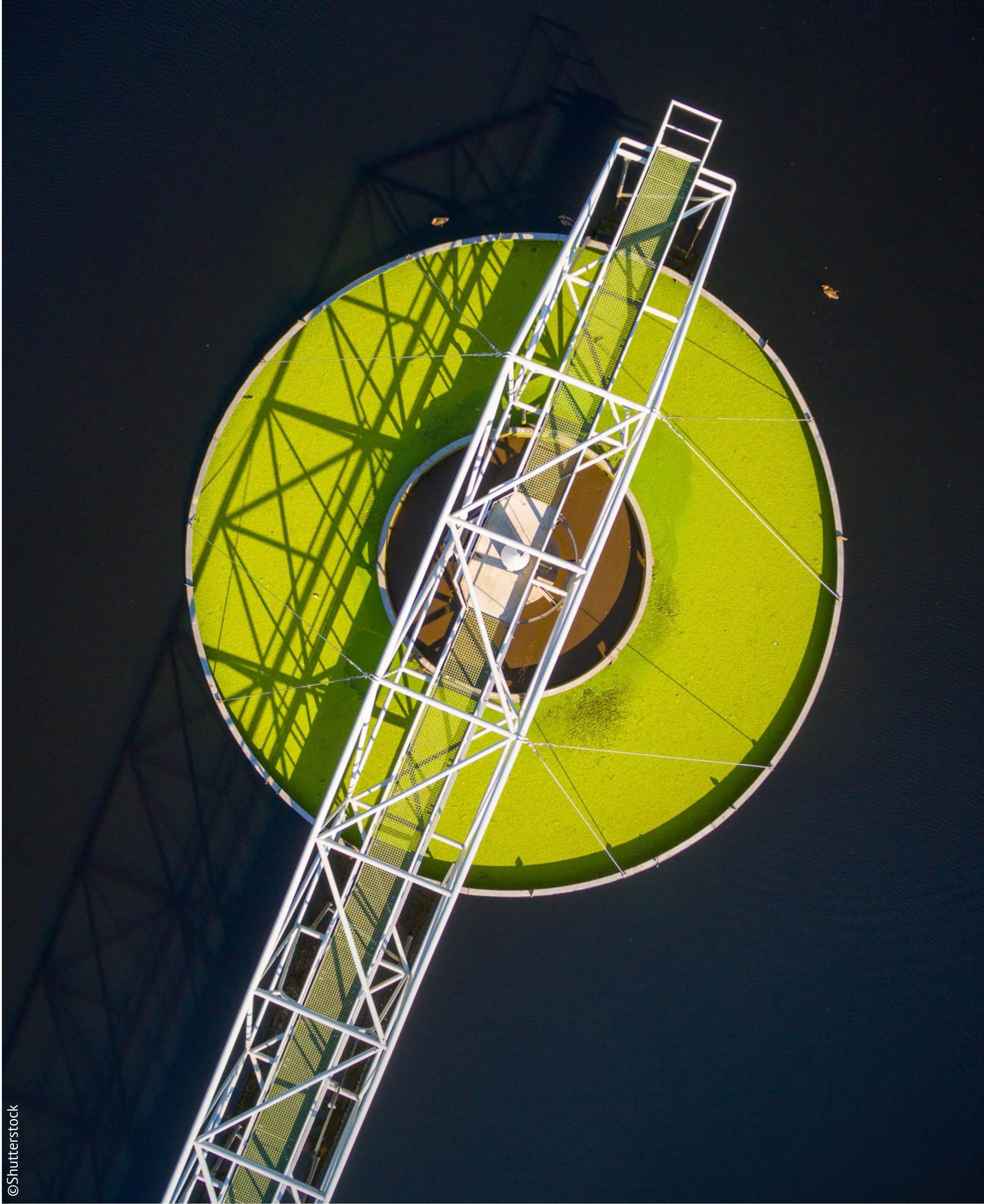
[2] The GWP is defined as the time-integrated, normally 100 years, radiative forcing from the emission of a given gas, relative to that of an equal mass of CO2. It is the most commonly used emission parameter to compare different GHGs and has become the default metric for transferring the emissions of gases to CO2 equivalent emissions (CO2e). IPCC (2014a).

1.3. Time horizon

For the establishment of baselines, the IPCC [2001] sees a general difficulty in predicting a development pattern over the long term due to the lack of knowledge about the dynamic linkages between technical choices and consumption patterns. These two factors interact with economic signals and policies, affecting the validity of baseline assumptions. Further uncertainties for long-term scenarios arise from potential political and social changes, which are primarily the case in developing countries and emerging economies amid massive urbanisation and industrialisation processes.

Apart from the above considerations, this document does not examine the carrying capacity of local water resources that limit the infinite expansion of human settlements in the long term. To do so, sophisticated hydrological modelling is required. Therefore, this methodology focuses on baselines of near to mid-term, up to about two decades ahead.

Step 2: Analysis of driving factors and key parameters



Step 2: Analysis of driving factors and key parameters

2.1. Key parameters

Based on the characteristics of GHGs and their emission pathways, the IPCC Guideline [2006] set standards for measuring emissions depending on various parameters and variables. To establish baseline scenarios in the urban water cycle, it is necessary to track the essential terms that evolve and characterise the tendency and magnitude of GHG emission variations. These are primarily the parameters associated with the range of anthropogenic activities that release the emissions. As such, an extensive analysis, as presented in *Annex B*, reveals that the development of the categories of key parameters will affect the future trajectory of GHG emissions in the urban water cycle.

In the present methodology, the group of **key parameters** refers to those for which future rates of change in BAU scenarios will be studied in this document. These parameters determine the variation range of other variables and total GHG emissions. As already summarised previously, key parameters include:

1. Resident population in the service area
2. Connection degree of water and sanitation infrastructures
3. Per capita water production and wastewater volume
4. Energy intensity per volume of water and wastewater
5. Emission factor of grid electricity
6. Per capita per day BOD_5 generation quantity
7. Per capita per day protein consumption quantity.

Apart from GHG emissions, this methodology also investigates the development of energy costs. Thus, the energy price is also seen as one of the key parameters, for which the analysis of the future trend is needed. Moreover, due to the vast potential to improve the water efficiency in low- and middle-income countries, the changes in the non-revenue water (NRW) ratio in the pilot countries are also projected based on the past trend. Thus, the group of key parameters also include:

8. Energy price
9. Non-revenue water.

2.2. Driving factors behind key parameters

The future values of key parameters are posed as the results of alterations of human activities, responding to socio-economic, environmental and technical drivers. Here, the driving factors behind the key parameters will be introduced and analysed in the context of the global trend.

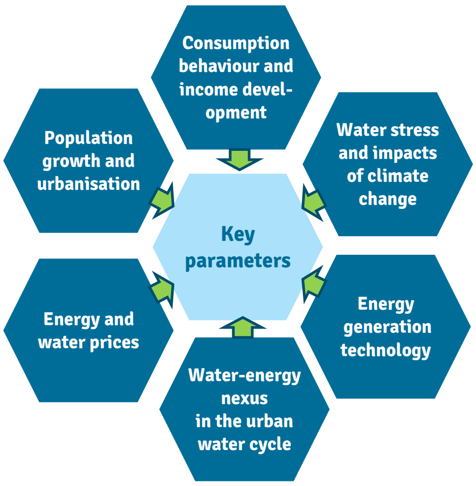


Figure 3. *Driving factors affecting key parameters*

Population growth and urbanisation

Population growth is the most important driving factor of GHG emissions in the water and wastewater sector, affecting the amount of water production and wastewater generation as well as BOD_5 and nitrogen load in the sewage.

The expansion of the human population has accelerated dramatically. Between 1900 and 2000, the total population has grown from 1.5 to 6.1 billion at a pace three times faster than during the entire previous history [Roser & Ortiz-Ospina, 2018]. Currently, 7.6 billion people live on Earth. By 2050, this number is estimated to hit 9.8 billion, and 11.2 billion in 2100 [UNDESA, 2017a].

The exponentially growing population poses a significant challenge to the carrying capacity of our planet. Water, with its essential role for life and economic activities, is particularly affected. Over the last several decades, the growth rate of water demand has doubled that of the population. At the same time, the inter-sectoral competition for water use has been intensified [WWAP, 2015]. Currently, about 80% of inhabitants worldwide live in areas where water security[3] is threatened [Vörösmarty et al., 2010]. With the further growth of the population, the global water demand is expected to be 55% higher in 2050 [OECD, 2012], while the water deficit is projected to increase 40% by 2030 [2030 WRG, 2009].

Today, 50% of the global population resides in cities, and this share will reach 70% by 2050. The urbanisation process, which is taking place primarily in low- and middle-income countries, generates specific and localised pressures on water and its management practices. In urban areas of these nations, where the slum population is rapidly expanding, the water supply, sanitation and hygiene services are often inadequate, posing a threat to human health, the environment and economic development. Investments in water and sanitation infrastructures result in considerable gains through protecting urban living conditions and securing economic activities. Additional financial benefits can be created by employing the productive potential of wastewater as a resource for energy and nutrients, as well as for other sectors such as agriculture [WWAP, 2015].

Consumption behaviour and income development

Consumption behaviour plays a role in several key parameters of the baseline projection, including per capita water consumption, BOD_5 generation and protein intake. Variations of consumer behaviour in developing countries and emerging markets are often driven by higher income accompanied by urbanisation, which changes the style and standard of living over time.

In urban areas, the expanding middle class have notably contributed to shifts towards more water-intensive consumption patterns, such as using more piped water on premises, dishwashers, washing machines, flushing toilets and showers. People also tend to build larger houses, eat more meat, drive more motor vehicles and use other energy-consuming devices. As a consequence, water uses for both production and domestic purposes has sharply increased [WWAP, 2015]. However, the relation between income and per capita water consumption, especially that for domestic uses, is not necessarily linear. According to the UN [WWAP, 2014], residents consume less water per person after reaching a certain income level. Reasons behind this include the adoption of more water-saving appliances and measures in homes, reduction of water losses including leakage from water distribution systems and growing awareness among consumers.

The personal BOD generation is also positively linked to economic wealth. Higher living standards lead to improved sanitary conditions and dietary consumption, which intensify organic contamination of water and thus increase the BOD load. Currently, the default values for BOD_5 generation adopted in the IPCC Guideline [2006] are generally higher for industrialised countries than for developing countries and emerging economies. However, the income level is not the only determining factor, and regional differences can be caused due to other socio-economic factors such as lifestyles, habits and technical features [Doorn & Liles, 1999; Henze & Comeau, 2008].

Protein consumption is also dependent on consumer behaviour. Diversified food commodities provide protein, with animal products containing higher protein content. Meanwhile, the different positions in the food chain make the animal protein more costly per unit weight than that from other sources [Grigg, 1995]. The amount of protein intake is, therefore, an issue of consumers' choices about food consumption pattern determined by their income, food prices and favoured tastes.[4] According to Henchion et al. [2017] and the Organisation for Economic Co-operation and Development and Food and Agriculture Organisation (FAO) [2015, 2018], income growth and urbanisation are the two primary drivers of general food consumption, promoting the diversification of the nutrition pattern towards more protein intake – especially from animal sources – in the developing world. Moreover, taste differences translate higher income into higher consumption of different food products, also contributing to regional variations in protein intake.

Generally, there are multiple reasons for changes in consumer behaviour, the quantification of the interrelations often requiring empirical investigations.

Water stress and impacts of climate change

Currently, alterations in both the quantity and quality of regional and global water resources are taking place due to climate change [IPCC, 2014b]. Most extreme events are characterised by the absence of or high quantities of water as the result of intensified water circulation [EPA, 2016; IPCC, 2014a]. Consequently, the regional and seasonal contrast in water resources is exaggerated: dry regions and seasons get drier, while wet regions and seasons become more humid. The increase in water temperature, low flows and heavy rainfall pose a further threat to the quality of water resources through pollutants including sediments, nutrients, pathogens and pesticides [Jiménez Cisneros et al., 2014; Kundzewicz et al., 2007].

Due to the essential role of water, hydrological changes lead to the most widespread impacts on human society. Municipal water services and infrastructure are considerably affected. Apart from the increased water demand and intensified competition with other sectors, further possible consequences for water supply are, for instance, the need for more extensive water storage due to river flow shifts and droughts, enhanced treatment requirements due to higher pollutants burden in raw water, and higher desalination needs in coastal regions. In the case of wastewater, three possible

[3] The United Nations (UN) define water security as the capacity to safeguard sustainable access to adequate quantities of acceptable quality water. UN, (2013), p.1.

[4] Individual food consumption preferences also vary, for instance if the family size and composition, place of residence, health situation or season of the year changes. Further possible influencing factors include education level, occupation, urbanisation and globalisation. Timmer, et al. (1983); Rampal (2018).

scenarios can occur: Wet weather causes higher amounts of rainfall that exceeds the design range and puts pressure on combined canal systems; Dry weather leads to cracking sewers and more infiltration and exfiltration of water and wastewater, increasing corrosion of sewers and maintenance costs; Rising sea levels lead to higher amounts of salty water affecting sewer systems. In both wet and dry conditions, greater pollutant and pathogen content is expected in wastewater [Jiménez Cisneros et al., 2014]. All of these issues will significantly increase energy consumption and operational and investment costs, as well as GHG emissions.

To address the upcoming challenges, municipal water management in the developing world shall be prepared as soon as possible. Substantial and sustained emission reductions in the near term reduce future challenges and costs significantly and increase the overall effectiveness of adaptation measures. Strategic benefits can be realised if the ongoing planning process is involved as early as today.

Energy generation technology

Energy-related emissions in the municipal water and wastewater services are, to a great extent, dependent on the carbon-intensity of the public grid. At the core of the transition process towards a more climate-friendly and sustainable energy system, the development of renewable energy has made significant progress with considerable cost cuts. Today, the total installed power capacities of renewables are higher than those of coal [IEA, 2018c].

However, coal still produces the highest amount of global electricity with a stable 40% share, while renewable sources as a whole take second place with 25%, followed by gas with 22%. Overall, fossil fuels are still responsible for the majority of electricity generation and hold constant at 65%. Nevertheless, due to the shift from more carbon-intensive oil to less carbon-intensive gas within the mix of fossil fuels, the global average carbon intensity of electricity generation is declining [IEA, 2018c].

The IEA [2018c] projected that the global electricity demand would grow by 60% by 2040 compared to 2017, overwhelmingly driven by increases in low- and middle-income countries. However, the implementation of innovative renewable energy technology is often constrained both financially and technically in these nations so that additional renewable capacities cannot fully meet the dramatic increases in electricity demand. Consequently, fossil fuels will grow further alongside renewable sources so that electricity sectors there will decarbonise at a slower pace [IEA, 2016c].

Water-energy nexus in the urban water cycle

According to the UN [WWAP, 2014] and IEA [2016c], the total freshwater withdrawals in high-income countries have stabilised due to improved water efficiency. Low- and middle-income countries have become the primary driver of the total freshwater withdrawals at a growth rate of about 1% per year since the 1980s [IEA, 2016c]. The IEA [2016c] also estimated that the energy consumption in the water and wastewater sector would more than double by 2040. This increase is more rapid than that of freshwater withdrawals and three times faster than the growth of the world's total final energy consumption.

Based on these projections and given the increased uncertainty about future water availability [IEA, 2016c], continuing the current practices in WWUs will lead to considerable challenges across multiple aspects. The identification of losses and the improvement of efficiency in the water-energy nexus are to be prioritised, especially considering that energy costs are usually the highest expenditures for WWUs and energy consumption emits the highest GHGs in the urban water cycle.

Water loss resulting from poor distribution efficiency is the most pressing problem in low- and middle-income countries. The level of water loss can reach 60% of water supplied, involving technical and operational problems and institutional, planning, financial and administrative issues [Khatri & Vairavamoorthy, 2008]. Enhanced water efficiency saves not only freshwater withdrawals but also the energy required, leading to emission and cost cuts as well as water needed in energy production. In the urban water cycle, regular maintenance, well-implemented water loss control program, better land management practice, matching water supply to demand, encouraging recycling and reuse are all available options to improve water efficiency [Makaya, 2015]. In general, technical, personnel and institutional capabilities are still to be developed for the promotion of water efficiency in the developing world [WWAP, 2015].

At the same time, WWUs' performance in energy consumption and GHG emissions can also be improved by promoting the energy efficiency of facilities. Based on the IEA studies [2016c], enormous potential for energy efficiency is to be exploited, particularly in wastewater treatment and water pumping, as well as freshwater distribution. The energy consumption of biological wastewater treatment can be cut by up to 50% through the broader deployment of variable speed drives, fine bubble aeration, better process control and more efficient compressors. In water and wastewater pumping, energy efficiency is improved through more efficient pumps and the usage of variable speed drives, as well as separate sewage systems and better sewer maintenance reducing infiltration and water inflow.

Recently, WWUs have started to recognise the potential of wastewater as an energy source. The utilisation of chemically bound energy is based on the carbon content in sewage that can be converted to methane-containing biogas in anaerobic conditions. This kind of energy is used as fuel for vehicles, power generation, heating and domestic cooking. It can also serve as a fuel substitute for a treatment plant itself, saving costs and reducing sludge and emissions. The advantage of chemically bound energy lies in the possibility of gathering and transportation without much loss [WWAP, 2014]. According to the IEA [2016c], wastewater contains energy that is five to ten times greater than the energy necessary to treat it. Although up to 0.56 kWh/m³ of electricity can theoretically be produced from sludge on average, there are still substantial constraints in practice[5] meaning that the energy neutrality of WWTPs on the global scale is more likely to be realised in the long term, i.e. beyond 2040.

Energy and water prices

Cost variations are a major factor for alterations in energy use in the water and wastewater sector. As electricity continues to gain ground in energy consumption, electricity prices are also projected to increase in the future. There are several reasons for this, namely growing fossil fuel prices, the investment costs to be recovered and, in some countries, politically determined levies, taxes and surcharges.

According to the IEA [2018c], the higher demand for limited fossil fuels will drive their prices up in the coming decades. This affects not only coal and oil, but natural gas prices will also increase in the longer term although they are currently at low levels and may even see a drop in the near term. Consequently, electricity generation costs from fossil-fuel power plants will increase in the future.

On the other hand, the integration of renewable capacities as technologies with zero marginal costs contributed to the recent decline in wholesale prices in several relatively mature electricity markets. However, the fixed costs to recover investments in grid and power plants more than counterbalance the production cost savings realised through the increased share of renewable energies. As a result, end-users will still be confronted with higher electricity charges [IEA, 2018c].

Furthermore, politically determined components will further increase the price of electricity. It is especially the case in those countries using economic incentives, such as carbon pricing mechanisms and subsidies for renewables to spur the transformation of the energy sector and technological innovations.

Whereas energy prices are shaped to a certain degree by market forces, water tariffs are principally influenced by policies and subsidies. Determined by social priorities, water prices are characterised by large disparities across countries. Various surveys indicate that water prices are often lower than the level for cost recovery of supply. The economic incentive for water conservation is thus principally missing due to under-pricing [IEA, 2016c]. For WWUs, low water prices can increase the amount of water to be supplied and wastewater to be treated. This not only causes increases in GHG emissions. Under the condition that electricity prices keep rising at the same time, low water prices can substantially deteriorate the financial performance of utilities.

2.3. Values and trends for projecting ECAM inputs

Since a broad set of parameters and metrics is required for the computation in the ECAM tool, these will first be categorised regarding the necessity of the handling. In this section, the parameters will be first classified into related items that are used in sub-stages. Additionally, this section is dedicated to guiding the users on how to work out the values and trends of the different parameters required. Although the parameters listed in this section are those characterise the tendency and magnitude of GHG emission variations under BAU considerations, additional parameters can be selected according to specific characteristics of the utility.

ECAM inputs are the final metrics that should be entered into the ECAM tool for the computation of BAU emissions, including:

a. Resident population in the service area
b. Population serviced by water supply, connected to sewers, serviced by WWTPs
c. Water and wastewater volume
d. Energy consumption for water supply and wastewater management
e. Emission factor of grid electricity (EF_{grid})
f. Per capita per day BOD_5 generation quantity
g. Per capita per year protein consumption quantity
h. Energy costs for water supply and wastewater management
i. Treatment types and natural water environment with the associated CH_4 emission factors
j. BOD_5 load in influent, effluent and removed as sludge
k. Nitrogen concentration in effluents.

Among them, the ECAM inputs of category a, e, f and g are also key parameters. Some (category b, c, d, h, j and k) are to be further quantified following the projection of the linked key parameters. Apart from these, the CH_4 emission factors (category i) are not associated with any key parameters and are solely determined by the technical features of the current treatment systems, which are assumed to be stable in BAU scenarios.

In order to facilitate users' handling, the "Tool of **P**rojecting **E**CAM **I**nputs for **G**HG **E**missions as BAU Scenarios (**PEIGE**)" in Excel format has been developed. The starting values – or the "current states" – that are indispensable for the projection are named **PEIGE inputs**.[6]

[5] Constraints include inefficiencies in the digestion process and electricity conversion as well as barriers limiting its uptake. Plants with an inflow smaller than 5 million litres per day are unable to recover energy economically. Diluted sewage due to high groundwater and stormwater infiltration is not suitable for generating biogas. The location and infrastructure is the further factor limiting the application in many areas. IEA (2016c).

[6] Apart from the ECAM inputs necessary for the GHG emissions and energy costs scenarios, PEIGE calculates several terms related to water efficiency for users' reference.

BAU trends

The values and trends to project ECAM inputs require the quantification and analysis of the development of the parameters presented in this section. To analyse BAU trends related to such parameters, status-quo values of parameters can be obtained from country-wide statistics available from various sources. The future trends of these parameters are attained from the global, regional and country-specific projections made by international organisations and institutions. If such projections are not available or applicable, the future trend is assumed to be in line with the trajectory from the near past derived from the existing statistics.

For the evaluation at the utility level, specific considerations must be kept in mind regarding the continuous urbanisation process in low- and middle-income countries. Substantial urban-rural divide is exhibited particularly in terms of population and infrastructure coverage. Due to the high sensitivity of the projection regarding the choice of urban, rural and national values for these two metrics, it is indispensable to differentiate the locations of utilities between city and countryside. To ensure a more precise focus, this methodology examines only utilities in urban areas, because, as introduced previously, pressures on water resources and management practices are generated more in higher concentrations there due to the massive demographic shift.

Consequently, special consideration must be given to the following:

- For EF_{grid}, BOD_5, and Protein, the projections can be assumed to be identical with the values of the national level in accordance with the IPCC Guideline.
- For population and infrastructure coverage, the status-quo values can usually be obtained from the utilities. The trend adopted for the future is the projection or the past trajectory based on the general development in one country's urban areas.
- For other parameters, the values of current states shall also be provided by users via monitoring data. The trend adopted is the same as that at the national level, without a regional focus. This is due to the deficient data basis for these parameters as well as the consideration that discrepancies between the nationwide and urban-specific values in terms of change rates could be insignificant.

Three different kinds of statistical methods are applied for the calculation of annual change rates, including arithmetic, exponential and geometric growth, as introduced in detail in *Annex F*.

2.3.1. Resident population
(Parameter No.: PO-01, PO-02)

The resident population refers to the total number of inhabitants residing in service areas of WWUs, regardless of whether they are served or not by the utility. The future development of the population decides the dimension of the settlements and the infrastructure that is necessary for an optimal situation. In the case that the coverage of water and sanitation facilities remains stagnant, the growing population is one of the dominant factors driving the water and wastewater quantities as well as the associated emissions.

Two different terms of the total resident population are used in the system considered:

- Resident population of **water supply** (POP_{ws_resi}),
- Resident population of **wastewater** (POP_{ww_resi}),

Table 1. *ECAM and PEIGE inputs of the resident population (PO-01, PO-02).*

No.	Name	Denotation	Units in PEIGE & ECAM
PO-01	Resident population of water supply	POP_{ws_resi}	Persons
PO-02	Resident population of wastewater	POP_{ww_resi}	Persons

Development trend of the urban population

The development of the population is generally determined by fertility, mortality, and migration [UNDESA, 2017b]. If the urban-rural distribution of the population is examined, the urbanisation process plays an important role in the demographic change of developing countries and emerging economies.

The UN Department of Economic and Social Affairs (UNDESA) updates comprehensive reviews of global prospects of demography and urbanisation to guide decision-makers in achieving the new Sustainable Development Goals. The results are regularly published in the form of the "World Population Prospects" and "World Urbanisation Prospects". Country-specific data related to the national population are projected up until 2100 [UNDESA, 2017a] and those regarding the urban population up to 2050 [UNDESA, 2018].

International organisations calculate rates of population increase in an exponential growth pattern as a conventional method. This method is also used in this methodology to calculate the annual growth rates using the UNDESA population figures. This approach is explained in detail in *Annex F*.

For urban utilities, it is assumed that the development trend in the future will undergo the trajectory of the total urban population in the corresponding country.

2.3.2. Population with access to water and sanitation services
(Parameter No.: PO-03, PO-05, PO-06)

The population with access to water and sanitation infrastructure is generally calculated from the total resident population in the service area and the proportion with the respective access to the infrastructure:

$$POP_{access} = POP_{resi} \times R_{access\_resi} \qquad (1)$$

Whereas total residents are projected by the above-described method, the connection degree of water and sanitation infrastructure also evolves with time, as the economic development and urbanisation process continues. The projection of infrastructure coverage will be the focus of this section.

The population with different infrastructure access in the system considered can be divided into:

Water Supply:
- Population serviced by water supply (POP_{ws_serv})

Wastewater:
- Population connected to sewers (POP_{ww_conn})
- Population serviced by WWTPs (POP_{ww_serv})

These are used for the evaluation in sub-stages, linked to the respective share in the total residents. ***Table 2*** classifies the parameters in terms of their relevance in sub-stages.

1. Preferably, data should be taken from the UNSD data pool and national reports for the service level of drinking water supply. This is due to maintaining source consistency with the parameters to be determined in the next section. If data are not available from these sources, the "proportion of the population with access to improved drinking water" from the JMP be an approximation. The uncertainty associated with water supply data is at a low level.
2. Statistics on sanitation services entail substantial discrepancies between the JMP data and those from national reports. This can be traced back to the data handling method used by the JMP, which develops the estimates by fitting a regression line to the collected data [WHO & UNICEF, 2017a]. The discrepancies that are particularly significant for the coverage of wastewater treatment can also be attributed to the different requirements of treatment quality that are considered in data reporting.

Table 2. *Population groups with different infrastructure access used in sub-stages and the associated ratios in total residents.*

Sub-stages	Population groups	Parameter-no.	Parameter feature	Ratio in total residents	Parameter-no.	Parameter feature
WS-Abstraction	POP_{ws_serv}	PO-03	PEIGE inputs, ECAM inputs	$R_{ws\_serv\_resi}$	PO-04	Key parameters
WS-Treatment	POP_{ws_serv}	PO-03		$R_{ws\_serv\_resi}$	PO-04	
WS-Distribution	POP_{ws_serv}	PO-03		$R_{ws\_serv\_resi}$	PO-04	
WW-Collection	POP_{ww_conn}	PO-05	PEIGE inputs, ECAM inputs	$R_{ww\_conn\_resi}$	PO-07	Key parameters
WW-Treatment	POP_{ww_serv}	PO-06		$R_{ww\_serv\_resi}$	PO-08	
WW-Discharge	POP_{ww_conn}	PO-05		$R_{ww\_conn\_resi}$	PO-07	

Development trend of the coverage of water and sanitation infrastructure (PO-04, PO-07, PO-08)

Various institutions publish statistics on the coverage degree of water and sanitation services, with international organisations seen as sources of high quality. For example, the Joint Monitoring Programme for Water Supply, Sanitation and Hygiene (JMP) of the World Health Organisation (WHO) and the United Nations Children's Fund (UNICEF) produces regular estimates of progress on drinking water, sanitation and hygiene (WASH) since 1990 [WHO & UNICEF, 2017a]. Meanwhile, the UN Statistics Division (UNSD) publishes water and waste data through the biennial Questionnaire on Environmental Statistics that are collected from national authorities [UNSD, 2016]. In many cases, national governments also compile water reports providing statistics on public service levels. Due to the differences in the objectives and focal points of data reporting, statistics contained in these various sources can exhibit sizeable discrepancies.

As a result, it is suggested to use the data as described below:

Whereas national statistics usually include wastewater treated to all levels, the JMP examines only improved/safely managed types of sanitation, which requires at least the secondary (biological) treatment [WHO & UNICEF, 2018]. As such, it is recommended to use national reports as sources of coverage degree of sewer systems in an attempt to maintain source consistency with parameters as discussed in the next section, providing they are relevant and the data are available.[7] Otherwise, JMP data are preferred. For the connection degree of wastewater treatment services, the JMP data are more appropriate and always adopted for the study envisaged.

In the future, the supply of water and sanitation services is expected to undergo further improvement. Where the connection degree has already reached a high level in urban areas, the elimination of the last small proportion of unconnected households may take a long time, and the expansion in rural areas will gain more attention and accelerate in comparison to the past. Otherwise, investments in large

[7] Due to the problem of divergence in the definition regarding the quality of wastewater treatment among data from various sources, the quantification of the per capita wastewater volume in the next section is preferably oriented to the collected wastewater volume and the corresponding number of inhabitants, i.e. those who are connected to sewers.

agglomerations will remain the central points. Generally, wastewater treatment has enormous potential for improvement in low- and middle-income countries, both in urban and rural settlements.

2.3.3. Water and wastewater volume

(Parameter No.: W-01, W-03, W-05, WW-01, WW-03, WW-05, WW-07)

The total volume of water and wastewater is an important ECAM input needed for the estimation of energy-related emissions. In general, it is the product of population and the volume of water produced or wastewater treated for each person on average:

$$VOL = POP \times VOL_{per\ capita} \tag{2}$$

The water and wastewater volume in sub-stages shall be related to the appropriate population groups according to their connection degree. While the population with different infrastructure access was projected in the previous section, this part will focus on the per capita water/wastewater volume.

Classification of related parameters

Different terms of water and wastewater volume are examined in sub-stages as listed below:

Water Supply:

- Volume of abstracted water (VOL_{wsa_conv})
- Volume of treated water (VOL_{wst_trea})
- Volume of water injected to distribution (VOL_{wsd_dist}).

Wastewater:

- Volume of WW conveyed for treatment (VOL_{wwc_conv}) including all the wastewater collected
- Volume of treated WW (VOL_{wwt_trea})
- Volume of WW discharged to a water body (VOL_{wwd_disc}) including all the wastewater collected, regardless of whether it is conveyed to be treated or discharged untreated
- Volume of reused effluent (VOL_{wwd_nonp}).

The link between the water and wastewater volume in sub-stages, the related resident groups, and their per capita quantity is outlined in ***Table 3.*** Logically, the per capita water volume of the three sub-stages of water supply should have the same growth rate, which is identical with the national average, while the sub-stages in the wastewater management process undergo a unified pattern in the per capita wastewater volume, similar to that at the national level.[8]

Development trend of per capita water and wastewater volume (W-02, W-04, W-06, WW-02, WW-04, WW-06, WW-08)

Table 3. *PEIGE inputs of the volume of billed authorised consumption (W-07).*

No.	Name	Denotation	Units in PEIGE / ECAM
W-07	Volume of billed authorised consumption	VOL_{wsd_bill}	m^3

The per capita water generation volume for domestic uses is influenced by several factors, including the change in end-user demands, water availability, and water loss. While the low water tariff and the continuous income increase stimulates residential water demands in low- and middle-income countries, the bottleneck in water utilities can pose a constraint. High water loss and lower water availability – the latter due to urbanisation, industrialisation, and climate impacts – reduce the water volume reaching households and

Table 4. *The water and wastewater volume used in sub-stages and the per capita terms.*

Sub-stages	Water/WW volume	Parameter-no.	Parameter feature	Per capita water /wastewater	Parameter-no.	Parameter feature
WS-Abstraction	VOL_{wsa_conv}	W-01	PEIGE & ECAM inputs	VOL_{wsa_conv} / POP_{ws_serv}	W-02	Key parameters
WS-Treatment	VOL_{wst_trea}	W-03		VOL_{wst_trea} / POP_{ws_serv}	W-04	
WS-Distribution	VOL_{wsd_dist}	W-05		VOL_{wsd_dist} / POP_{ws_serv}	W-06	
WW-Collection	VOL_{wwc_conv}	WW-01	PEIGE & ECAM inputs	VOL_{wwc_conv} / POP_{ww_conn}	WW-02	Key parameters
WW-Treatment	VOL_{wwt_trea}	WW-03		VOL_{wwt_trea} / POP_{ww_serv}	WW-04	
WW-Discharge	VOL_{wwd_disc}	WW-05		VOL_{wwd_disc} / POP_{ww_conn}	WW-06	
WW-Reuse	VOL_{wwd_nonp}	WW-07		VOL_{wwd_nonp} / POP_{ww_conn}	WW-08	

[8] The ratio of reused effluent also evolves so that the per capita reused effluent, discharged WW, and treated WW could change differently. However, only fragmented data (except for Jordan) are available for drawing a pattern. Moreover, a downscaling problem exists that the national development cannot be directly applied for individual utilities, if these do not meet the requirements and are excluded from reuse applications. Thus, a fixed ratio of wastewater reuse is assumed here.

thus the average water consumption. Consequently, the pattern of per capita water volume is most likely the result of the trade-off between the supply and demand side, n which the supply-side management is believed to dominate at present. Due to the complexity of involved factors, this methodology projects the per capita water volume directly by using the past growth rate of water generation as opposed to the end-user demand. The same procedure is conducted for the projection of the per capita wastewater volume. The wastewater generation of an average resident is positively correlated to the per capita water consumption, which is, in turn, linked to the per capita water generation via the parameter NRW. Thus, wastewater generation trends can be developed in connection to water production. However, there are substantial deviations among data for NRW in most cases, meaning that the projected trends embody a very high level of uncertainty. As a result, it is recommended that the trend of the per capita wastewater be established separately, i.e. under the assumption that its past pattern will continue. The projection of the per capita water consumption will be presented later in the combination of NRW for users' reference.

Due to the discrepancies related to the data on the coverage of wastewater treatment as illustrated in the previous section, the calculation in this section is based on collected/generated wastewater volumes to minimise uncertainty. In terms of the statistical method, the compound annual growth rate (CAGR) can be applied.

2.3.4. Billed authorised consumption volume
(Parameter No.: W-07)

The volume of billed authorised consumption shows the end-user water consumption, as the remainder of the water volume injected to distribution after NRW is deducted. According to IWA water balance, the NRW includes physical losses due to leakage, commercial losses including unauthorised consumption and billing errors, and unbilled authorised consumption by utilities themselves or for other purposes [Kingdom et al., 2006]. This methodology and PEIGE provide the possibility to sketch the future trend of NRW and end-user consumption in a no policy change situation.

Development trend of non-revenue water ratio (W-08)

In order to examine the past development of NRW in the, national statistics on water production, consumption, sales, and losses can be explored. Depending on the data availability, water losses covering different scopes will be displayed as an approximation to NRW. The development pattern of NRW is expected to undergo a linear trend, i.e., arithmetic variation.

PEIGE inputs for projecting the volume of billed authorised consumption W-07

The absolute quantity of volume of billed authorised consumption is needed as PEIGE inputs for the projection. Whereas utilities obtain the figures from their metering and invoicing documents, nationwide values are provided in the table below. The numbers are calculated based on total water generation data and the NRW ratio determined above in this chapter.

2.3.5. Energy consumption
(Parameter No.: E-01, E-03, E-05, E-07, E-09, E-11, E-13, E-15)

In order to determine CO_2 emissions in the urban water cycle, the quantity of electricity consumed specifies the extent of human activities resulting in emissions. Intuitively, this item is calculated as the product of the total volume of water or wastewater and the energy needed to produce each volume of water or handle each volume of wastewater. The energy quantity per volume of water/wastewater indicates the energy intensity of water supply and wastewater treatment:

$$E = VOL \times E_{per\ VOL} \qquad (3)$$

Electricity consumption in sub-stages shall be linked to the appropriate water/wastewater volume and the associated energy intensity. The first part of this section will classify the parameters by sub-stages.

Like the development of per capita water/wastewater volume, this guideline assumes that the energy intensity in utilities undergoes the general trend of the national average.

Classification of related parameters

Different variables related to energy consumption are considered in sub-stages as listed below:

Water Supply:
- Electricity consumed for total water supply (E_{ws})
- Electricity consumed for water abstraction (E_{wsa})
- Electricity consumed for water treatment (E_{wst})
- Electricity consumed for water distribution (E_{wsd})

Wastewater:
- Electricity consumed for total wastewater management (E_{ww})
- Electricity consumed for wastewater collection (E_{wwc})
- Electricity consumed for wastewater treatment (E_{wwt})
- Electricity consumed for wastewater discharge (E_{wwd})

The allocation of the electricity consumption quantity to the respective water/wastewater volume and the energy intensity in sub-stages is presented in ***Table 5***.

Development trend of energy intensity (E-02, E-04, E-06, E-08, E-10, E-12, E-14, E-16)

The energy intensity differs between the water and wastewater sectors as well as across the sub-stages due to different technical approaches utilised there. Moreover, diversified factors, such as the topography, distance, system design, water sources, raw water and wastewater quality, as well as the legal requirements, lead to disparities among utilities and countries [IEA, 2016c; WWAP, 2014].

There is a high deficiency in the data inventory regarding energy intensity in the urban water cycle at the national level for the countries being investigated, especially in detail for each sub-stage. As a result, the identification of the past country-specific trend of energy performance is rarely possible. Nevertheless, the assumption that the previous trend would continue might also systematically underestimate the magnitude of the future increases in BAU scenarios. The driving factor that is becoming increasingly prominent is the climate impacts expected in the upcoming decades, which pose higher pressure by affecting the water availability both in quantity and quality together with urbanisation, industrialisation and pollution. Higher reliance on non-traditional water or access to deeper groundwater resources, as well as higher wastewater treatment requirements, lead to greater energy consumption [IEA, 2016c].

Taking the future setting in the water domain into consideration, the IEA [2016c] projected the global average electricity consumption and intensity of the entire water and wastewater services as a whole. The IEA's projection is established on the grounds of the typical range of energy intensity for various processes, as illustrated in ***Figure*** **2.** System boundary.

Source: Modified from ECAM Methodology Version 2.0.

3.

As noted previously, water abstraction, wastewater treatment, and water distribution are the primary sources of energy consumption in the water and wastewater sector, and also the major contributors to intensified energy demands in the future. An analysis of the results presented in the IEA report [2016c] reveals that the energy intensity in wastewater management in developing countries will be 17% higher on average in 2040 compared to 2014, implying a CAGR of 0.6%. The energy intensity of water abstraction and distribution is assumed to have a slower growth rate than that of wastewater services, but still at a relatively high level. Besides the factors such as climate change mentioned above, developing countries will encounter a more significant challenge to water transport, as the extension of water infrastructures focuses increasingly on rural areas.

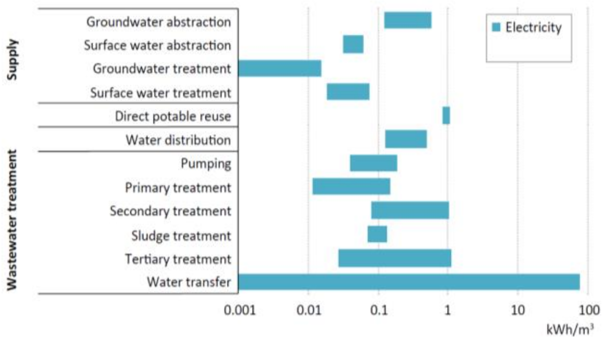


Figure 4. *Typical energy intensity for various processes in the water and wastewater sector*

2.3.6. Energy costs
(Parameter No.: EC-01)

Future energy expenditures are estimated by multiplying total electricity use (E_{ws} & E_{ww}) by electricity prices (P_{elec}). The quantity of electric power consumed is calculated in the previous section, while the future trend of P_{elec} shall be identified in this section. It is based on variations of the national average and applied to evaluations at the utility level.

Electricity prices are characterised by high volatility and vary significantly across nations. Projections of electricity tariffs are conducted through complex models, dependent on a single country's tariff scheme. In the past, the electricity prices in countries investigated all underwent growing development courses. Higher fuel prices and the amortisation of investments in new capacities for satisfying the rising electricity demands [IEA, 2018c] will lead to further increases in electricity prices. The option to phase out subsidies and ease fiscal pressure will also be a contributing factor.

For the BAU projection, assuming there are no policy changes, the past trend is thus expected to continue in the

Table 5. *The allocation of the energy consumption quantity to water/wastewater volume and energy intensity in sub-stages.*

Sub-stages	Electricity consumption	Parameter-no.	Parameter feature	Energy intensity per volume of water/ww	Parameter-no.	Parameter feature
WS-Total	E_{ws}	E-01	PEIGE & ECAM inputs	E_{ws} / VOL_{wsd_dist}	E-02	Key Parameters
WS-Abstraction	E_{wsa}	E-03		E_{wsa} / VOL_{wsa_conv}	E-04	
WS-Treatment	E_{wst}	E-05		E_{wst} / VOL_{wst_trea}	E-06	
WS-Distribution	E_{wsd}	E-07		E_{wsd} / VOL_{wsd_dist}	E-08	
WW-Total	E_{ww}	E-09	PEIGE & ECAM inputs	E_{ww} / VOL_{wwt_trea}	E-10	Key Parameters
WW-Collection	E_{wwc}	E-11		E_{wwc} / VOL_{wwc_conv}	E-12	
WW-Treatment	E_{wwt}	E-13		E_{wwt} / VOL_{wwt_trea}	E-14	
WW-Discharge	E_{wwd}	E-15		E_{wwd} / VOL_{wwd_disc}	E-16	

future. The pattern is developed based on the deflated average electricity prices for industries and services over the available timespans from different sources.

***Table 6**. ECAM and PEIGE inputs of the electricity price, emission factor for grid electricity and protein generation per capita per year (EC-01, CF-01, CF-02).*

No.	Parameter name	Denotation	Unit	Features
EC-01	National electricity prices	P_{elec}	currency/kWh	KP, PEIGE inputs
CF-01	Emission factor for grid electricity	EF_{grid}	$kgCO_2/kWh$	KP, PEIGE inputs, ECAM inputs
CF-02	Protein generation per capita per year	PROTEIN	kg/capita/year	KP, PEIGE inputs, ECAM inputs

2.3.7. Emission factor for grid electricity

(Parameter No.: CF-01)

The emission factor of grid electricity EF_{grid} is calculated as the result of the annual total emissions of a country or a region divided by its total annual amount of electricity generated. Although there could be regional disparities depending on the spatial coverage of power plants and their technologies, ECAM adopts the aggregated national outcome for the assessment of utilities. Thus, this guideline also applies the identical EF_{grid} for BAU scenarios.

From 2012 on, the IEA updated the country-specific electricity-only emission factors, providing a sound basis for the examination of the development path. Based on analyses of different IEA reports [2014, 2015, 2016a, 2017, 2018a, 2018b], the EF_{grid} and respective past development to obtain the CAGR can be calculated.

2.3.8. Protein generation per capita per year

(Parameter No.: CF-03)

The protein amount generated in municipal wastewater is necessary to determine the nitrogen content and the resulting N_2O emissions. The protein produced through human's body wastes is dependent on the dietary protein consumption. The values embedded in ECAM refer to the amount of food available for human consumption [FAO, 2010]. The current Food Balance Sheets of FAOSTAT use "per capita supply", specifying that this item is estimated based on supply-side data as an approximation of the real consumption level [FAO, 2017].

As stated in ***Section 2.1***, protein consumption is determined by the household's income, food price levels, and dietary preferences. The quantification of the evolution pattern of protein intake in correlation with these factors requires a disaggregated demand analysis of diversified food commodities in the respective countries. Difficulties arise in the estimation of the magnitude of price impacts, especially if changes are taking place simultaneously in multiple food commodities [Timmer et al., 1983].

In this methodology, the simplified method is used under the assumption that historical development will continue in the future. In line with the ECAM tool, the national average protein intake is used for BAU projections without the consideration of regional divergence.

2.3.9. BOD_5 generation per capita per year

(Parameter No.: WW-11, WW-12, WW-13)

The IPCC 2006 Guideline widely adopted the per capita BOD_5 values estimated by the US Environmental Protection Agency (EPA) [Doorn & Liles, 1999].

As already mentioned, the BOD_5 value is positively related to income. However, many other socio-economic factors also have an impact. Hence, the correlation pattern between BOD_5 and the drivers exhibits differences across countries, requiring empirical studies and panel data to perform a regression test.

2.3.10. CH_4 emission factors

(Parameter No.: CF-04, CF-05, CF-06, CF-07)

To quantify CH_4 emissions, the emission factors associated with the treatment types and the environment of receiving waters are required. In the BAU studies, assuming the persistence of the existing technical systems, these emission factors will be regarded as fixed in the time evolution. Thus, only the current values need to be determined.

2.3.11. BOD_5 loads

(Parameter No.: WW-11, WW-12, WW-13)

In order to estimate methane emissions in wastewater treatment, the BOD_5 loads during the wastewater treatment are required. This is dependent on the influent BOD_5 loads, the effluent BOD_5 loads and the amount of BOD_5 removed in sludge, which is calculated as follows:

$$BOD_{wwt} = BOD_{infl} - BOD_{effl} - BOD_{slud} \qquad (4)$$

The influent BOD_5 load (BOD_{infl}) is the quantity of total organics in wastewater (TOW) generated by the residents serviced by WWTPs, dependent on the population of this resident group, their average BOD_5 generation per capita per day, and the length of the assessment period, as introduced by equation (D) in ***Annex B***.

Meanwhile, it is assumed in ECAM that 10% of the influent BOD_5 content remains in the wastewater effluent as BOD_{effl}. The amount of BOD_5 removed as sludge (BOD_{slud}) is dependent on the wastewater treatment technique and varies between 0% and 65% of the influent BOD_5 loads.

In BAU scenarios, it is assumed that the removal efficiency will remain at the current level. As such, BOD_5 loads don't exhibit endogenous variations and are determined by the evolution of the serviced population and their per capita BOD_5 generation quantity. Hence, BOD_5 loads (BOD_{infl}, BOD_{effl}, and BOD_{slud}) of the year t are quantified in relation to the previous year t-1 as:

$$BOD_{loads}^{t} = BOD_{loads}^{t-1} \cdot \frac{POP_{ww\_serv}^{t}}{POP_{ww\_serv}^{t-1}} \cdot \frac{BOD_5^{t}}{BOD_5^{t-1}} \quad (5)$$

For **utilities**, BOD_{infl}, BOD_{effl}, and BOD_{slud} can be automatically projected in PEIGE once users have entered the current monitoring data into the respective cells. The resulting ECAM inputs must then be inputted into ECAM.

2.3.12. Nitrogen concentration in the effluent
(Parameter No.: WW-14)

The nitrogen concentration in effluent NC_{effl} is important in determining N_2O emissions from discharged sewage from WWTPs. Since the effluent includes both treated and untreated wastewater, the total nitrogen content in the effluent comprises the loads in the collected but untreated sewage as well as the remaining nitrogen in the treated wastewater. Based on the IPCC quantification standards, the analysis provided in ***Annex E*** shows that the development of NC_{effl} is closely linked to variations of the resident population, service coverage, per capita protein consumption and effluent volume, all of which are projected in previous chapters.

Meanwhile, the projection of NC_{effl} also requires the nitrogen removal efficiency ($R_{N\_wwt\_rmvd}$) of the WWTP, which is fixed under the assumption of BAU scenarios that the technical performance remains stable. Depending on climatology, technology, and the design, operation and maintenance conditions, the nitrogen removal efficiency varies among utilities [Krishna Reddy et al., 2017; Law et al., 2012].

For a single utility, the PEIGE tool calculates $R_{N\_wwt\_rmvd}$ and projects future NC_{effl} automatically using the formulas introduced in ***Annex E***. In order to accomplish this task, users shall enter the current NC_{effl} into the Excel tool, which is generally part of the monitoring data.

Table 7. *PEIGE and ECAM inputs related to BOD_5 and nitrogen load*

No.	Parameter name	Denotation	Units ECAM	Features
CF-03	BOD_5 generation per capita per day	BOD_5	g/capita/day	KP, PEIGE/ECAM inputs
CF-04	CH_4 emission factor of uncollected WW	$EF_{ww\_ch4\_unc}$	$kgCH_4/kgBOD$	ECAM inputs
CF-05	CH_4 emission factor of collected & untreated WW	$EF_{ww\_ch4\_unt}$	$kgCH_4/kgBOD$	ECAM inputs
CF-06	CH_4 emission factor of WW treatment process	EF_{wwt_ch4}	$kgCH_4/kgBOD$	ECAM inputs
CF-07	CH_4 emission factor of discharged effluent	EF_{wwd_ch4}	$kgCH_4/kgBOD$	ECAM inputs
WW-11	Influent BOD_5 load	BOD_{infl}	kg	PEIGE & ECAM inputs
WW-12	Effluent BOD_5 load	BOD_{effl}	kg	PEIGE & ECAM inputs
WW-13	BOD removed as sludge	BOD_{slud}	kg	PEIGE & ECAM inputs
WW-14	Total nitrogen concentration in the effluent	NC_{effl}	mg/L	PEIGE & ECAM inputs

Step 3: Data collection & projection

Step 3: Data collection & projection

Having identified the key parameters affecting BAU emission scenarios and studied the different factors driving their evolution in the previous section, this step differentiates between the different types of data needed to develop BAU scenarios.

Data to fit projections

The previous section aimed at analysing the BAU trends and driving factors behind each parameter driving the emission of GHGs in urban water utilities. The methodology provides possible sources and pathways to analyse the behaviour of such parameters and obtain the different change rates, according to national and local considerations.

The "Tool of **P**rojecting **E**CAM **I**nputs for **G**HG **E**missions as BAU Scenarios (**PEIGE**)" was briefly introduced in the previous step. PEIGE takes the considerations from the previous section and has the mathematic formulas required for the projection. The different change rates need to be inputted into PEIGE according to the utility and country that will be analysed and depending on the specific BAU trends studied for the respective water utility.

Initially, the tool proposes the analysis from the years 2015 until 2040. Nevertheless, this can be adjusted and fit to the different users' requirements. Moreover, the tool has a colouring system of the cells in which the user must input the information as follows:

- Grey: change rates or CAGR values
- Green: initial or starting values
- Yellow: projected data.

Initial data or starting values

This step requires de initial set of data considered as the starting values – or the "current states" – that are indispensable for the projection. The PEIGE tool suggests the year 2015 as the starting year.

The starting values or initial values need to come preferably from the utility. These data must be the most representative of the year chosen as the initial year to establish the scenarios.

An overview of all parameters with their numbering, denotation, units, parameter feature and chapters analysing their values and trends in this methodology is provided in detail in *Annex C*.

Uncertainty Analysis

The approach presented in this guideline suggests the collection of data from different sources. Therefore, it is important to analyse the uncertainty resulting from the data used.

The GHG inventory method of the IPCC entails uncertainty related to default parameters, emission factors, and other metrics used, as explained in detail in the ECAM methodology [WaCCliM, 2019]. Since the IPCC guideline and ECAM lays the groundwork for the BAU scenario studies, this uncertainty is also inherent to the approach developed in this document.

The second aspect is linked to the methodology itself, which was addressed in part in the previous chapters. A major point is the application of a country-wide development trend on single utilities, which can exhibit individual performance in multiple aspects.

The third point is the statistical method used to determine the past trend. All the growth patterns applied only consider the start and end values of the reference period. The calculated result is thus very sensitive to the choice of the two data points.

Step 4: GHG analysis as BAU scenarios using ECAM

©Shutterstock

Step 4: GHG analysis as BAU scenarios using ECAM

The previous steps focused on preparing the different data and trends that are necessary to establish baseline emission scenarios.

This final step translates all the information outlined in this methodology into the trajectory of GHG emissions using the tool ECAM. This process can be better understood by analysing the different tasks of the tools used:

- the methodology document defines the future trend of the key parameters
- PEIGE projects ECAM inputs via automatic programming, once their current values (PEIGE inputs) have been entered[9]
- ECAM is the ultimate tool for calculating the BAU emissions at a certain point of time in the future

The process chain to convert the information from this guideline into BAU scenarios is presented in Figure 4 and has the following considerations:

1. prepare the starting values as PEIGE inputs by following the references and instructions in this chapter
2. enter the change rates or CAGR values into the grey cells. The starting values shall be inputted into the green highlighted cells of PEIGE for the future values of ECAM inputs
3. enter the projected ECAM inputs from the yellow highlighted cells of PEIGE into ECAM to compute the quantity of the respective BAU emissions.

1

Prepare the change rates or CAGR values:

- of resident population of water supply and wastewater
- of the ratio of population serviced by water supply, connected to sewers, and serviced by the wastewater utility
- of the per capita volume of abstracted water, treated water and the per capita volume of water injected to distribution for the water supply system
- of the energy intensity for all the stages of the water supply and wastewater systems
- of the electricity price (EC-01)
- of the emission factor for grid electricity
- of the year protein consumption
- of the BOD5 generation (CF-03)

Prepare starting values as PEIGE inputs for:

- Resident population in the service area (PO-01,PO-02)
- Population serviced by water supply connected to sewers, and serviced by the wastewater utility
- Volume of water and wastewater (W-01,W-03,W-05, WW-01,WW-03,WW-04, WW-07)
- Volume of billed authorized water consumption (W-07)
- BOD5 load in influent, effluent and removed sludge (WW-11, WW-12, WW-13)
- Nitrogen Concentration in the effluent (WW-14)
- Energy consumption (E-01, E-03, E-05, E-07, E-09, E-11, E-13, E-15)
- National electricity price (EC-01)
- Emission factor for grid electricity (CF-01)
- Per capita per year protein consumption (CF-02)
- Per capita per day BOD5 generation (CF-03)

2

Go to the **PEIGE tool** and introduce the values according to the following colours:

- Grey: change rates or CAGR values
- Green: initial or starting values

PEIGE will automatically project the inputs

3

Go to **ECAM** and enter the projected ECAM inputs (yellow cells of PEIGE).

Figure 5. *The process chain of the guideline, PEIGE tool, and ECAM tool.*

[9] Exception: PEIGE does not handle values of CH_4 emission factor, ECAM inputs i), which shall be provided by users themselves on the utility level.

6 Bibliography

Bibliography

2030 WRG (2030 Water Resources Group). (2009). Charting our water future: Economic frameworks to inform decision-making. 2030 WRG. Washington, DC. Available: *http://www.2030wrg.org/wp-content/uploads/2014/07/Charting-Our-Water-Future-Final.pdf* [Accessed 4 March 2019].

Doorn, M. J. & Liles, D. (1999). Quantification of methane emissions and discussion of nitrous oxide, and ammonia emissions from septic tanks, latrines, and stagnant open sewers of the world. No. EPA/600/R-99/089 (NTIS PB2000-101018). U.S. Environmental Protection Agency (EPA). Washington, DC.

EPA (Environmental Protection Agency) [US]. (2016). Understanding the link between climate change and extreme weather. Last update: 19 October 2016. Available: *https://19january2017snapshot.epa.gov/climate-change-science/understanding-link-between-climate-change-and-extreme-weather_.html* [Accessed 28 February 2017].

FAO (Food and Agriculture Organisation). (2010). Food Balance Sheets. Available: *http://www.fao.org/fileadmin/templates/ess/documents/food_security_statistics/FoodConsumptionNutrients_en.xls* [Accessed 11 December 2018].

(2014). *FAO Statistical Yearbook 2014: Asia and the Pacific food and agriculture.* Available: *http://www.fao.org/3/a-i3590e.pdf* [Accessed 19 February 2019].

(2016). AQUASTAT main database. Available: *http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en* [Accessed 15 October 2018].

(2017). FAOSTAT, Food Balance Sheets. Last update: 12 December 2017. Available: *http://www.fao.org/faostat/en/#data/FBS* [Accessed 12 February 2019].

Grigg, D. (1995). The pattern of world protein consumption. In: *Geoforum, **26** (1)*, pp. 1-17. DOI: 10.1016/0016-7185(94)00020-8.

Henchion, M., Hayes, M., Mullen, A. M., Fenelon, M., & Tiwari, B. (2017). Future Protein Supply and Demand: Strategies and Factors Influencing a Sustainable Equilibrium. In: *Foods (Basel, Switzerland), **6** (7)*, p. 53. DOI: 10.3390/foods6070053.

Henze, M. & Comeau, Y. (2008). Wastewater characterisation. In: *Biological wastewater treatment: principles modelling and design* [Henze, M., Loosdrecht, M. C. M. v., Ekama, G. A. & Brdjanovic, D. (Eds.)]. London: IWA Publishing.

IBNET (International Benchmarking Network). (2019). Benchmarking database. Available: *https://www.ib-net.org/* [Accessed 22 January 2019].

IEA (International Energy Agency). (2014). *CO_2 emissions from fuel combustion 2014.* Paris: OECD / IEA. DOI: 10.1787/co2_fuel-2014-en.

(2015). *CO_2 emissions from fuel combustion 2015.* Paris: OECD / IEA. DOI: 10.1787/co2_fuel-2015-en.

(2016a). *CO_2 emissions from fuel combustion 2016.* Paris: OECD / IEA. DOI: 10.1787/co2_fuel-2016-en.

(2016b). *Mexico energy outlook.* Paris: OECD / IEA. DOI: 10.1787/9789264266896-en.

(2016c). *World energy outlook 2016.* Paris: OECD / IEA. DOI: 10.1787/weo-2016-en.

(2017). *CO_2 emissions from fuel combustion 2017.* Paris: OECD / IEA. DOI: 10.1787/co2_fuel-2017-en.

(2018a). *CO_2 emissions from fuel combustion 2018.* Paris: OECD / IEA. DOI: 10.1787/22199446.

(2018b). *Electricity Information 2018.* Paris: OECD / IEA. DOI: 10.1787/electricity-2018-en.

(2018c). *World energy outlook 2018.* Paris: OECD / IEA. DOI: 10.1787/weo-2018-en.

(2018d). *World energy prices 2018.* Paris: OECD / IEA.

IMF (International Monetary Fund). (2019). International Financial Statistics (IFS). Last update: 07 January. Available: ***http://data.imf.org/?sk=4C514D48-B6BA-49ED-8AB9-52B0C1A0179B* [Accessed 12 January 2019].**

International Water Association (IWA). (2015). Can the water sector deliver on carbon reduction? Available: *http://www.iwa-network.org/can-the-water-sector-deliver-on-carbon-reduction/* [Accessed 1 March 2019].

IPCC (Intergovernmental Panel on Climate Change). (2001). *Climate change 2001: mitigation*. Contribution of Working Group III to the Third Assessment Report of the IPCC. Cambridge, New York: Cambridge University Press.

(2006). *2006 IPCC Guidelines for national greenhouse gas inventories*. [Eggleston H.S., B. L., Miwa K., Ngara T. and Tanabe K. (Ed.)]. Japan: IGES.

(2014a). *Climate change 2013: the physical science basis*. Contribution of Working Group I to the Fifth Assessment Report of the IPCC. [Stocker, T. F., Qin, D., Plattner, G.-K., Tignor, M. M. B., Allen, S. K., Boschung, J., *et al.* (Eds.)]. Cambridge: Cambridge University Press. DOI: 10.1017/CBO9781107415324.

(2014b). *Climate change 2014: impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects*. Contribution of Working Group II to the Fifth Assessment Report of the IPCC. [Field, C. B., Barros, V. R., Dokken, D. J., Mach, K. J., Mastrandrea, M. D., Bilir, T. E., *et al.* (Eds.)]. Cambridge: Cambridge University Press. DOI: 10.1017/CBO9781107415379.

Janssens-Maenhout, G., Crippa, M., Guizzardi, D., Muntean, M., Schaaf, E., Dentener, F., *et al.* (2017). EDGAR v4.3.2 Global Atlas of the three major Greenhouse Gas Emissions for the period 1970-2012. In: *Earth Syst. Sci. Data Discuss.*, ***2017***, pp. 1-55. DOI: 10.5194/essd-2017-79.

Jiménez Cisneros, B. E., Oki, T., Arnell, N. W., Benito, G., Cogley, J. G., Döll, P., *et al.* (2014). Freshwater resources. pp. 229-270. In: *Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of Working Group II to the Fifth Assessment Report of the IPCC* [Field, C. B., Barros, V. R., Dokken, D. J., Mach, K. J., Mastrandrea, M. D., Bilir, T. E., *et al.* (Eds.)]. Cambridge: Cambridge University Press. DOI: 10.1017/CBO9781107415379.008.

JRC (Joint Research Centre) of the European Commission & PBL (Netherlands Environmental Assessment Agency). (2016). Emissions Database for Global Atmospheric Research (EDGAR), release version 4.3.2 (1970-2012). Last update: 30 October 2017.[Accessed 1 December 2018]. DOI: 10.2904/JRC_DATASET_EDGAR.

Khatri, K. & Vairavamoorthy, K. (2008). Challenges for urban water supply and sanitation in the developing countries. DOI: 10.1201/9780203878057.ch7.

Kingdom, B., Liemberger, R., & Marin, P. (2006). The challenge of reducing non-revenue water (NRW) in developing countries. How the private sector can help: a Look at performance-based service contracting. Water supply and sanitation sector board discussion paper series No. 8. The World Bank. Available: *https://siteresources.worldbank.org/INTWSS/Resources/WSS8fin4.pdf* [Accessed 22 January 2019].

Krishna Reddy, Y. V., Adamala, S., Levlin, E. K., & Reddy, K. S. (2017). Enhancing nitrogen removal efficiency of domestic wastewater through increased total efficiency in sewage treatment (ITEST) pilot plant in cold climatic regions of Baltic Sea. In: *International Journal of Sustainable Built Environment, **6** (2)*, pp. 351-358. DOI: 10.1016/j.ijsbe.2017.05.002.

Kundzewicz, Z. W., Mata, L. J., Arnell, N., Döll, P., Kabat, P., Jiménez, B., *et al.* (2007). Freshwater resources and their management. pp. 173-210. In: *Climate change 2007: impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the IPCC* [Parry, M., Canziani, O., Palutikof, J., Linden, P. v. d. & Hanson, C. (Eds.)]. Cambridge: Cambridge University Press.

Law, Y., Ye, L., Pan, Y., & Yuan, Z. (2012). Nitrous oxide emissions from wastewater treatment processes. In: *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences, **367** (1593)*, pp. 1265-1277. DOI: 10.1098/rstb.2011.0317.

Makaya, E. (2015). Water loss management strategies for developing countries: Understanding the dynamics of water leakages. Universität Kassel / Witzenhausen. Kassel. Available: *https://d-nb.info/1112580042/34* [Accessed 1 December 2018].

Mara, D. (2004). Domestic wastewater treatment in developing countries. Earthscan. London / Sterling.

Marsalek, J., Jiménez, B., Malmquist, P. A., Karamouz, M., Goldenfum, J., & Chocat, B. (2006). *Urban Water Cycle Processes and Interactions*. UNESCO International Hydrological Programme, Technical Documents in Hydrology No. 78. Paris: UNESCO. Available: *https://hydrologie.org/BIB/Publ_UNESCO/TD_078_2006.pdf* [Accessed 1 March 2019].

OECD (Organisation for Economic Co-operation and Development). (2012). *OECD Environmental Outlook to 2050: the consequences of inaction*. Paris: OECD Publishing. DOI: 10.1787/9789264122246-en.

OECD / FAO. (2015). *OECD-FAO Agricultural Outlook 2015-2024*. DOI: 10.1787/agr_outlook-2015-en, 10.1787/agr-outl-data-en.

(2018). *OECD-FAO Agricultural Outlook 2018-2027*. DOI: 10.1787/agr_outlook-2018-en.

Roser, M. & Ortiz-Ospina, E. (2018). World Population Growth. *Oxford Martin Programme on Global Development, University of Oxford*. Last update: April 2017. Available: *https://ourworldindata.org/world-population-growth* [Accessed 20 November 2018].

Timmer, C. P., Falcon, W. P., & Pearson, S. R. (1983). *Food policy analysis.* In: A World Bank publication. Baltimore, Md. [u.a.]: Johns Hopkins Univ. Press.

UN (United Nations). (2013). *Water security and the global water agenda.* A UN-Water analytical brief. [Bigas, H. (Ed.)]. Hamilton: United Nations University. 37 pages. Available: *http://www.unwater.org/downloads/watersecurity_analyticalbrief.pdf* [Accessed 02 March 2016].

UNDESA (United Nations Department of Economic and Social Affairs). (2017a). World Population Prospects 2017. Available: *https://population.un.org/wpp/* [Accessed 25 December 2018].

(2017b). World Population Prospects: the 2017 revision, methodology of the United Nations population estimates and projections. UN. New York. Available: *https://population.un.org/wpp/Publications/Files/WPP2017_Methodology.pdf* [Accessed 1 March 2019].

(2018). World Urbanisation Prospects 2018. Available: *https://population.un.org/wup/* [Accessed 25 December 2018].

UNSD (United Nations Statistics Division). (2016). Environment Statistics (ENVSTAT). Available: *https://unstats.un.org/unsd/envstats* [Accessed 1 March 2019]

Vörösmarty, C. J., McIntyre, P. B., Gessner, M. O., Dudgeon, D., Prusevich, A., Green, P.*, et al.* (2010). Global threats to human water security and river biodiversity. In: *Nature, **467** (7315)*, pp. 555-561. DOI: 10.1038/nature09440.

WaCCliM (Water and Wastewater Companies for Climate Migitation). (2019). ECAM 2.2 Methodology. Available: *http://wacclim.org/library/ecam-methodology-guide/* [Accessed 20 March 2019].

WHO (World Health Organisation) & UNICEF (United Nations International Children's Emergency Fund). (2017a). Progress on Drinking water, Sanitation and Hygiene – 2017 update and SDG baselines. Available: *https://washdata.org/report/jmp-2017-report-final* [Accessed 1 February 2019].

(2017b). The WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene (JMP) database. Available: *https://washdata.org/* [Accessed 1 February 2019].

(2018). JMP Methodology: 2017 update & SDG baselines. Available: *https://washdata.org/report/jmp-methodology-2017-update* [Accessed 1 February 2019].

WWAP (World Water Assessment Programme of UN). (2014). The United Nations World Water Development Report 2014: Water and energy. UNESCO. Paris.

(2015). The United Nations World Water Development Report 2015: Water for a sustainable world. UNESCO. Paris.

Annex A
Overview of all GHG emissions from water and wastewater services

	Water abstraction	Water treatment	Water distribution	WW collection	WW treatment	WW discharge
Scope 1 – Direct emissions						
CO_2, CH_4 and N_2O emissions from on-site engine stationary fossil fuel combustion	o	o	o	o	o	o
CH_4 from sewers or biological wastewater treatment				o	▪	
N_2O from sewers or biological wastewater treatment				o	▪	
Scope 2 – Indirect emissions						
Indirect emissions from electric energy	▪	▪	▪ ○○	▪ ○	▪	▪ ○
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			o	o		o
Emissions from the manufacturing of chemical used		o			o	
Emissions from the construction materials used	o	o	o	o	o	o
CH_4 and N_2O emissions from wastewater discharge without treatment				▪		
CO_2, CH_4 and N_2O emissions from sludge transport offsite					o	
N_2O emissions from effluent discharge in receiving waters						▪

○ ***Emissions not quantified, even though they exist***
▪ ***Emissions quantified in the guideline***
• ***Unless wastewater collection/discharge is by gravity***
○○ ***Unless water distribution is gravity (natural) fed***

Source: ECAM Methodology version 2.0, with adaptations.

Annex B
Analysis of key parameters shaping baseline GHG emissions in the urban water cycle

The GHG quantification methodology defined in the IPCC Guideline [2006] provides the basis for the studies on the parameters that are critical in shaping baseline scenarios. The measurement follows the general rule that emissions are the product of the magnitude of human activity resulting in emissions taking place in a given period and the average emission rate of a given GHG for a given source relative to units of activity:

$$Emissions = Activity\ Data \cdot Emission\ Factor \qquad (A)$$

Since the activity data and emission factors vary for gases, a concise analysis is detailed hereafter to identify the key parameters and terms affecting baseline projections of GHG emissions in the urban water cycle.

Key parameters determining CO2 emissions

CO_2 emissions as defined by this methodology are those from fossil fuel combustion attributed to purchased electricity. The emissions are quantified as the product of electric power consumption in kilowatt-hours (kWh) and the emission factor in kg CO_2 per kWh electricity:

$$Emissions_{CO_2} = Amount\ of\ Electricity\ Consumed \cdot Emission\ Factor\ per\ Unit\ Electricity \qquad (B)$$

For the emission factor of grid electricity (EF_{grid}), the average annual country default value for electricity supply is usually applied, if local data are not available. EF_{grid} differs from year to year due to reasons such as changes in the fuel mix and efficiency improvement of grid power generation. Fuel mix variations can be caused by the gradual structural transformation over a longer term as well as temporary fluctuations in the fuel supply, especially in those countries that are heavily dependent on energy import. Consequently, the development trend of the emission factor in the future shall be studied in order to project relevant CO_2 emissions.

The evolution of the quantity of electricity consumption is dependent on multiple issues and can be further broken down into subcomponents as follows:

Water supply:
- The total population in the service area of water utilities (POPws_resi)
- The ratio of residents served by the water utilities (Rws_serv_resi)
- The quantity of water to be produced for each resident on average to meet the consumption needs (VOLws/POPws_serv)
- The amount of energy required to abstract, treat and distribute each unit volume of water (Ews/VOLws)

Wastewater management:
- The total population in the service area of WWTPs (POPww_resi)
- The ratio of residents connected to sewers (Rww_conn_resi) and served by WWTPs (Rww_serv_resi)
- The average quantity of wastewater to be managed for each resident (VOLww/POPww_serv)
- The amount of energy required to collect, treat, and discharge each unit volume of wastewater (Eww/VOLww)

For the detailed evaluation at the sub-stage level, the CO_2 emissions from electricity can be expressed in a mathematic relation to the terms described above as:

$$Emissions_{CO_2} = \sum_i POP_{resi} \cdot \frac{POP_i}{POP_{resi}} \cdot \frac{VOL_i}{POP_i} \cdot \frac{E_i}{VOL_i} \cdot \frac{C_i}{E_i} \qquad (C)$$

Where
- i refers to the sub-stages in the water and wastewater services.
- POPresi refers to the total residents in the service area.
- POPi is the population of the resident group that is relevant for stage i concerning access to the water and wastewater services. In the water supply, POPi is the same for all the sub-stages as those served by water services. In the wastewater management, POPi considered in both collection and discharge is the group connected to sewers, while POPi in treatment refers to the population whose wastewater is treated in WWTPs.
- Ci/Ei refers to the carbon intensity of electricity consumed in sub-stage i.

Key parameters determining CH_4 emissions

CH_4 emissions considered in the urban water sector all belong to the wastewater section. The emission process is substantially determined by the total organically degradable carbon in wastewater (TOW) and the type of treatment technologies and conditions that characterise the CH_4 emission rate from the organics.

The TOW is most important as it indicates the amount of carbon that can be released as CH_4. For domestic wastewater, the Biochemical Oxygen Demand over five days, denoted as BOD_5, is the most frequently used parameter to measure the organic component. The activity data TOW is thus quantified as a function of the population, their average BOD_5 generation per person per day, and the length of the period considered:

$$TOW = POP \cdot BOD_5 \cdot Days \qquad (D)$$

The emission factor, expressed in kg CH_4 per kg BOD_5, is dependent on the treatment and discharge pathway. It is the product of the maximum CH_4 producing potential, usually as default or country-specific value, and the methane correction factor. The latter, which indicates the degree of the anaerobic condition is given as a default value for different technologies and discharge environment by the IPCC.

Since wastewater treatment removes a large fraction of BOD with sludge, the fraction of TOW that remains in the wastewater as the potential source of CH_4 emissions can be greatly reduced. Although the anaerobic digestion of the sludge also converts the removed organics into methane which is partly released as biogas, the emission in this step can be controlled to zero through the valorisation of biogas to an energy source.

Consequently, the development of CH_4 emissions in baseline scenarios, i.e., in the existing treatment system and discharge environment, is predominantly determined by variations of organics generated by the total population and the degree of wastewater treatment including methane recovery. Therefore, three questions arise in the evaluation of BAU scenarios, namely:

- The number of the total population in the service area of WWTPs (POPww_resi)
- The ratio of residents connected to sewers (Rww_conn_resi) and served by WWTPs (Rww_serv_resi)
- The quantity of BOD5 generated by each resident per day in the same length of the assessment period (BOD5)

Thus, the relation between CH_4 emissions and the parameters can be expressed as:

$$Emissions_{CH_4} = \left[\sum_j \left(POP_{resi} \cdot R_j\right) \cdot \left(1 - S_j^{BOD}\right) \cdot T_j^{CH_4}\right] \cdot BOD_5^{a.p.} \qquad (E)$$

Where
- j indicates the resident groups with different connection degrees, divided into those whose wastewater is not collected, collected but not treated, and fully collected and treated.
- POPresi refers to the total residents in the service area.
- Rj is the proportion of group j in the total population POPresi .
- S_j^{BOD} is the ratio of BOD removal in treatment processes of group j. For those whose wastewater is not treated, the result equals zero.
- Tj refers to the emission rate associated with the treatment/discharge system of group j.
- $BOD_5^{a.p.}$ refers to the per person BOD5 generation in the assessment period.

Key parameters determining N2O emissions

In order to quantify N_2O emissions in the urban water cycle, the activity data required are the total nitrogen (TN) load in the sewage, which can be calculated as the product of the population producing this part of wastewater, their average protein consumption quantity per person per year, the length of the period considered and the nitrogen content in per unit protein. The result is corrected by default parameters as defined by the IPCC [2006] to include non-consumed protein washed away as food waste and protein contained in co-discharged industrial or commercial wastewater. Thus, the nitrogen content is estimated as:

$$TN = POP \cdot \left(\frac{PROTEIN}{365} \cdot Days\right) \cdot F_{Nitrogen\,in\,Protein} \cdot F_{NON-CON} \cdot F_{IND-COM} \qquad (F)$$

At the same time, the N_2O emission factor associated with receiving water for untreated wastewater and discharged effluents from WWTPs is a fixed value defined by the IPCC [2006] based on assumptions regarding the occurrence of nitrification and denitrification in rivers and estuaries.

The nitrogen compounds in sewage can be removed by different technologies during wastewater treatment. This reduces the nitrogen content in the treated effluents as well as the potential quantity of N_2O emissions in the natural water body. The ECAM tool also considers emissions during the treatment, but this component of the emissions is estimated at only 3.2 g N_2O per person per year [IPCC, 2006]. Thus, the total N_2O emissions of treated sewage are significantly lower than the situation, providing the wastewater is directly discharged without treatment.

In summary, baseline N_2O emissions in an existing technical system are predominantly determined by variations of the protein generation as well as the coverage and degree of wastewater treatment. For future studies on BAU scenarios, three separate issues are of importance:

- The total population in the service area of WWTPs (POPww_resi)
- The ratio of residents connected to sewers (Rww_conn_resi) and served by WWTPs (Rww_serv_resi)
- The quantity of protein consumption per person per day in the same length of the assessment period (PROTEIN)

Equation (G) shows the mathematical connection between the parameters and N_2O emissions:

$$Emissions_{N_2O} = \left[\sum_j \left(POP_{resi} \cdot R_j \right) \cdot (1 - S_j^N) \times T_j^{N_2O} \right] \times PROTEIN^{a.p.} \qquad (G)$$

Where
- j indicates the resident groups with different connection degrees, divided into those whose wastewater is not collected, collected but not treated, and fully collected and treated.
- POPresi refers to the total residents in the service area.
- Rj is the proportion of group j in the total population POPresi .
- S_j^N is the ratio of nitrogen removal of group j. For those whose wastewater is not treated, the result equals zero.
- Tj refers to the emission rate associated with the treatment/discharge system of group j.
- PROTEINa.p. is the per person protein consumption in the assessment period.

Annex C
Overview of parameters and ECAM inputs

Parameters	Parameter-no.	Key parameters (KP)	PEIGE inputs	ECAM inputs	Denotation	Units in PEIGE / ECAM
Resident population of water supply	PO-01	Y (U-N)	Y	Y	POP_{ws_resi}	persons
Resident population of wastewater	PO-02	Y (U-N)	Y	Y	POP_{ww_resi}	persons
Population serviced by water supply	PO-03		Y	Y	POP_{ws_serv}	persons
Ratio of the population serviced by water supply	PO-04	Y (U-N)			$R_{ws\_serv\_resi}$	%
Population connected to sewers	PO-05		Y	Y	POP_{ww_conn}	persons
Population serviced by WWTPs	PO-06		Y	Y	POP_{ww_serv}	persons
Ratio of the population connected to sewers	PO-07	Y (U-N)			$R_{ww\_conn\_resi}$	%
Ratio of the population serviced by WWTPs	PO-08	Y (U-N)			$R_{ww\_serv\_resi}$	%
Volume of abstracted water	W-01		Y	Y	VOL_{wsa_conv}	m³/year
Per capita volume of abstracted water	W-02	Y			VOL_{wsa_conv} / POP_{ws_serv}	m³/capita/year
Volume of treated water	W-03		Y	Y	VOL_{wst_trea}	m³/year
Per capita volume of treated water	W-04	Y			VOL_{wst_trea} / POP_{ws_serv}	m³/capita/year
Volume of water injected to distribution	W-05		Y	Y	VOL_{wsd_dist}	m³
Per capita volume of water injected to distribution	W-06	Y			VOL_{wsd_dist} / POP_{ws_serv}	m³/capita/year
Volume of billed authorised consumption	W-07		Y		VOL_{wsd_bill}	m³
Non-Revenue Water	W-08	Y			NRW	%
Per capita end-user consumption	W-09				VOL_{wsd_bill}/ POP_{ws_serv}	m³/capita/year
Per capita end-user consumption	W-10				VOL_{wsd_bill}/ POP_{ws_serv}	L/capita/year
Volume of wastewater conveyed for treatment	WW-01		Y	Y	VOL_{wwc_conv}	m³
Per capita volume of wastewater conveyed for treatment	WW-02	Y			VOL_{wwc_conv}/ POP_{ww_conn}	m³/capita/year

Parameters	Parameter-no.	Key parameters (KP)	PEIGE inputs	ECAM inputs	Denotation	Units in PEIGE / ECAM
Volume of treated wastewater	WW-03		Y	Y	VOL_{wwt_trea}	m^3
Per capita volume of treated wastewater	WW-04	Y			$VOL_{wwt\_trea}/POP_{ww\_serv}$	m^3/capita/year
Volume of discharged effluent to water body	WW-05		Y	Y	VOL_{wwd_disc}	m^3
Per capita volume of discharged effluent	WW-06	Y			$VOL_{wwd\_disc}/POP_{ww\_conn}$	m^3/capita/year
Volume of reused effluent	WW-07		Y	Y	VOL_{wwd_nonp}	m^3
Per capita volume of reused effluent	WW-08	Y			$VOL_{wwd\_nonp}/POP_{ww\_conn}$	m^3/capita/year
Volume of discharged & reused effluent	WW-09				$VOL_{wwd}= VOL_{wwd\_disc}+VOL_{wwd\_nonp}$	m^3
Per capita volume of discharged & reused effluent	WW-10				VOL_{wwd}/ POP_{ww_conn}	m^3/capita/year
Influent BOD_5 load	WW-11		Y	Y	BOD_{infl}	kg
Effluent BOD_5 load	WW-12		Y	Y	BOD_{effl}	kg
BOD removed as sludge	WW-13		Y	Y	BOD_{slud}	kg
Total nitrogen concentration in the effluent	WW-14		Y	Y	NC_{effl}	mg/L
Ratio of removed nitrogen in treated wastewater	WW-15				$R_{N\_wwt\_rmvd}$	%
Electricity consumed for total water supply	E-01		Y (A)	Y (A)	E_{ws}	kWh
Energy intensity of total water supply	E-02	Y (A)			E_{ws}/ VOL_{wsd_dist}	kWh/m^3
Electricity consumed for water abstraction	E-03		Y	Y	E_{wsa}	kWh
Energy intensity of water abstraction	E-04	Y			E_{wsa}/ VOL_{wsa_conv}	kWh/m^3
Electricity consumed for water treatment	E-05		Y	Y	E_{wst}	kWh
Energy intensity of water treatment	E-06	Y			E_{wst}/ VOL_{wst_trea}	kWh/m^3
Electricity consumed for water distribution	E-07		Y	Y	E_{wsd}	kWh
Energy intensity of water distribution	E-08	Y			E_{wsd}/ VOL_{wsd_dist}	kWh/m^3
Electricity consumed for total wastewater	E-09		Y (A)	Y (A)	E_{ww}	kWh
Energy intensity of total wastewater	E-10	Y (A)			E_{ww}/ VOL_{wwt_trea}	kWh/m^3
Electricity consumed for wastewater collection	E-11		Y	Y	E_{wwc}	kWh
Energy intensity of wastewater collection	E-12	Y			E_{wwc}/ VOL_{wwc_conv}	kWh/m^3

Parameters	Parameter-no.	Key parameters (KP)	PEIGE inputs	ECAM inputs	Denotation	Units in PEIGE / ECAM
Electricity consumed for wastewater treatment	E-13		Y	Y	E_{wwt}	kWh
Energy intensity of wastewater treatment	E-14	Y			E_{wwt}/ VOL_{wwt_trea}	kWh/m³
Electricity consumed for wastewater discharge	E-15		Y	Y	E_{wwd}	kWh
Energy intensity of wastewater discharge	E-16	Y			E_{wwd}/ VOL_{wwd_disc}	kWh/m³
National electricity price	EC-01	Y	Y		P_{elec}	national currency/kWh
Energy costs of total water supply	EC-02			Y	EC_{ws}	national currency
Energy costs of total wastewater	EC-03			Y	EC_{ww}	national currency
Emission factor for grid electricity	CF-01	Y	Y	Y	EF_{grid}	$kgCO_2$/kWh
Protein generation per capita per year	CF-02	Y	Y	Y	PROTEIN	kg/capita/year
BOD_5 generation per capita per day	CF-03	Y	Y	Y	BOD_5	g/capita/day
CH_4 emission factor of uncollected wastewater	CF-04			Y	$EF_{ww\_ch4\_unc}$	$kgCH_4$/kgBOD
CH_4 emission factor of collected but untreated wastewater	CF-05			Y	$EF_{ww\_ch4\_unt}$	$kgCH_4$/kgBOD
CH_4 emission factor of wastewater treatment process	CF-06			Y	EF_{wwt_ch4}	$kgCH_4$/kgBOD
CH_4 emission factor of discharged effluent	CF-07			Y	EF_{wwd_ch4}	$kgCH_4$/kgBOD

Remarks: Y: Yes Y (U-N): Yes, with urban-national divide Y (A): Yes for Tier-A-only assessment

Annex D
Projection of nitrogen concentration in the effluent

The nitrogen content in the effluent is the result of the TN of all collected wastewater minus the part that is removed in the treatment. The corresponding nitrogen content NC_{effl} can be expressed as:

$$NC_{effl} = \frac{TN_{collected\ WW} - TN_{treated\ WW} \cdot R_{N\_wwt\_rmvd}}{VOL_{wwc}} \qquad (H)$$

Where $R_{N\_wwt\_rmvd}$ refers to the ratio of nitrogen removed from the treated wastewater.

Based on equation (F) in ***Annex B*** and assuming that the technical performance remains stable in the BAU scenarios, equation (H) can be applied to project nitrogen concentration in year t (NC_{effl}^{t}) and extended as:

$$NC_{effl}^{t}[mg/L] = \frac{\left[POP_{ww\_conn}^{t} - POP_{ww\_serv}^{t} \cdot R_{N\_wwt\_rmvd}\right] \cdot PROTEIN^{t} \cdot 0.16 \cdot 1.1 \cdot 1.25}{VOL_{wwc}^{t}} \cdot 1000 \qquad (I)$$

Where

- 1000: NCeffl is converted from kg/m³ to mg/L
- PROTEIN: per capita per year protein consumption in kg protein
- 0.16: factor of nitrogen content in per unit protein Fnitrogen in protein, default = 0.16 kg N/kg protein
- 1.1: factor of non-consumed protein as food waste FNON-CON, 1.1 for developing countries
- 1.25: factor for industrial/commercial co-discharged protein into the sewage system FIND-COM

While all other parameters are projected with the approches developed in various parts of ***Chapter 0***, the value of the term $R_{N\_wwt\_rmvd}$ needs to be determined.

On the **national level**, the average value of $R_{N\_wwt\_rmvd}$ is suggested in ***Chapter 2.3.12*** based on the distribution of different treatment technologies. The associated national mean of NC_{effl} as PEIGE inputs is also provided in this chapter.

On the **utility level**, the value of $R_{N\_wwt\_rmvd}$ can be identified methmatically through on-site data. Since $R_{N\_wwt\_rmvd}$ is assumed to be fixed over the entire period of BAU scenarios, equation (I) can be re-formulated as a function of $R_{N\_wwt\_rmvd}$ depending on other variables in year t as:

$$R_{N\_wwt\_rmvd} = \frac{POP_{ww\_conn}^{t}}{POP_{ww\_serv}^{t}} - \frac{\left(VOL_{wwc}^{t} \cdot \frac{NC_{effl}^{t}}{1000}\right)}{POP_{ww\_serv}^{t} \cdot PROTEIN^{t} \cdot 0.16 \cdot 1.1 \cdot 1.25} \qquad (J)$$

Based on equation (J), the current (fixed) value of $R_{N\_wwt\_rmvd}$ can be determined mathematically using PEIGE inputs (2015 values) of the items POP_{ww_conn}, POP_{ww_serv}, PROTEIN, VOL_{wwd} and NC_{effl}:

$$R_{N\_wwt\_rmvd} = \frac{POP_{ww\_conn}^{2015}}{POP_{ww\_serv}^{2015}} - \frac{\left(VOL_{wwc}^{2015} \cdot \frac{NC_{effl}^{2015}}{1000}\right)}{POP_{ww\_serv}^{2015} \cdot PROTEIN^{2015} \cdot 0.16 \cdot 1.1 \cdot 1.25} \qquad (K)$$

Both equation (I) and (K) have been programmed in PEIGE, which calculates $R_{N\_wwt\_rmvd}$ and NC_{effl} in BAU scenarios in mg/L automatically after users enter the current NC_{effl} – of a single utility or the average national value – into the Excel tool.

Annex E
Statistical methods for calculating average growth rates

Average growth rates are widely used in scientific research as well as in daily life. They describe the course of changes of a certain variable during a certain period. Growth rates are subject to assumptions about patterns of growth. In this guideline, three different types of annual growth rates are applied, namely arithmetic, exponential, and geometrical growth. In this section, all three patterns will be described briefly according to UNSD [UNESCAP, 2015].

Arithmetic growth rates

Arithmetic growth means the variable decreases or increases by a constant absolute quantity in each period unit and implies a linear trend. The average arithmetic growth rate (r_{AG}) of the variable X between the time point 0 and t is derived as:

$$r_{AG} = \frac{\left(\frac{X_t}{X_0} - 1\right)}{t} \qquad (L)$$

Consequently, the value of the variable X at the time point t is calculated in relation to the value at the starting time point 0 as:

$$X_t = X_0 \cdot (1 + r_{AG} \cdot t) \qquad (M)$$

X_t can also be quantified based on the value at the previous time point t-1 through:

$$X_t = X_{t-1} + (r_{AG} \cdot X_0) \qquad (N)$$

For the BAU scenario establishment, the infrastructure coverage and NRW are assumed to undergo an arithmetic trend.

Exponential growth rates

Exponential growth means the growth compounds continuously at every instant of time, or the variable grows at a constant rate at every infinitesimal of time. It is the limiting case of compounding. The exponential growth rate is mostly used in the scientific field of biology. For the BAU scenarios, the population is assumed to grow exponentially as it is a conventional method adopted by international organisations such as the UN.

The average exponential growth rate (r_{EG}) between time point t and 0 is calculated by:

$$r_{EG} = \frac{LN\left(\frac{X_t}{X_0}\right)}{t} \qquad (O)$$

Consequently, the value of the variable X at the time point t is calculated in relation to the value at the starting time point 0 as:

$$X_t = X_0 \cdot e^{(r_{EG} \cdot t)} \qquad (P)$$

In the BAU Guideline, the absolute quantity of population has been projected by UNDESA for every single year in the future. Thus, the corresponding growth rate varies from year to year, denoted as r_t and derived from UN data through:

$$r_t = LN\left(\frac{POP_t}{POP_{t-1}}\right) \qquad (Q)$$

Thus, PEIGE calculates the population of year t based on the population of the year before and the embedded growth rate r_t as:

$$POP_t = POP_{t-1} \cdot e^{r_t} \qquad (R)$$

Hence, the population of year t is related to the population of the starting year POP_0 as follows:

$$POP_t = POP_0 \cdot e^{r_1} \cdot e^{r_2} \ldots \cdot e^{r_t} = POP_0 \cdot e^{(r_1 + r_2 \ldots + r_t)} \qquad (S)$$

Geometric growth rates

Geometric growth is a special case of exponential change. It occurs when the variable decreases or increases by a certain ratio from one period to the other. Since the variable is increasing, geometric growth implies incremental changes are becoming larger in the absolute quantity. The geometric growth method is one of the prevailing patterns used in practice. This guideline applies it to project all variables except the two described above.

Geometric average growth rate, also widely named compound annual growth rate (CAGR), is calculated as follows:

$$r_{CAGR} = \left(\frac{X_t}{X_0}\right)^{\frac{1}{t}} - 1 \qquad (T)$$

Consequently, the value of the variable X at the time point t is calculated in relation to the value at the time point 0 as:

$$X_t = X_0 \cdot (1 + r_{CARG})^t \qquad (U)$$

The relation of the value at the time point t with the value at the previous time point t-1 is measured as:

$$X_t = X_{t-1} \cdot r_{CAGR} \qquad (V)$$

All three patterns do not take into consideration the intermediate values between the first and last points. Therefore, the calculated growth rates are very sensitive to the choice of starting and ending positions and very reactive to temporary fluctuations. Hence, in the case of higher data uncertainty, the average value over three consecutive years is used for the start and end values in the BAU methodology, which is also a common practice.

For more detailed information, please refer to UNESCAP [2015].

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

www.wacclim.org

Published by:
c/o **Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)** GmbH
Postfach 5180 / 65726 Eschborn / Germany
T: +49 61 96 79-0
E: info@giz.de
I: www.giz.de

c/o **IWA – International Water Association**
Alliance House / 12 Caxton Street /
London SW1H 0QS / United Kingdom
T: +44 207 654 5500
E: water@iwahq.org
I: www.iwa-network.org

Contact:
wacclim@giz.de
www.wacclim.org
@WaCCliM_Projekt

October 2020

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