Water and Wastewater Companies for Climate Mitigation

WaCCliM

The Roadmap to a Low-Carbon Urban Water Utility

The Roadmap

to a Low-Carbon Urban Water Utility

An international guide to the WaCCliM approach

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Forewords

By Kalanithy Vairavamoorthy

IWA Executive Director

This year, the International Water Association (IWA) has been developing its new 5-year strategic plan and one of its key strategic goals relates to the need for innovations to help the urban water sector respond to the challenges associated with global change pressures. As such, I am very proud that IWA participated in the WaCCliM Project, as it provides a major contribution in the transition to carbon-neutral urban water and wastewater services.

Having been associated with IWA for over 20 years, I have heard first-hand from our worldwide membership that their cities are facing a range of dynamic regional and global pressures. Climate change is predicted to cause significant changes affecting different cities in different ways, with some experiencing more frequent droughts and water shortages, while others will have more intense storm events with subsequent flooding issues.

While the water sector has to cope with the impacts of climate change, it also contributes up to 17 percent of greenhouse gas emissions locally. Hence, there is a need for fundamental change in the way we manage urban water based on a foundation of research, technology and innovation.

The IWA, through its worldwide membership, is at the forefront in promoting the development of these innovations, by bringing together experts from across the globe to catalyse change towards more sustainable urban water management. The Association achieves this by demonstrating research and sharing knowledge across a range of different geographical, climatic and socio-cultural settings, so that the global adoption of more sustainable solutions is accelerated.

Carbon-neutral and climate-resilient water systems are essential to this and IWA is proactively encouraging global utilities from within its membership and beyond to become leaders in climate mitigation and adaptation. The WaCCliM Project and the Roadmap to a Low-Carbon Urban Water Utility has provided solid evidence of how this can be achieved. We believe that many of our utility members will be early adopters of the WaCCliM roadmap, as it will help guide and inspire them on the path to carbon-neutral urban water and wastewater services.

IWA hopes that through the WaCCliM Project, we can help create a new generation of urban leaders with radically different thinking to deliver a real paradigm shift in urban water management. IWA, along with its global partners, will continue to produce knowledge, technologies, models and techniques, to create and support these new urban leaders.

By Thomas Stratenwerth

Head of Division – General, European and International Water Management Issues
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Around 2005 the Joint Research Centre of the European Commission issued two reports on the possible impacts of climate change on European waters and seas. These quite alarming reports were presented to and discussed by the European Water Directors. Consequently, we in the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety held a conference on Climate Change and the European Waters during the German European Union presidency in 2007, which was successful in raising awareness. For me, this was the starting point for intensive engagement in the development of the German Strategy for Adaptation to Climate Change, which has been my responsibility since then.

We have only just started to experience the drastic impacts of climate change on water and energy availability. An increased awareness of the interrelation between water, energy and carbon is the first stepping stone in developing a sectorial strategy to reduce greenhouse gas emissions that will support the transition to a climate-resilient future. The water sector's contribution to this transition and to the Nationally Determined Contributions under the Paris Agreement starts from a greater focus on energy requirements, greenhouse gas implications and clear carbon emission reduction targets.

Since 2013, the International Climate Initiative of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety has been supporting the '**Water and Wastewater Companies for Climate Mitigation**' (WaCCliM), a programme jointly implemented between the International Water Association and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). WaCCliM assists utilities in significantly reducing their greenhouse gas emissions, supporting the development of mitigation strategies in the water sector and having the final goal of achieving transformational changes and leading the sector to a **low-carbon economy**. WaCCliM has been implemented in Mexico, Peru, Thailand and Jordan. The tools developed with a focus on supporting utilities in emerging economies are a major achievement of this project.

The **Roadmap to a Low-Carbon Urban Water Utility**, a legacy from the WaCCliM project, builds on the experiences gained during the implementation of the project. It will support water utility managers around the world in their efforts to improve performance and achieve carbon neutrality of their utilities while raising the awareness of policy-makers to the substantial contributions the water sector can provide in meeting greenhouse-gas reduction targets. Local action is needed to support global targets!

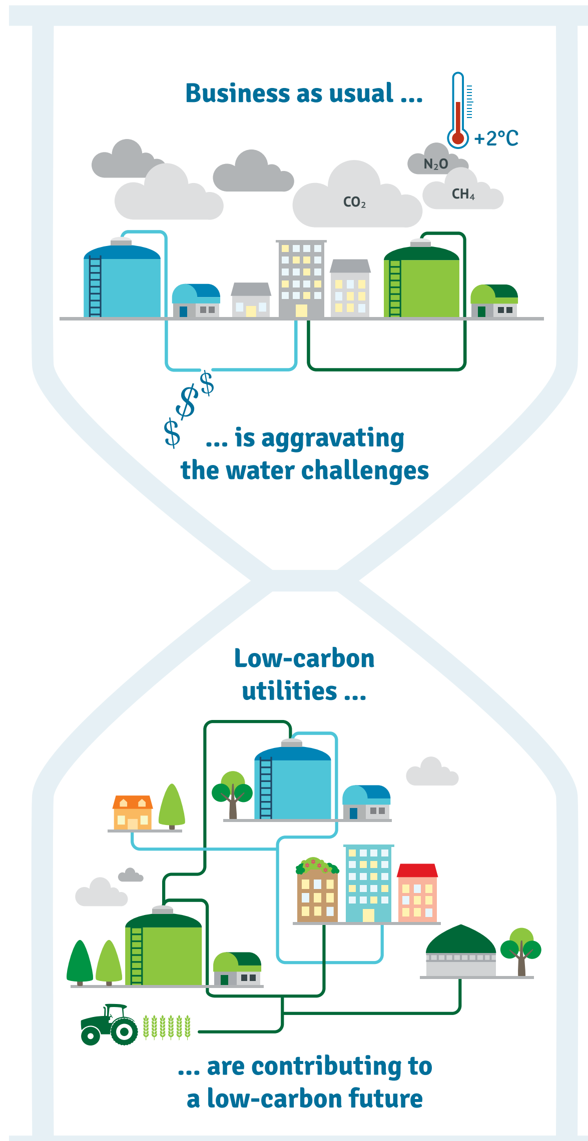
Content

Executive Summary

The Roadmap to a Low-Carbon Urban Water Utility presents utility managers with an approach to address their most pressing challenges, while reducing carbon emissions through measures that either have a return on investment through energy or water savings, or that correspond to planned investments as part of the asset management plan to maintain or improve their services. Utilities adopting this approach are contributing to a carbon-neutral future, by instigating a change of mind-set, not only in urban water management but also by inspiring all other urban services through sharing the risks and the urgency to act to avoid aggravated impacts of climate change, of which water utilities are among the first victims: water scarcity, flooding and deteriorated water quality.

To become a low-carbon urban water utility and a leader in climate change mitigation, champions are needed, who will drive the change in their respective urban water utilities and cities. It is also about realising that urban water management is intrinsically linked to energy consumption and production, as well as to greenhouse gas (GHG) emissions and opportunities to reduce/offset them. The urban water utilities represent an untapped potential to further reduce overall GHG emissions. Diluted in the total global emissions, it might seem like a small contribution; however, if the urban water sector were to become carbon neutral, it could contribute the equivalent of 20% of the sum of committed reductions by all countries in the Paris Agreement (i.e. the Nationally Determined Contributions). In addition, because water is connected to all urban sectors, and many low-carbon measures would be best implemented in partnership with other sectors, water utilities can drive an even bigger impact, by catalysing and supporting the low-carbon mind-set in all other urban sectors.

The process for utility champions to progress towards low-carbon urban water is highlighted below, as five steps that the utility implements several times, with each iteration increasing the capacity of the utility to contribute to a carbon-neutral future.



1 Motivate Action

It begins with identifying the drivers that will make the connection between the utility's main objectives and the low-carbon opportunities. Once this connection is made, the dialogue with the utility's stakeholders can start towards initiating a low-carbon mind-set.

2 Assess Your System

This connection is then strengthened through assessing the utility's urban water systems. The assessment is a visualisation of the existing level of carbon emissions and the most important water and energy inefficiencies using a holistic approach to water, wastewater and drainage services, recognising that all urban 'waters' are inter-connected. It is also a way of pointing out how reducing these inefficiencies may contribute to lowering the GHG footprint.

3 Identify Opportunities

Evaluating opportunities to reduce emissions in the light of planned improvements is a way to ease into applying the mind-set shift to more stakeholders within the utility. All GHG reduction measures considered have also to deliver on the utility's objectives. Eventually reducing carbon emission will be one of the objectives, as we already observe in a handful of advanced utilities; however, until then, the approach is to link necessary improvements to opportunities to reduce emissions.

4 Implement Measures

The initial technical measures implemented typically relate to existing plans. The approach is initially opportunistic, making the link between planned measures and GHG reduction. It is a method to initiate a GHG monitoring process. The implementation of additional technical measures often requires strengthening or developing enablers through other types of measure that relate to capacity, financing, policies and stakeholder engagement.

5 Monitor Impact

Monitoring and visualising the impact of the measure on the utility's carbon footprint by monitoring adequate data and using adapted tools to inform stakeholders is a key step. It will inform future iterations of the five basic steps of 'The Roadmap to a Low-Carbon Urban Water Utility' and support communications to increase the number of stakeholders supporting the low-carbon transition.

As the utility goes through these iterative steps over the years and its planning cycles, the utility will evolve towards becoming an urban water utility of the future: low-carbon, holistic and sustainable.

Glossary

Note: in this document, the term 'water utility' is used to refer both to drinking water and to wastewater utilities because many of the guidelines apply to both (see below).

Carbon Neutrality – The state of emitting negligible to net zero carbon emissions during operations.

Climate Change – Long-term, significant changes in global or regional climate patterns.

Climate Financing – Financial resources set aside for funding climate mitigation projects worldwide.

ECAM – Energy Performance and Carbon Emissions Assessment and Monitoring tool.

ESCO – European Skills/Competences, qualifications and Occupations.

Greenhouse Gas Emissions (GHGs)/Carbon Emissions – The gases that lead to heat being retained in Earth's lower atmosphere such as carbon dioxide, nitrous oxide, and methane.

Holistic – Thinking of a system, including all of its individual parts, as interconnected parts in reference to the whole.

Low-Carbon – Relating to a method that leads to low to net zero carbon emissions into the atmosphere.

Public-Private Partnership (PPP) – cooperative arrangement between two or more public and private actors, usually over a longer period.

Sustainable – a state of being maintained at an agreed upon 'acceptable' level in terms of economic, environmental, and social impacts.

Sustainable Development Goals (SDGs) – 17 global goals set by the United Nations in 2015 with specific targets to achieve per category.

Urban Water Cycle (UWC) – A man-made cycle encompassing various stages that water passes through during time in a city environment, before returning to the Natural Water Cycle.

Urban Water Sector – The actors which are involved in the maintenance, delivery, and management of water within cities.

Urban Water Utilities – Public or private entities which provide drinking water supply, wastewater collection and treatment, and/or urban drainage services. **In this document, the term 'urban water utilities' or just 'water utilities' is used to refer both to drinking water and to wastewater utilities.**

WaCCliM – Water and Wastewater Companies for Climate Mitigation.

Introduction

Why a roadmap and for whom?

The transition to low-carbon urban water utilities is an innovative idea, only currently embraced by a few forward-thinking utilities. This roadmap is directed at urban water utility managers in charge of planning future actions, as well as at the stakeholders who will support the utility action plans. Because only a few 'early adopter' utilities have embarked on a low-carbon transition, this roadmap intends to support other utilities in understanding and championing the need for contributing to a carbon-neutral future, and to guide them through a process of change. This roadmap can be applied to all utilities worldwide, but was specifically developed with utilities in emerging economies in mind because service performance and data management challenges are often prominent in their operations and future planning.

Global water sector momentum: early adopters reaching carbon neutrality

Climate change has prompted action around the world to mitigate greenhouse gas (GHG) emissions, as evidenced by the Paris Agreement, United Nations Sustainable Development Goals, as well as local, regional and national initiatives aimed at reducing emissions across all sectors. The mind-set shift in the urban water sector towards carbon neutrality has recently started in some developed nations, initiating with GHG emission reduction policies and implementation actions. Several water utilities worldwide, such as in Amsterdam, Copenhagen, Hamburg, Melbourne and New York, are already leading the sector with specific goals for GHG reduction or carbon neutrality, to be achieved by approaches including energy efficiency, renewable energy use, water reuse, biogas valorisation and operational optimisation that also often results in reducing energy consumption and operational costs. However, this mind-set is still considered innovative, and many utilities that can have a big impact on a global scale typically have not adopted that path yet. Utilities in emerging economies, struggling with service levels and low wastewater treatment coverage, can have a substantial impact and were therefore targeted by the Water and Wastewater Companies for Climate Mitigation (WaCCliM) project [1] (see Annex I) to make the transition to a low-carbon urban water sector more impactful globally. The first part of the roadmap is intended to support utility managers in their own mind-set change and secondly in making the case to their stakeholders on why this transition is critical. Change can only happen if individuals are convinced of its necessity and become champions who lead by example. Institutions also support the change, but any policy implementation relies on individuals applying it and turning it into actions.

Setting a path for utilities to transition to low-carbon

The WaCCliM project supports drinking water and wastewater utilities –also referred to as urban water utilities – with implementation of measures that both enhance their service performance and lower their carbon emissions. The project is a global initiative, with the overarching goal to transition to a carbon-neutral urban water sector. The approach laid out in this document was developed specifically with water utilities in emerging economies in mind within the context of the WaCCliM project, but it can serve utilities anywhere as climate change is a global problem. It targets reducing the water, energy and carbon footprints of urban water utilities through an iterative five-step process which may be used by utilities to find their own path to a low-carbon future. The roadmap is intended to guide urban water utility managers through these steps and leads to resources hosted on the Knowledge Platform 'Climate Smart Water' [2], which follows the same structure as this roadmap.

Utilities start to champion a carbon-neutral future

Beyond the implementation of measures to existing facilities, utilities have a role to play in meeting Sustainable Development Goal (SDG) 6, and supporting their cities with the approaches and new infrastructure that will contribute to climate resilience and carbon neutrality; and to other targets, such as improved social equity, well-being, health, and sound management of resources, etc. Depending on the regions, and local pressures, the urban water sector might not initially become completely carbon neutral, but utilities can still become low-carbon and do whatever they can to help make a difference. In all cases, the stakeholders of the urban water sector can become the champions in their cities to foster a carbon-neutral future.

[1] More information at www.wacclim.org
[2] Knowledge Platform can be found at www.ClimateSmartWater.org

Part 1:

Our Changing Climate and the Role of the Urban Water Sector in Avoiding a Looming Crisis

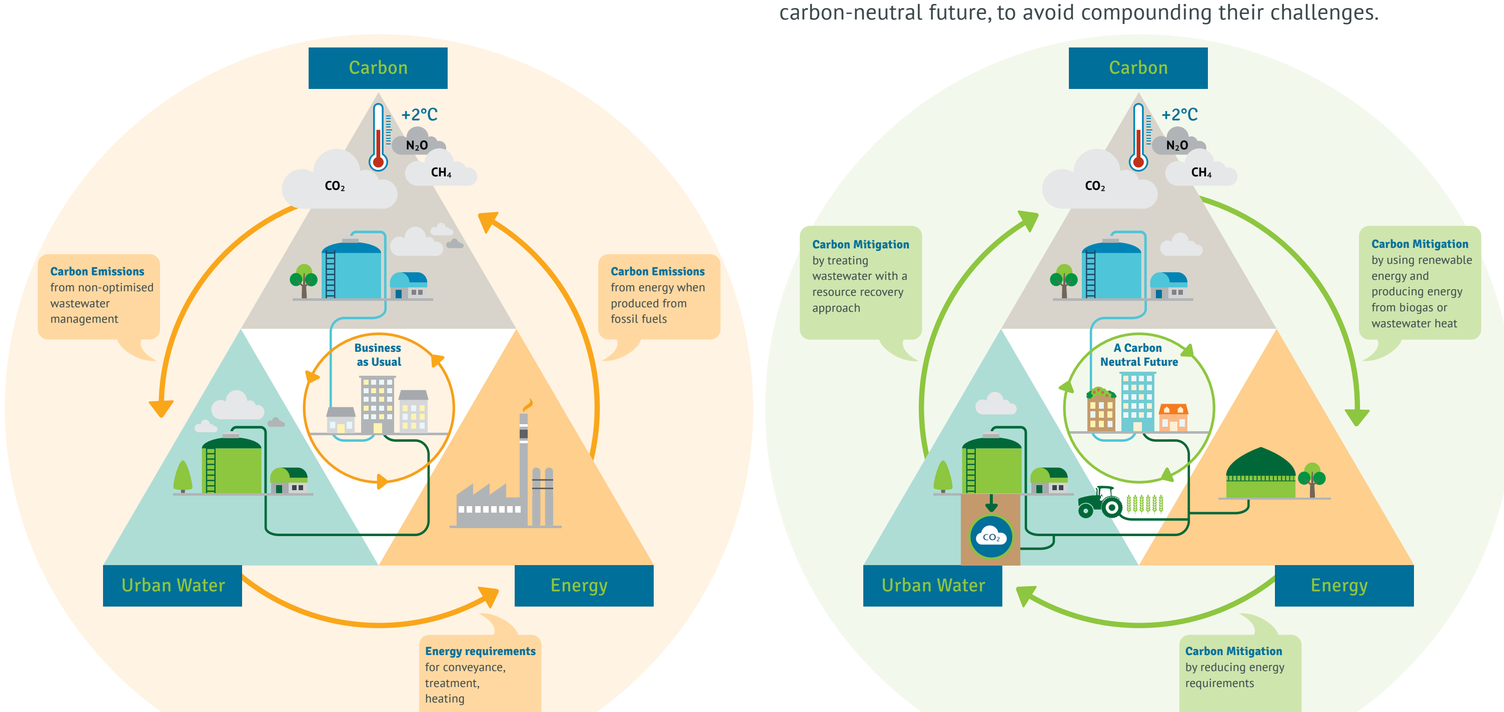
This part is to support utility managers and, more widely, urban water stakeholders: first in their own mind-set change, and secondly in making the case to their other stakeholders on why this transition is critical. Figures and text elements may be adapted or copied in internal communications. Figures are available for download at **www.ClimateSmartWater.org**.

1. Urban water management, energy, and carbon are inseparable

Abstracting, treating and conveying water in cities can require a lot of energy, and generating energy sometimes uses a lot of water. This fundamental resource relationship is called the water–energy nexus (Olsson, 2015). This concept is expanded to the water–energy–carbon nexus, introduced here. It brings into the equation the GHG emitted from the way water is managed, and highlights the opportunities to reduce global GHG emissions and their climate change effects by reducing energy consumption, producing renewable energy, reducing direct emissions from wastewater management and offsetting emissions by valorising wastewater by-products (e.g. fertiliser production).

- The energy used, in many cases, is derived from a traditional fossil fuel source, such as coal, oil or natural gas. Energy production with these traditional fossil fuel sources produces GHGs such as carbon dioxide, methane and nitrous oxide. Renewable energy can be produced from recovering biomass, or heat in the wastewater. Renewable energy can also be produced from hydro turbines, wind turbines, and solar panels operated by utilities.
- Managing wastewater as a resource results in the production of biogas and recovery of nutrients, which offset carbon emissions. However, poor management of wastewater leads to increased methane and nitrous oxide emissions.

Climate change is a direct cause for concern for urban water utilities because it can induce severe droughts and floods, affecting groundwater and surface water availability and quality. The utilities' challenges to provide safe water and protect water quality are compounded by the impacts of climate change, and at the same time utilities might further contribute to increased emissions if a mind-set shift to low-carbon solutions is not initiated. Business-as-usual is no longer a viable option: utilities are challenged to adapt to these impacts but also to champion the transition to a carbon-neutral future, to avoid compounding their challenges.



Business as usual aggravating the impacts of climate change **Low-carbon utilities for a carbon-neutral future**

Figure 1. The water–energy–carbon nexus: the GHG emissions from the urban water sector and opportunities to reduce them, demonstrating the vicious and virtuous cycles above.

The water–energy nexus describes the apparent and complex interdependent relationship between water and energy resources. The higher the water use by end users, the higher the energy use, and then the higher the water use for energy production, resulting in a vicious cycle and ultimately in higher carbon emissions (Figure 1). The increase in carbon emissions contributes to climate change, which negatively impacts the availability of water and energy, and shortages in one resource can directly affect the availability of the other; hence, the water–energy–carbon nexus. Therefore, without a low-carbon intervention, the vicious water–energy–carbon cycle will continue and lead to unsustainable urban water management.

The urban water cycle (UWC) has different stages, and the water–energy–carbon nexus plays out at each stage. The roadmap helps water utilities navigate the water–energy–carbon nexus for the whole UWC, identify where inefficiencies lead to higher carbon emissions, where challenges can be turned into opportunities for GHG reduction, and how measures can be implemented, while monitoring performance. Each urban water system is different in terms of configuration, elevations, demands, water source types, receiving waters, etc.; however, the roadmap approach is beneficial for every utility. In later sections, the interrelated water and energy impacts between stages of the UWC are examined.

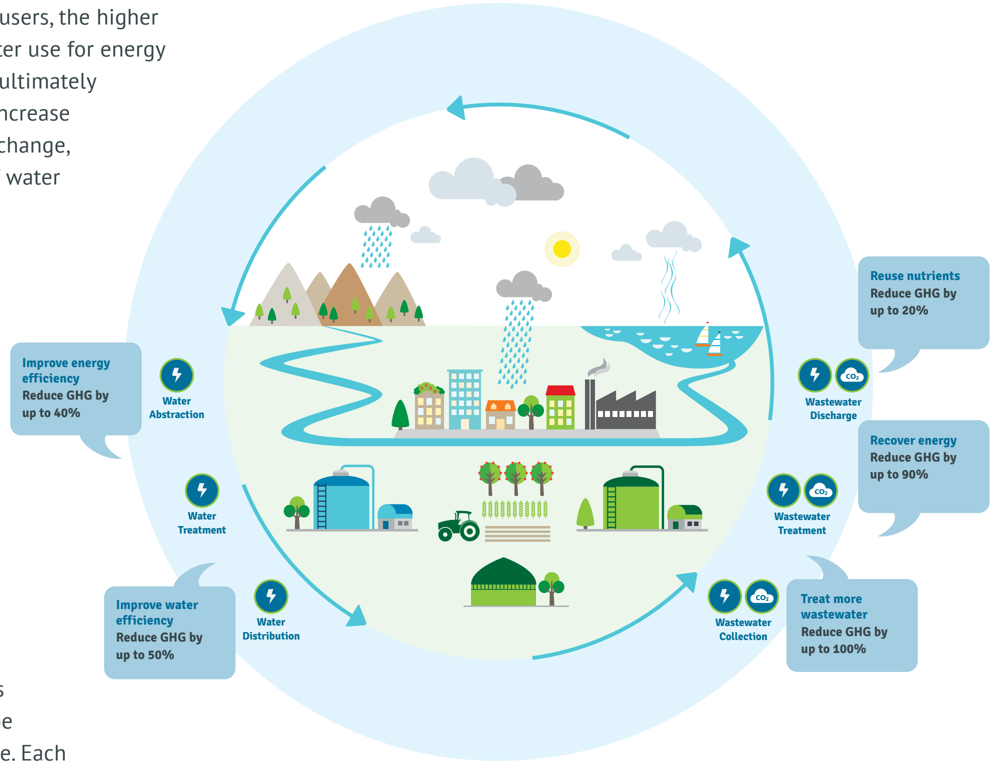


Figure 2. The UWC uses energy at every stage, and emits GHG in the wastewater stages. There are opportunities to reduce carbon emissions at every stage.

2. Water utilities have a stake in addressing the global climate crisis

Climate change directly impacts the availability and quality of water supplies, posing an increasing burden on cities to maintain their water security. Water utilities are some of the first to cope with the impacts of climate change leading to water scarcity, water quality and flooding challenges. However, they also contribute to global emissions from energy consumption, as well as nitrous oxide and methane emissions from wastewater management. Water utilities collectively influence up to 12% of regional total primary energy consumption. The bulk of this energy consumption is attributable to water users, for water heating. Urban water utilities themselves typically account for 1-2% of total global primary energy use (Sanders & Webber, 2012; Kenway *et al.*, 2015); and sometimes up to 6% of regional electricity use (Liu *et al.* 2016). At the same time, delivering water is an essential service which relies on water supplies that are subject to local environmental conditions. These supplies, such as rivers, reservoirs and lakes, are highly sensitive to severe events caused by fluctuations in climate. These severe

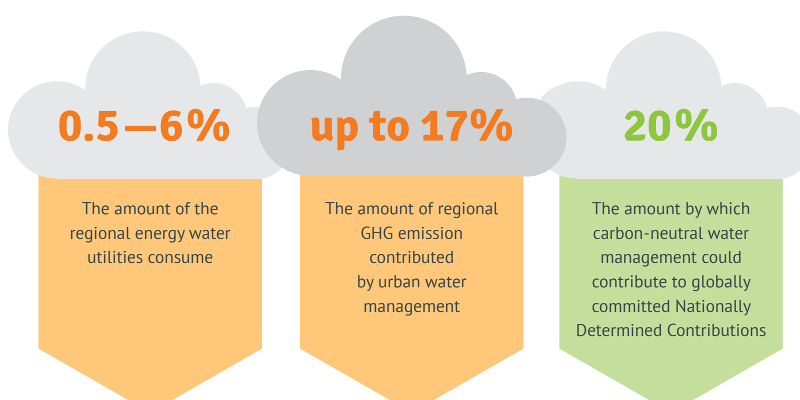


Figure 3. Utilities can contribute their share to a carbon-neutral future, for more on urban water sector energy use, see Sanders & Webber 2012; Kenway et al. 2015; Liu et al. 2016.

events regularly make the headlines of global news: droughts leading to water scarcity, sea level rise leading to saltwater intrusion, and floods leading to infrastructure damage. All of these events impact water quality and service performance, and unfortunately show no sign of slowing down. Because they are among the first climate change threats, water utilities have a stake in becoming the leaders towards proactive climate change mitigation and adaptation.

Through low-carbon, low-energy improvement measures, urban water utilities reduce emissions while supporting adaptation to the impacts of climate change, for example by reducing water loss. Likewise, when adaptation measures are implemented, they can easily include opportunities for emissions reduction (e.g. low-energy solutions, water reuse). This preference towards implementing low-carbon, low-energy measures when planning necessary improvements follows a mind-set shift towards a carbon-neutral future. This innovative trend is already embraced by a few early adopters, but still requires more champions to achieve the global target of maintaining the average temperature rise below 2°C.

Urban water utilities tend to have urgent demands for reaching primary service performance and increasing infrastructure. Carbon neutrality does not take first priority. Many urban water utilities in emerging economies must meet their service demand for growing populations on very low budgets. That is already a universal challenge, as recognised by the United Nations SDGs, specifically SDG 6 [3]: Ensure availability and sustainable management of Water and Sanitation for All. Meeting both global challenges of the 2°C target for global warming and SDG 6 go hand-in-hand because of common sustainability goals. However, it requires more than a few small changes to business-as-usual: it requires changing how utilities approach their own strategic planning and role within their communities and global sector to integrate the carbon-neutral future mind-set into all actions. The next section proposes a roadmap that includes guidance for utilities in identifying how service improvement measures may also lead to lowering their carbon footprint with the intent to support a global mind-set shift, towards low-carbon urban water management.

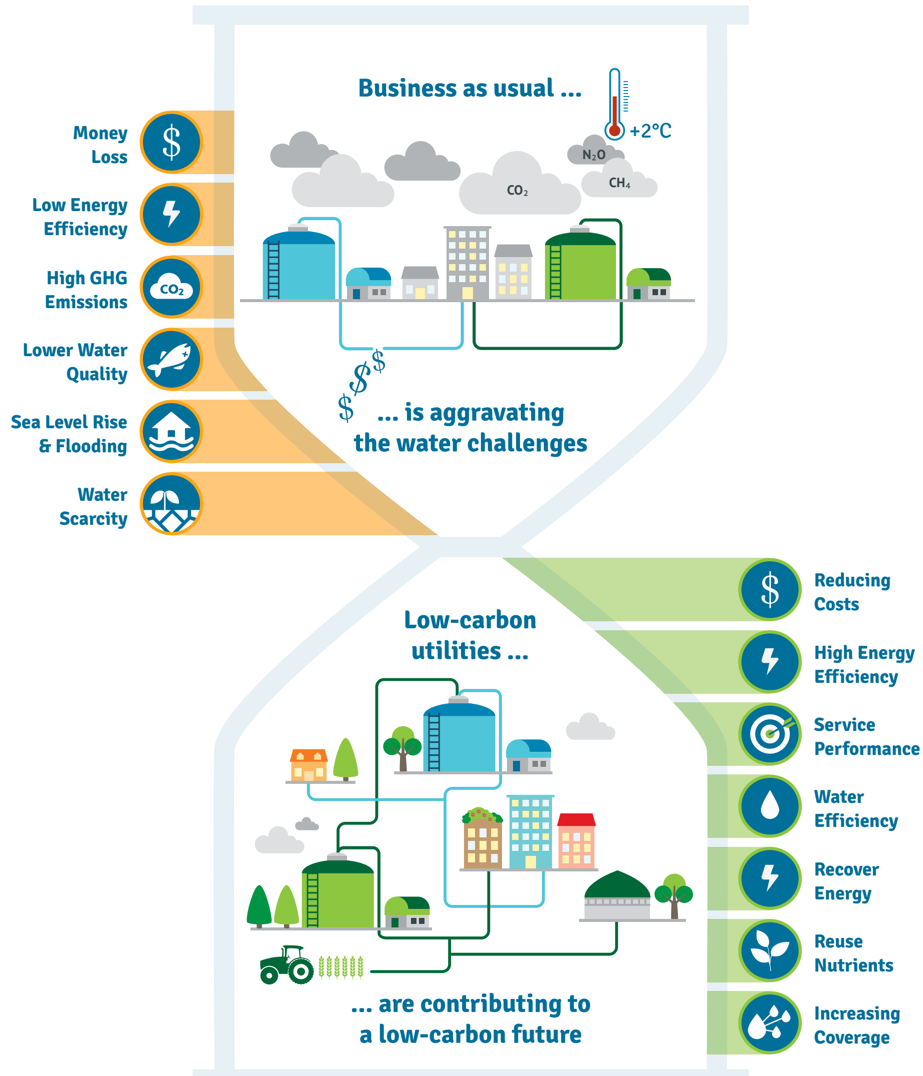


Figure 4. Time is running out to keep our planet stable and below a temperature rise of 2°C: taking purposeful decisions now towards a carbon-neutral future can help avoid future risks.

[3] Sustainable Development Goal 6; learn more at https://sustainabledevelopment.un.org/sdg6

Figure 5. The global water sector mind-set shift to address challenges as opportunities.

3. Turning challenges into opportunities

As described earlier, utilities today are facing current and emerging water sector challenges. That can generally be overwhelming when planners first meet to try to prepare for an uncertain future. However, the same situation can be viewed from two different angles. Many utilities already face a need to develop further, beyond their current coverage areas, infrastructure capacities and technology levels. Addressing these service challenges can be seen as an opportunity to also contribute to a carbon-neutral future. Climate financing to support the global need to adapt to and mitigate the impacts of climate change is also an opportunity to improve service performance and utilities' capacities. This mind-set of turning challenges into opportunities is critical to transitioning urban water utilities into important contributors to climate change mitigation.

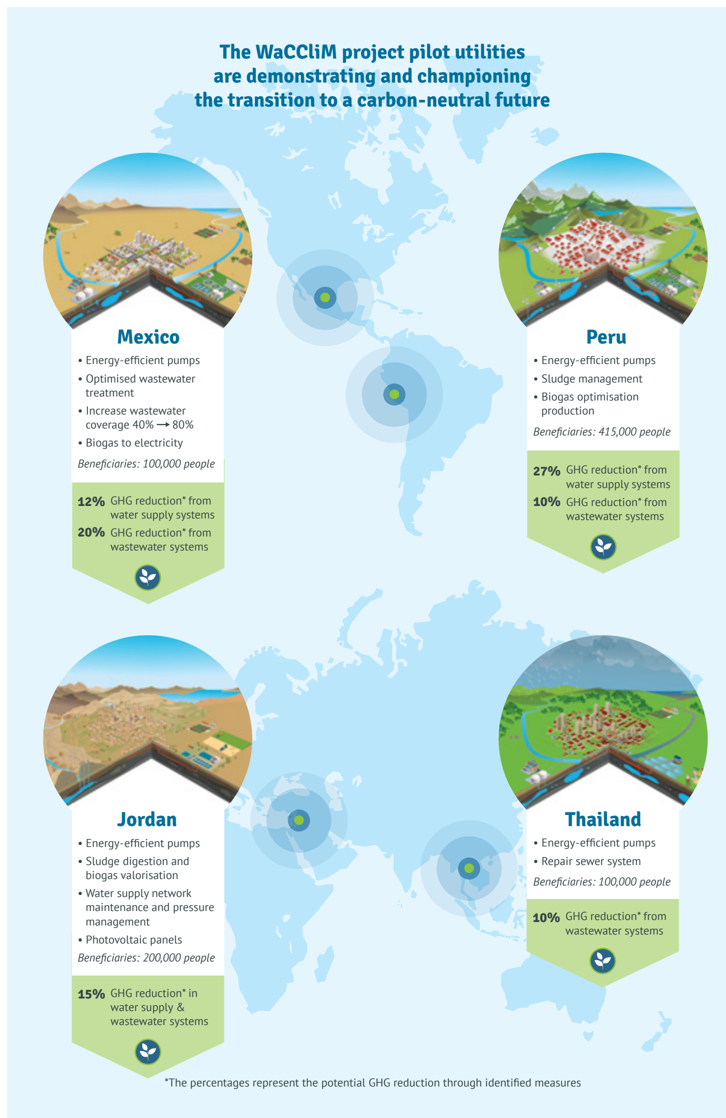


Figure 6. How can GHG emissions be reduced through operational improvement measures? The WaCCliM project pilot facilities demonstrate some first examples.

Part 2:

A Roadmap for Urban Water Utilities to Transition to a Carbon-Neutral Future – Five Iterative Steps

This part is intended to guide urban water utility managers, and more generally all urban water stakeholders, through the iterative steps of implementing change towards low-carbon. This process is called the 'roadmap'.

The roadmap process: an iterative approach towards implementing change

The road to a low-carbon, holistic and sustainable future begins with identifying drivers that connect the utility's main objectives and low-carbon opportunities. Once this connection is made, the dialogue with the utility's stakeholders can start towards initiating the low-carbon mind-set. To reinforce this connection, it is useful to assess the utility's urban water systems, and point out the existing level of carbon emissions to highlight the highest water and energy inefficiencies. This process aims to show how reducing these inefficiencies may contribute to lowering the GHG footprint. This initial assessment may be performed using various software tools, or by using the Energy Performance and Carbon Assessment and Monitoring (ECAM) tool (a free tool developed by the WaCCliM project), which allows the utility to start the process with basic data, and provides the utility with a first visualisation of where the biggest benefits may be. Evaluating opportunities to reduce emissions in the light of planned improvements is a way to ease into applying the mind-set shift locally. The implementation of measures often requires strengthening or developing enablers such as capacity, financing mechanisms or utility governance models that enable a low-carbon, holistic approach to water, wastewater and drainage services. In a first iteration through the roadmap, utilities often implement measures without a specific low-carbon objective, but they can still evaluate the impact of the measure on their carbon footprint by monitoring adequate data.

Figure 7. The roadmap to low-carbon urban water utilities: an iterative and continuous process.

The five-step approach for utilities to champion a carbon-neutral future

Step 1 Motivate Action

This step is about identifying objectives and drivers that will be the basis for any follow-up actions.

Step 2 Assess Your System

This step is about visualising emissions and water and energy inefficiencies using a holistic approach to drinking water, wastewater and drainage systems. It introduces a GHG emissions assessment of different levels of precision, depending on the data, with tools such as the ECAM. Facts and figures presented in an informative way are key to driving further action.

Step 3 Identify Opportunities

This step is about identifying where taking action is the most promising to address the objectives, while seizing opportunities to reduce GHG emissions. Eventually reducing carbon emissions will be one of the key objectives, as we already observe in a handful of advanced utilities; however, the approach is to initially link necessary improvements to opportunities to reduce emissions. Under this step, the utility is guided through each stage of the UWC to find out what factors influence these emissions. This deep-dive into the urban water system is intended to educate utilities on all of the UWC GHG emissions sources, as well as to support utilities in continuously identifying opportunities to reduce emissions and merge objectives after their initial iteration of the roadmap process.

Step 4 Implement Measures

This step is about what is needed actually to implement measures that will result in GHG emissions reductions. It guides utilities through identifying the enablers they need to strengthen, such as utility capacity, existing policies, financing strategies and stakeholder engagement.

Step 5 Monitor Impact

This step is also about visualising emissions, but this time it is also about visualising the impact of the measures implemented. It requires using current data with the same tools as for the assessment. Monitoring is used to verify and measure emissions reductions after implementation. Demonstrating this monitoring capacity is key to accessing climate financing. It will inform the new baseline assessment of step 2 for future iterations through the roadmap.

As utilities adopt a low-carbon mind-set and become 'champions' of a carbon-neutral future, the idea is that they start to continuously go through these steps as part of a low-carbon programme and as they integrate these steps into their decision processes. As they implement the approach, they will also be improving their data management, their assessment, and their own capacity and results each time (see Figure 7).

Now the document will walk through the overall five steps and elaborate on the examples given above. Further information and resources can be found at the WaCCliM Knowledge Platform [4].

Step 1. Motivate low-carbon action

This step is about identifying objectives and drivers that will be the basis for any follow-up actions. It is initiated by a champion who has led the utility through understanding why water utilities have a stake in taking action towards a carbon-neutral future. This understanding is key to making the connections between the objectives and opportunities to meet those objectives while reducing emissions. This step does not require planning actions yet, but it does require looking at the current issues from a different perspective. Even though this is a simple thought exercise, it is a powerful tool for driving change. This is the kind of lasting innovative strategising that is necessary to reach a low-carbon, holistic and sustainable future.

1.1 The relationship between drivers, objectives, and opportunities in supporting low-carbon actions

This section guides utilities through understanding the relationship between objectives, drivers and enablers to support the implementation of opportunities to mitigate GHG emissions.

Utility objectives mainly refer to the primary objectives, which must be met by virtue of being an urban water utility. Depending on whether it is a drinking water or wastewater utility, these primary objectives include the following:

- meet drinking water demands (production/distribution);
- provide adequate wastewater collection and treatment;
- meet water quality regulations;
- meet minimum performance criteria (water pressure, fire flow, pipe velocities, etc.);
- ensure a balanced budget.

The utility's objectives translate into drivers such as reducing operating costs, improving customer relations or increasing coverage, and more (refer to next section). The unique objectives and drivers lead each utility to defining actions needed to improve towards the objectives. These actions are then implemented only if the right enablers are in place. A utility, led by a champion into this roadmap process for the first time, is unlikely to have 'reducing carbon emissions' as one of its primary objectives. Therefore the entry point for the champion will be to link the existing drivers to low-carbon opportunities.

Objectives	Drivers	Opportunities
• Meet current service demands • Minimise operating costs • Meet environmental standards / watershed health	• Boost overall utility capacity • Maximise service performance • Reduce energy use and water loss • Increase efficiency • Prepare for future climate scenarios • Meet future demands of coverage • Deal with water scarcity	• Optimise operations • Reduce water consumption • Reuse water • Biogas valorisation • Expand wastewater treatment coverage • Renewable energy

Table 1. Some common water utility drivers, objectives and opportunities. There are more to be discovered during this process.

1.2 Drivers push the agenda

As introduced in section 1.1, drivers are often agenda-driven motivations that spur utilities to action. Whether the utility is initially successful in addressing these drivers does not directly impact their ability to meet basic objectives today. The potential drivers vary from utility to utility, depending on a wide range of factors, such as adhering to public policies, institutional culture, current climate change impacts, moving towards the circular economy and improving service performance. Some of the possible drivers that can align with GHG reduction are outlined below, along with additional challenges that some of the drivers pose.

[4] www.climatesmartwater.org

- **Meeting a high service performance level**
  Maintaining or increasing service levels is the main mission of all utilities, and the standards are usually set by regulation authorities. This can be achieved while reducing the water, energy and carbon footprints per resident receiving service. The productive interaction with, and education of, customers is an important component of successful service.

- **Operational cost**
  There are many water utilities actively seeking new opportunities to reduce their operating costs. As energy makes up most of a water utility's costs, reducing energy consumption is the key driver in reducing GHG emissions. Similarly, reducing water losses in the drinking water system and infiltration and inflow in sewers is another key driver for GHG reduction because pumping and treating more water than is needed increases energy consumption and costs.

    - *Challenge to reduce energy costs through conservation and renewable energy* – With an average of 10–35% of an urban water utility's operating expenditure going towards the energy bills, a strong driver to action is reducing energy costs through initial energy conservation. This can also be achieved through the production and use of renewable energy, which is a solution that may bring utilities to energy neutrality and therefore drastically cut emissions.

- **Overall utility efficiency**
  Many utilities have several key performance indicators that they try to meet in an effort to maximise the overall utility efficiency. In some cases, water utilities are ranked on the basis of these indicators by different government agencies, thereby providing an additional incentive to be more efficient. Therefore, overall water utility efficiency is a natural driver for GHG mitigation, because these indicators often examine energy and water loss, and these efficiency rates impact the utility's GHG emissions.

- **Challenge to increase water efficiency**
  As mentioned previously, the less drinking water that is lost from pipes before reaching customers, and the less water that enters sewers, the lower the energy consumption and treatment costs for water utilities. Likewise, the shift in natural water supply availability as a result of climate change and the pressures of growing urban populations will force water utilities to make the most of available resources through conservation, reducing water loss, infiltration and inflow, and water reuse.

- **Challenge to meet agreed upon targets**
  Governments, cities and industries in many countries have committed to achieving GHG emission reduction targets, and the water sector has a large role to play in meeting these targets. Relevant to addressing urban growth and meeting the SDGs, investments to improve existing systems' efficiencies and expand wastewater treatment services are required. It is anticipated that increasing regulatory pressure will catalyse new investments for utilities to improve service and work towards carbon neutrality in the near future.

- **Increasing coverage**
  Water utilities should strive to provide reliable access to water and sanitation for all residents within their service areas, in accordance with SDG 6. Therefore, expanding their services and increasing the coverage area of wastewater treatment is always a priority. Expansion can also contribute to GHG reduction as a result of reduced discharge of untreated wastewater into receiving water bodies. The reduction of GHG emissions through expanding coverage and service is an additional environmental benefit to future projects, complementary to improving public health and biodiversity. This aspect is particularly important for seeking help from international financing entities, which are specifically looking for multiple environmental benefits per project.

    - *Challenge to achieve higher wastewater coverage* – Expanding wastewater coverage not only improves public health and biodiversity, but also reduces GHG emissions generated from the direct discharge of untreated wastewater. It is also an opportunity for growth in a city as cities cannot thrive without proper water and sanitation.

- **Water utility culture**
  This refers to the overall mentality and approach a water utility has towards providing water services. Utilities can already be forward thinking, innovative, i.e. adopting and open to the mind-set shift, or they can be currently focused only on meeting the basic needs and business-as-usual. Therefore, the pre-existing culture of the water utilities influences their priorities and can function as an indirect driver of GHG emissions reduction.

- **Climate change impacts**
  Many water utilities are already dealing with the effects of water scarcity and more frequent, higher magnitude drought and flooding events. All of these events negatively impact the availability and quality of water in water supplies and receiving waters. Therefore, implementing measures such as water reuse (for water scarcity) and green infrastructure (for flooding) is initially done out of necessity, and not primarily to reduce GHG emissions. However, addressing these crises presents the prime opportunity to link the utility's drivers to GHG reduction because measures to address these crises can also help reduce GHG emissions.

    - *Challenge to secure water against climate change* – Pressing needs for adaptation to deal with water scarcity, intense rain events and population growth are intensifying in many parts of the world. Smarter adaption to these constraints can be facilitated using the roadmap approach proposed here.

- **Anticipating GHG emissions reduction goals/regulations**
  The current awareness of a utility towards GHG emissions reduction is largely dependent upon whether voluntary or mandatory GHG reduction targets have been implemented by their government at any level. For example, New York City has a local law requiring its city agencies to reduce their

GHG emissions by 80% by 2050, the 80×50 initiative [5]. As it is a city agency, the water utility is acutely aware of its GHG emissions and is always looking for opportunities to reduce them. Therefore, government regulations and initiatives can catalyse operational improvements and be an important driver for solutions.

- **Maintaining a healthy water environment**
  Whether it is for public health, biodiversity, tourism, local economy, recreation, real estate or quality of life, maintaining healthy water bodies around cities is an important goal every utility should have. This represents another key driver for GHG emissions reduction through the expansion and improvement of wastewater treatment coverage.

These are just some examples of the common drivers of water utilities around the globe that can propel action towards improvements and align with climate mitigation outcomes. Following this logic, it is important for water utilities to identify what their top drivers are first, and then to see how those can align with actions that also offer promising opportunities to reduce GHG emissions. As mentioned before, these also need to align with enablers, which are further discussed under Step 4: Implementing Actions.

Step 2. Assess your system: where do your GHG emissions stand?

This step is about visualising emissions and water and energy inefficiencies using a holistic approach across the whole UWC. Facts and figures presented in an informative way are key to driving further action.

2.1 The basis of a useful baseline assessment

The purpose of performing a baseline assessment of a water utility's GHG emissions is to set the starting reference point, against which the water utility can compare reductions from future scenarios and from implemented measures to demonstrate progress towards the goals. The baseline assessment results are a visualisation of the existing situation, or of the baseline year if in the past, drawn on the basis of key facts and figures relating to energy and the type and quality of operations. The quality and accuracy of this visualisation relies on the data used. Before diving further into the methodology, an overview on the benefits of good data management and baseline assessment are discussed.

Data management is a key consideration for GHG assessment. There can be lots of data available; however, without a strategy and tool to produce valuable information, it is hard to make decisions that are both effective and sustainable. Even if the initial assessment is done with approximate data with the mind-set of raising awareness, it is important to then refine this assessment to understand the actual baseline emissions of the individual water utility, otherwise reporting on impact is impossible. In addition to providing a means to report on results, this refined assessment can result in immediate benefits from basic improvements, such as repairing leaks or changing pump operation. However, before reaching this point, the utility must address its own current data management practices, and whether there is room for improvement.

The baseline assessment and future assessments rely on a sound data management framework. Without an organised framework to facilitate continued assessment beyond the first trial, implementation of the WaCCliM approach would either not take place or eventually cease because of the effort required to collect good data each time an assessment is needed. In this chapter, the general methodology needed to assess emissions and the steps to develop a utility-specific framework for regular assessment, including data management and use of software tools, is presented.

[5] Read more about the initiative here: https://www1.nyc.gov/site/sustainability/codes/80x50.page

2.2 Introduction to general methodology

The general methodology for beginning assessment, which supports Step 3 – Identify Opportunities is outlined below.

- Assess what data is currently available within the utility and in what format i.e. time frequency and time coverage of current data profile.
- Introduction to ECAM (see glossary) tool through training.
- Start using the tool by:
    1. Collecting data from the identified sources and ensuring data quality.
    2. Inputting data into the selected tool.
    3. Performing a baseline assessment for the individual utility, reviewing results, and identifying largest emissions source.
- Map the utility's most important objectives and drivers, but also the opportunities for improvement measures and the enablers (e.g. financing or training opportunities) that are already known to the utility. These elements will be key to informing and orienting the identification of measures that both address the objectives and contribute to a lower carbon footprint. These elements are also likely to change as a utility goes through several iterations of the roadmap process.
- Develop a data management and assessment framework based upon the utility's current capacity and towards future data needs.

This methodology is elaborated in the subsequent sections. For more information on this process, visit the Knowledge Platform [6].

2.3 Beginning assessment: critical components

The following are critical components needed to begin assessment:

- Data management capacity and coherent processes;
- ECAM tool.

Without these components, assessment of overall GHG emissions cannot take place. For the first assessment, the utility should compile what data it currently has in the format it typically uses. Any future data needs or process adjustments can be planned for in further framework development; however, this is not necessary to begin an initial assessment.

2.3.1 The ECAM tool

The ECAM tool was developed under the WaCCliM project to assess and monitor the GHG emissions of water utilities. As climate change is a global problem, the ECAM tool is meant for use by all water utilities. However, understanding that data availability may be limited in some emerging economies, defaults for various aspects were developed to facilitate assessments. Looking to the future, this tool also includes the option to input more data over time as the level of data management for the utility increases, using a tiered approach. The flexibility of this tool allows a refined assessment of emissions sources and opportunities to reduce them, as described in the following section. The tool is based on IPCC methodology, has open-source code and is free to use for all. The first step in developing and implementing a utility-specific framework for GHG data management and assessment is learning how to use [7] the ECAM tool and the methodology [8] behind it. This will help in developing the necessary technical capacity, understanding what data are needed to run the tool and identifying which processes are necessary to transfer data from the sources to the ECAM tool. The specific applications of the tool include baseline assessments, monitoring, and evaluating opportunities for mitigating GHG emissions.

Figure 8. The ECAM software tool as it appears on a computer.

[6] www.climatesmartwater.org
[7] Manual found here: http://climatesmartwater.org/library/introduction-to-ecam/
[8] Methodology found here: http://climatesmartwater.org/library/ecam-methodology/

2.3.2 Data management framework: what is needed going forward

Without a comprehensive data framework including the procedures for collecting and inputting accurate data into the tool, the extent to which the WaCCliM approach can be implemented will be very limited. Some proposed steps in building this framework are outlined below, with further detailed information in Annex II and the Knowledge Platform. It is highly recommended for efficient data collection and tool use that, after the utility identifies the most optimal opportunities from an initial assessment, the framework is centred around data collection and tool use focused on maximising these opportunities. This can save time and resources towards planning the measures that may provide the utility with the most benefits over time.

- **Data quality / Process review**
  A crucial step in performing assessment and constructing a data framework is performing a data quality and process review. An example such as the WaCCliM data quality/process matrix (see Knowledge Platform) [9] demonstrates a complete example of identifying and evaluating the various data available for estimating GHG emissions.
- **Data priority / Quality survey**
  The next step in developing a data framework is performing a data priority/quality survey. This is done to check any pressing data limitations, as identified in the data quality/process matrix, against the daily operational priorities of the utilities.
- **GHG Reduction Analysis Data Requirements**
  Data required for GHG reduction studies are generally more detailed and collected at a higher frequency than other studies, as they are intended to give some insight on the dynamics of the urban water system that impact GHG emissions. The data may also not directly relate to variables used for estimating GHG emissions. A comprehensive summary of data that can be used in GHG reduction analysis may be found on the Knowledge Platform [10].
- **Central Data Repository**
  In general, the recommended course of action is to leverage existing data processes, and either enter the pre-existing data saved in existing places or electronic files, such as Microsoft Excel files, into a central data repository, where the data can be frequently updated and accessed for performing GHG assessment on a continuous basis.
- **Recommended framework construction**
  Once the recommended data processes for relaying current data from the data sources to the central repository are identified, it is recommended implementing the framework as illustrated and described in an example on the Knowledge Platform11, where the data can be frequently updated and accessed for performing GHG assessment on a continuous basis.

The overall framework presented is generalised; however, in actual applications, specific data processes will be required to support implementation of the framework. The specific data processes will be dependent on the individual utility's current data management, resources and overall capacity. A recommended framework together with the specific data processes can be refined, adapted and improved as the utility's capacity (i.e. hardware, software, staff expertise, etc.) increases over time. Therefore, the framework is flexible and is intended to facilitate use of software such as the ECAM tool for generating baseline assessments. Once the baseline assessment is done, it is possible to move onto evaluating opportunities.

[9] Search for WaCCliM data quality/process matrix in www.climatesmartwater.org/assess
[10] Search for Summary of GHG Reducation Analysis Data on www.climatesmartwater.org/assess
[11] Search for Recommended GHG Data Management and Mitigation Framework in www.climatesmartwater.org/assess

Step 3. Identify opportunities

This step is about identifying where taking action is the most promising to address objectives, while seizing opportunities to reduce GHG emissions. Opportunities to take action are linked to their ability to deliver on the utility's objectives. Eventually reducing carbon emissions will be one of the objectives, as we already observe in a handful of advanced utilities; however, until then, the approach is to link necessary improvements to opportunities to reduce emissions. In section 3.3, the utility is guided through each stage of the UWC to find out what factors influence these emissions. This deep-dive in the urban water system is intended to support utilities in their second or third iteration of the roadmap process.

3.1 Addressing utility challenges with low-carbon solutions

Central to the WaCCliM approach is looking at challenges not simply as hurdles to overcome, but rather as opportunities for growth and capacity development and applying low-carbon measures. Even without the catalysing effect of climate change on industry innovation, water utilities are constantly faced with the need to improve services. This drives them forward to take on technological advancements and new strategies not previously used. Operational optimisation encompasses a wide range of actions which usually leads to energy and water efficiency and GHG emissions reduction.

3.2 Introduction to general methodology

Following the development of a data framework in the previous section, this step is about starting the journey to real application and results. First, the new framework can be applied to generate the initial and subsequent baseline assessments or monitoring results, which show the current GHG emissions for the entire UWC of the utility. The assessments will also point out the promising opportunities that address both the utility's drivers and GHG reduction goals. The following methodology for evaluating opportunities along this path is proposed:

- technical assessment via a tool;
- review current capital improvement and master plans to identify opportunities;
- review promising opportunities with other urban water stakeholders;
- assess feasibility and cost–benefit of measures over time.

As this roadmap is universally applicable, while also being geared towards utilities in emerging economies, the following section assumes that a utility is or will be using a software tool, such as ECAM, for assessment. More detail on ECAM tool use for this step is given below.

Figure 9. The opportunities that can arise from challenges and addressing initial drivers.

The ECAM tool outputs the amount of GHG emissions produced by the utility at each stage of the UWC. The summary from the ECAM tool quickly identifies which stage is the highest contributor and from which source. However, each stage needs individual review afterwards, because it might not be feasible to mitigate emissions from every source. The utility should target the highest sources of emissions first, which are also feasible to mitigate in a first round of implementation and aligned with meeting utility objectives and drivers. For ideas on finding solutions at each stage, the WaCCliM Knowledge Platform [12] can be consulted. Furthermore, other tools can be used to assess the performance of the utility, where it can improve and whether these improvements can lead to GHG reduction. For example, a tool such as a wastewater treatment process model can be used to identify treatment process improvements, and then those process improvements can be further assessed in ECAM to quantify the GHG reduction benefits.

Once it is clear where the most promising opportunities are in meeting operational improvements, maintenance and GHG reduction, planned capital improvements should be reviewed. This is important because there may already be overlap between the new opportunities identified through the baseline assessment and what is already being planned by the utility. When these overlaps occur, it is fortunate because there may already be financing available for a project. Similarly, a review of measures involving other urban stakeholders is useful, because shared goals can lead to a combined project, which is more likely to qualify for external funding at either the national or international level.

[12] Search for Annex of Solutions at www.climatesmartwater.org

3.3 Understanding the emissions: what influencing factors exist at each stage of the UWC

The UWC describes the life cycle when water is taken from the natural environment and cycled through man-made cities, then sent back to natural water bodies. The UWC begins at the water source of a city, which can be from sources such as surface water (lakes, reservoirs, rivers), groundwater, seawater, rainwater, reclaimed water or any combination thereof. From the source, water is abstracted for potable water supply through the drinking water abstraction stage. Then it is conveyed to the drinking water treatment stage, which, depending on the source and standards, will involve a wide range of treatment techniques from chemical addition or disinfection, to conventional filtration and even reverse osmosis. After the drinking water treatment stage, the water is delivered to end users during the drinking water distribution stage. After use, the water enters wastewater collection, and then the wastewater treatment stage. After wastewater treatment, the water passes to the discharge/reuse stage where it either enters back into the waterways and is ultimately reintroduced into the natural water cycle, or is recycled and reused. As the UWC is man-made, it requires various kinds of electromechanical equipment to manage, such as engines, pumps, motors, blowers, mixers and the fuel/electricity to operate this equipment. The use of all this equipment contributes to GHG emissions during each stage of the cycle. Furthermore, there are chemical and biochemical reactions taking place during the decomposition of wastewater, which also results in the production of GHG emissions at the end of the cycle. Figure 10 provides a graphical representation of the UWC and its related GHG emissions sources.

Figure 10. The various stages of the UWC and the energy use, water loss and GHG emissions that can occur during them.

The next section presents each stage of the UWC and investigates the potential sources of emissions from each of them, and the factors that can influence the volume of emissions at each stage. This process will help in understanding where the highest sources of emissions are, and how they can be addressed effectively later. More details on solutions are available on the Knowledge Platform at **ClimateSmartWater.org**.

3.3.1 Drinking water abstraction

Depending on the type, distance and elevation of a city's water source(s), GHG emissions from the drinking water abstraction stage are typically generated by energy consumption for the pumping of water from the source to the treatment facility. In most cases, the GHG emissions are indirect emissions from importing grid electricity to run pumps; however, there can also be direct GHG emissions (methane, nitrous oxide and carbon dioxide) from fuel consumption/combustion for powering the pump engines or equipment via emergency generators. If the source is surface water and above the elevation of the city, it is possible that the water can be transported to treatment using gravity instead of pumps, in which case there would be no additional GHG emissions. Other key factors that impact the GHG emissions in the drinking water abstraction stage include the following.

- **Drinking water demanded by end users**
  The higher the drinking water demand, the more water needing to be abstracted. This leads to a potentially higher energy consumption from pumping and transporting water to the drinking water treatment facility. The end user's demand and how they use drinking water directly impacts the GHG emissions. Therefore, the less drinking water demanded, the less GHG emissions generated from the abstraction stage.

- **Water loss**
  By virtue of how drinking water systems are operated, which is to maintain certain pressures or storage tank levels, any water loss in the system will require more energy to replace it and maintain adequate pressures in the system. Therefore, the less water loss throughout the entire drinking water system, the less water that needs to be abstracted and the less GHG emissions generated from the abstraction stage.

- **Pump efficiency**
  Assuming the volume of water and pump head conditions are optimum, the pump efficiency dictates the energy consumption, and the GHG emissions of the abstraction system. Therefore, the higher the pump efficiency, the less GHG emissions generated from the abstraction stage. Changing climate and population conditions will put a greater strain on current pumps since water will have to be pumped over a greater time and possibly distance. This will make the efficiency even more critical over time.

3.3.2 Drinking water treatment

The GHG emissions from the drinking water treatment stage depend on the type of treatment and electromechanical equipment used to operate the treatment facilities, such as pumps, motors, blowers, mixers, flocculators, etc. In most cases, the GHG emissions in the drinking water treatment stage are indirect emissions from importing grid electricity to operate the electromechanical equipment; however, just as in the case of drinking water abstraction, there can be direct GHG emissions from fuel consumption/combustion for engines driving the pumps or powering equipment with emergency generators. Typically during conventional filtration, which is the most common treatment type for surface water supplies, most energy consumption is due to pumping and filter backwash operations. In seawater reverse osmosis, most energy consumption is due to pumping through high-pressure membranes. However, some systems, usually groundwater supplies, may only need to be disinfected, so the energy consumption during actual treatment is minimal. Key factors that impact GHG emissions in the drinking water treatment stage include the following.

- **Drinking water demanded by end users**
  The more drinking water that is demanded, the more water that has to be treated. The end user's demand and how they use drinking water impacts the GHG emissions. Therefore, the less drinking water demanded, the less GHG emissions generated from the treatment stage.

- **Water loss**
  By virtue of how drinking water systems are operated, which is to maintain certain pressures or storage tank levels, any water loss in the system will require more energy later to replace and treat the water for end users. Therefore, the less water loss in the system, the less water that must be treated and the less GHG emissions generated from the treatment stage.

- **Pump efficiency**
  Assuming the volume of water and pump head conditions are optimum, the pump efficiency of treatment system pumps can dictate the energy consumption and GHG emissions. Therefore, the higher the pump efficiency, the less GHG emissions generated from the treatment stage. Changing climate and population conditions will put a greater strain on current pumps since water will have to be pumped over a greater time and possibly distance. This will make the efficiency even more critical over time.

- **Filter backwashing sequence**
  How the filter backwash sequence is initiated in conventional filtration can affect the frequency of backwashing. The more times that filters are backwashed, the more energy consumed during the process. Therefore, it is critical to optimise the backwashing sequence, such that filters are not excessively backwashed. The more optimal the sequence, the less GHG emissions generated from the treatment stage.

- **Membrane process**
  In seawater reverse osmosis, the transmembrane pressure typically regulates the energy required for pumping seawater through the membrane in desalination. Owing to the nature of the process, the raw water salinity, and the required permeate salinity, the energy consumption for seawater reverse osmosis tends to be significantly higher than for conventional drinking water treatment. However, the configuration and control of the process, as well as the types of membrane used, can be optimised to minimise energy consumption and GHG emissions. The more optimal the process, the less GHG emissions generated from the treatment stage.

- **Ultraviolet disinfection**
  Ultraviolet disinfection and how it is operated, controlled, and maintained can have an impact on the GHG emissions from energy consumption. In general, the higher the volume of water treated, and the higher the ultraviolet disinfection dose, the higher GHG emissions generated from the ultraviolet disinfection process. However, the dose (as impacted by water turbidity), control and maintenance can be optimised to minimise these emissions, while still meeting minimum disinfection requirements.

3.3.3 Drinking water distribution

Depending on the distance and elevation of the end users in relation to the treatment facilities, GHG emissions in the drinking water distribution stage will typically be related to energy consumption for the delivery of drinking water from the facilities to the end users. This stage usually requires pumping within the distribution system network to deliver water to end users at the minimum required pressure. The minimum required pressure varies by region: in highly urbanised areas with very tall buildings, the pressure is greater. In most cases, the GHG emissions are indirect emissions from using grid electricity to run pumps; however, just as in the case of drinking water abstraction and treatment stages, there can be direct GHG emissions from fuel consumption/combustion for engines or emergency generators driving the pumps. If the drinking water treatment takes place above the elevation of the city, it is possible that the water can be transported to the end users by gravity only, avoiding extra emissions. Other key factors that impact the GHG emissions in the drinking water distribution stage include the following.

- **Drinking water demanded by end users**
  As in the case for the previous two stages, the amount of drinking water demanded impacts the GHG emissions of the drinking water distribution stage. The more drinking water that is demanded, the more drinking water that has to be distributed and pumped to the customers. The end users impact the GHG emissions. Therefore, the less drinking water demanded, the less GHG emissions generated from the distribution stage.

- **Water loss**
  By virtue of how drinking water systems are operated, which is to maintain certain pressures or storage tank levels, any water loss in the system will require more energy to replace the same water to the end users. Therefore, the less water loss in the system, the less GHG emissions generated from the distribution stage.

- **Pump efficiency**
  Assuming the volume of water and pump head conditions are optimum, the pump efficiency can dictate the energy consumption and GHG emissions of the distribution system. Therefore, the higher the pump efficiency, the less GHG emissions generated from the distribution stage. Changing climate and population conditions will put a greater strain on current pumps since water will have to be pumped over a greater time and possibly distance. This will make the efficiency even more critical over time.

3.3.4 Wastewater collection

The GHG emissions related to the wastewater collection stage can include (but are not limited to) indirect carbon dioxide emissions from grid electricity consumption for wastewater pumping with electric motors, and/or direct GHG emissions from fuel consumption for engine-driven or powered pumps. The energy consumption for pumping is dependent on the amount of wastewater pumped, as well as the distance and elevation of the end users in relation to the wastewater treatment plant (WWTP). Methane (is produced by methanogenesis when there are anaerobic conditions in sewers (Guisasola et al., 2008), and emitted downstream wherever there might be stripping of methane from the liquid to the air. Generally, long detention times in the sewers leads to a greater risk of methane production and emissions (Foley et al., 2010). Methane emissions have a significantly higher global warming potential than carbon dioxide, so it should become a high priority when possible to minimise detention times in the collection system, whether those systems are gravity or pressure, to reduce methane emissions. Although some studies have reported nitrous oxide emissions to be significant from sewers (Short et al., 2014), the conditions leading to nitrous oxide emissions in sewers are still not very well understood. Other key factors that impact the GHG emissions in the wastewater collection stage include the following.

- **Drinking water demanded by end users**
  The more drinking water demanded and used by households, the more water is then drained into sewers and in some cases later pumped. Furthermore, the more wastewater in the sewer, the greater the possibility for methane production and emission. The end users' demand impacts the GHG emissions. Therefore, the less drinking water demanded, the less GHG emissions generated from the wastewater collection stage.
- **Pump efficiency**
  Assuming the volume of water and pump head conditions are optimum, the pump efficiency can dictate the energy consumption and GHG emissions of the collection system. Therefore, the higher the pump efficiency, the less GHG emissions generated from the wastewater collection stage.
- **Infiltration and inflow**
  In the case of sewers systems which require pumping, the more infiltration and inflow there is into the collection system, the more energy consumption needed to pump the additional water. Therefore, the less infiltration and inflow, the less GHG emissions generated from the wastewater collection stage.
- **Direct discharge of untreated wastewater**
  The direct discharge of untreated wastewater can create methane and nitrous oxide emissions in receiving waters. This occurs when not all of the wastewater is collected and conveyed to the WWTP. Therefore, increasing the coverage area of wastewater treatment, by collecting and conveying more wastewater to the WWTP, can reduce or eliminate these GHG emissions.

3.3.5 Wastewater treatment

In many cases, indirect carbon dioxide emissions from grid electricity consumption to power electromechanical equipment, such as pumps, blowers, mixers, and screens, needed for various wastewater treatment unit operations, make up most of a WWTP's GHG emissions. Typically, the aeration process is the most energy intensive. Therefore, opportunities to optimise the aeration system and control should be evaluated whenever possible, assuming that the air supply is controllable and dissolved oxygen can be measured in short time intervals throughout the day. In some cases, nitrous oxide, which is produced from biological nitrogen removal processes, impacts the WWTP's carbon footprint significantly because of its higher global warming potential (300 times that of carbon dioxide). Therefore, reducing nitrous oxide emissions through process optimisation is a high priority whenever feasible. Read more on nitrous oxide and how it is produced in the ECAM methodology, available on the Knowledge Platform [13]. There is the potential for additional methane emissions from the incomplete flaring of biogas during anaerobic digestion, non-well managed activated sludge systems, leaking biogas piping and sludge storage. Direct emissions of carbon dioxide, methane and nitrous oxide from the fuel consumption/ combustion for engine-driven pumps and blowers can also occur. Methane and nitrous oxide are emitted from sludge disposal off-site, with emission volumes depending on the sludge disposal method and the type of sludge (i.e. undigested and digested). Other key factors that impact GHG emissions in the wastewater treatment stage include the following.

- **Drinking water demanded by end users**
  The more water that is demanded and used, the more wastewater needing to be treated in the system. The end users impact the GHG emissions of the wastewater treatment stage by how much and how they use their drinking water. Therefore, the less drinking water demanded, the less GHG emissions generated from the wastewater treatment stage.
- **Pump efficiency**
  Assuming the volume of water and pump head conditions are optimum, the pump efficiency dictates the energy consumption and GHG emissions of wastewater treatment. Therefore, the higher the pump efficiency, the less GHG emissions generated from the wastewater treatment stage.
- **Infiltration and inflow**
  The more infiltration and inflow there is into the collection system and conveyed to the WWTP, the more energy used to process the additional water that has entered the system. Therefore, the less infiltration and inflow, the less GHG emissions generated from the wastewater treatment stage.

[13] ECAM Methodology found here: http://climatesmartwater.org/library/ecam-methodology/

- **The level of treatment**
  The more stringent levels of treatment required (generally based on the water quality of the receiving waters), the more GHG emissions generated from mainly energy consumption for aeration. Therefore, the less stringent levels of treatment required, the less GHG emissions generated from the wastewater treatment stage.

- **Ammonia load and aeration control**
  The diurnal ammonia loads coming to the WWTP and how the aeration is controlled for ammonia removal (when it is required) can have a significant impact on both energy consumption and nitrous oxide emissions. Depending on the ammonia concentrations/loads, too much or too little dissolved oxygen can result in high nitrous oxide production and emissions. The control of dissolved oxygen in biological reactors is fundamental. Therefore, an appropriate dissolved oxygen concentration can lessen GHG emissions generated from the wastewater treatment stage.

- **Chemical oxygen demand/total nitrogen (COD/N) ratio**
  The COD/N ratio in wastewater can influence the nitrous oxide emissions from heterotrophic denitrification. A low COD/N ratio resulting from carbon-limited wastewater can inhibit the reduction steps necessary to reducing nitrate to nitrogen gas during denitrification. When the COD/N ratio is low, nitrous oxide, which is an intermediate in this process, can accumulate and be emitted rather than being reduced to nitrogen gas. Adding external carbon in this case can help both the nitrogen removal process and to minimise nitrous oxide emissions.

- **Biogas production/valorisation**
  Whether biogas is produced and valorised to off-set grid electricity consumption or engine fuel has a significant impact on the WWTP carbon footprint. Therefore, the more biogas produced and used as energy, the less GHG emissions from the wastewater treatment stage.

- **Onsite treatment**
  For residents not receiving wastewater treatment services from the water utility, they must rely on their own onsite treatment, such as septic tanks, and these will produce additional GHG emissions. The volume of emissions varies depending on the type of treatment and how well the treatment system is maintained and serviced. Therefore, the better the maintenance on onsite systems, the less GHG emissions from the wastewater treatment stage.

3.3.6 Wastewater discharge/reuse

If effluent from the WWTP is returned to the environment and discharged to a receiving water body, then the resulting GHG emissions are due to pumping. Pumping is required on the basis of elevation and distance from the discharge point to the WWTP. Additionally, nitrous oxide is emitted from nitrogen discharged [14] into the effluent of the WWTP. If the WWTP effluent is reused instead, then the resulting GHG emissions will be dependent on the following.

1. The type of treatment required is based on the type of reuse, and the electromechanical equipment required, such as pumps, motors, blowers, mixers, and ultraviolet units.

2. The distance and volume of water either pumped or delivered by truck to reuse customers. If the type of reuse is indirect or direct potable reuse, the energy consumption is the highest because of the energy-intensive membrane filtration/reverse osmosis process required.

Other key factors that impact the GHG emissions of the discharge/reuse stage include the following.

- **Reuse water demanded by end users**
  The more reuse water that is demanded, the more wastewater effluent needing to be treated and/or delivered. The end users impact the GHG emissions of the discharge/reuse stage by how they use water. Therefore, the less reuse water demanded, the less GHG emissions generated from the discharge/reuse stage. However, there are generally more offsetting benefits if water is reused in terms of water security and/or reduced GHG emissions.

- **Pump efficiency**
  Assuming the volume of water and pump head conditions are optimum, the pump efficiency dictates the energy consumption and GHG emissions. Therefore, the higher the pump efficiency, the less GHG emissions generated from the discharge/reuse stage.

- **Infiltration and inflow**
  The more infiltration and inflow into the collection system and conveyed to the WWTP, the more energy used to discharge the additional water if pumping is required. Therefore, the less infiltration and inflow, the less GHG emissions generated from the discharge/reuse stage.

To summarise the detailed information presented here, the emissions overview table on the Knowledge Platform [15] demonstrates the potential GHG emissions sources throughout the UWC for water utilities and their various influencing factors.

[14] See ECAM Methodology: http://climatesmartwater.org/library/ecam-methodology/
[15] Search for Emissions Overview Table on ClimateSmartWater.org

	Water abstraction	Water treatment	Water distribution	Wastewater collection	Wastewater treatment	Wastewater discharge / reuse
Scope 1 - Direct emissions						
CO_2, CH_4 and N_2O emissions from truck transport of water (drinking water, wastewater, reuse water)			●	o		●
CO_2, CH_4 and N_2O emissions from on-site engine stationary fossil fuel combustion	●	●	●	●	●	●
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 use	●	●	●	●	●	●
Scope 3 - Other indirect emissions						
Emissions from the manufacture / transport of chemicals		o			o	
Emissions from the construction materials used	o	o	o	o	o	o
CH_4 and N_2O emissions from collected wastewater discharge without treatment				●		
CO_2, CH_4 and N_2O emissions from truck transport of sludge off-site					●	
CH_4 and N_2O from sludge management					●	
N_2O emissions from effluent discharge in receiving waters						●

o *Emissions not quantified in the ECAM tool, even though they exist*

● *Emissions quantified in the ECAM tool*

Table 2. Direct and indirect emissions at each stage of the UWC.

3.4 Impacts compounded across stages

As water moves through each stage of the UWC, there are GHG emissions impacts that compound, magnify and interact between stages. Water utilities can better navigate the UWC by implementing various solutions to minimise not only GHG emissions at each stage, but their compounded effects as well. By far the most influencing factor on UWC final emissions is how the end users consume and use drinking water and the total volume used for different purposes. The effects from water demanded by end users can trickle through the whole UWC, all the way from drinking water abstraction to wastewater discharge/reuse. In the case of water reuse, offsets exist for some of the GHG emissions, depending on how the water is reused and whether it replaces drinking water for non-potable purposes. If water reuse replaces drinking water for non-potable purposes, such as irrigation, then the emissions related to drinking water abstraction, treatment and distribution can be avoided. Furthermore, there would be less nitrous oxide emissions in receiving waters because less effluent from the WWTP is discharged.

What happens in one stage impacts other stages of the UWC, and these impacts can compound GHG emissions either in previous stages, and/or later stages. As noted, water loss in the drinking water distribution system can impact the GHG emissions of drinking water abstraction, drinking water treatment and drinking water distribution. Infiltration and inflow in the wastewater collection system not only impacts the wastewater collection system, but also the wastewater treatment and discharge/reuse stages; this is because the more water that enters the collection system, the more water is conveyed to the WWTP and discharged.

3.5 The need for a holistic and discerning approach

From a closer look at each stage of the UWC, it is clear that all stages are interconnected and dependent on influencing factors. Therefore, the only way to effectively approach management of this cycle is to view it holistically, meaning considering all parts of the whole at one time. Taking this approach will facilitate accurate decision making when assessing opportunities for improvement and the best solution that also reduces GHG emissions. A holistic approach firstly considers how a proposed solution can address a priority challenge the utility is facing, then examines the impact that solution can have on other parts of the system, including the overall emissions. Furthermore, a holistic approach considers the contextual trade-offs of each solution. For example, desalination, direct potable reuse and indirect potable reuse can each be viable solutions for supplementing existing supplies and mitigating water scarcity; however, they normally generate a higher carbon footprint due to their energy-intensive processes. This impact could be mitigated with the substitution of renewable energy instead. A successful holistic planning process will consider the trade-offs and try to minimise or offset drawbacks when selecting solutions to implement.

Another example is biogas production. A holistic approach will consider each of the following factors if a WWTP is currently not producing biogas, and is considering adding anaerobic digestion to produce biogas.

- The addition of anaerobic digestion requires a significant amount of energy for pumping, mixing and sludge heating. If the biogas is valorised, the energy recovered should offset the energy required for the biogas production itself; but if it is not considered, the benefits may be less than expected.
- The digestion of sludge will also reduce the amount of sludge disposed off-site, which reduces the GHG emissions from sludge disposal.
- The addition of anaerobic digestion may require additional treatment capacity as a result of higher loading from return streams of digester supernatant and centrate to the head of the process, which also requires more energy consumption.

These are just a few examples of contextual considerations, but the holistic approach helps in viewing the big picture when managing all UWC stages. It is a fundamental outlook towards an integrated approach and mind-set shift across the whole urban water sector.

3.6 Feasibility exploration: critical considerations for success

Implementing solutions within the utility, which are also effective GHG reduction measures, cannot occur in an isolated context. There can be missed opportunities or poor investments in the long run without a realistic view on the utility's current and future directions. This should also take into account technology advancement and replacement over time. Therefore, utility master plans (or mid- to long-term planning) must be reviewed alongside short-term capital planning. This analysis would identify the appropriate financing scheme and timing of the chosen implementation measures.

For example, a baseline study can indicate that inefficient pumps should be replaced. However, if they are simply replaced for higher efficiency pumps of the same capacity, there is a risk that water demands a few years later will require different operating conditions, and result in the pumps being no longer efficient, or worse, inadequate and needing replacement again. In this long-term scenario, what would initially cost millions of Euros in pump replacement could cost more than double in a short period of time if the pumps have to be replaced again. This demonstrates how a holistic and long-term view towards solution selection is vital to lasting success.

After understanding the full UWC stage-by-stage, seeing opportunities for improvement and undergoing in-depth planning considering all contextual factors relevant to the utility's unique drivers and challenges, a feasibility study can be conducted in preparation for implementation. The feasibility study should be structured in such a way that it is also valid for review by external financing entities and interested urban stakeholders. It is best to prepare a guideline of what the feasibility study should include, so that it can be submitted to a financing entity and stakeholders convincingly. The following are some suggested components.

- A detailed description of technical measures and associated investment and operational costs (i.e. a technical feasibility study).
- A detailed description of how the policy and financing mechanisms can enable the measure(s) (i.e. financial feasibility).
- Demonstrating how the project helps the community as a whole, and can tie into and benefit other local projects such as restoration for ecotourism and safe housing developments.
- Timeline and next steps to carry project forward.

From a comprehensive feasibility study, the utility is ready to put plans into action, and implementation of feasible measures is explored next.

3.7 Aligning opportunities with the utility's objectives, drivers and enablers

There are many projects that a utility can pursue; however, it is useful to consider how their individual objectives can be linked to the best opportunities, which can also open doors to new methods of financing. Examples have been given in the previous sections of how drivers can indirectly or directly lead to GHG emissions reductions; however, it is further suggested revisiting the objectives, drivers, opportunities and enablers using a mapping exercise. Mapping the utility's unique matrix can help pinpoint where to focus efforts for data collection, assessing GHG emissions, and navigating opportunities that fit the utility's current objectives. This holistic strategising is critical to focusing the GHG assessment efforts (step 2), and investigating the opportunities (step 3), which are both financially feasible for the utility and can lead to long-term benefits in service performance and GHG emissions reduction. Figure 11 shows how starting with financing that may be available for certain GHG reduction opportunities, GHG reduction can be traced back to meeting the utility objectives.

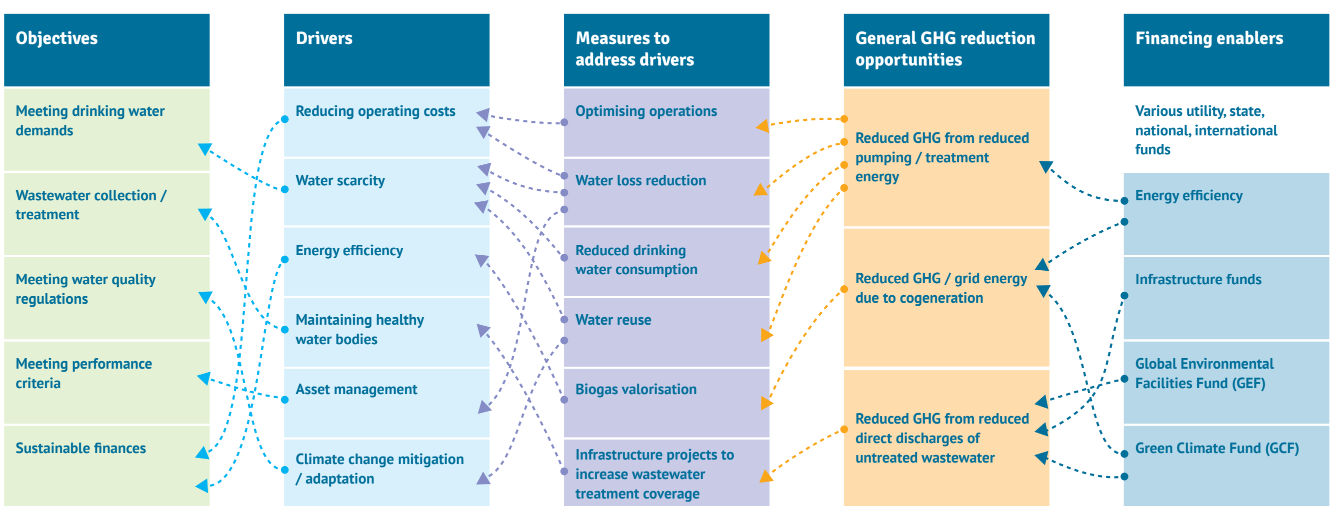


Figure 11. Aligning GHG reduction opportunities with a utility's unique objectives, drivers and enablers.

Step 4. Implement measures: setting plans into motion

This step is about what is needed to actually implement measures that will result in GHG emissions reductions. It guides utilities through identifying the enablers required to support future measures, while prompting them to think strategically about the longer-term project development cycle. The main enablers mentioned are financing strategies, utility capacity, existing policies and stakeholder engagement.

In step 3, the focus was on identifying the technical measures that allow utilities to address their objectives and drivers, but also contribute to reducing GHG emissions. Utilities may implement two types of measure that result in GHG emissions reduction: (1) technical measures that directly tackle a current issue; and (2) measures related to creating an enabling environment and higher capacity for future technical measure implementation. Both strategies are productive, and the latter is considered important when first beginning the planning process, as project development may require first the consideration of relevant policy direction and programme development – including the potential for a pipeline of related projects and not one isolated measure.

The implementation of direct technical measures requires a clear vision, capacity and the ability to self-finance or access financing, which topic is covered in the first section below. The second type of measure relates to improving the enabling environment through capacity, policies and stakeholder engagement. These 'soft measures' are critical to long-term success and longevity of the project development cycle of a utility, and are discussed is the subsequent sections.

4.1 Financing

4.1.1 Overview of the typical financing gap

There are three types of revenue that contribute to balancing the utilities' budget, as shown in Figure 12.

- Tariffs – user payment (including self-supply).
- Taxes – subsidies from the public sector: investments grants and subsidies for operation and maintenance.
- Transfers – subsidies from external sources; official development assistance, non-governmental organisations and corporate social responsibility.

In a financially sound utility, operational budgets are used for improving day-to-day operations and system optimisation, which include a few GHG reduction measures that can be implemented without further support. When capital improvement budgets are needed to finance infrastructure projects, the funding gap may be filled by a variety of mechanisms, including involving private financing. Private financing is particularly applicable for measures that relate to energy and water savings or energy production and generate a saving on the utility's operational budget, which becomes an income to reimburse the private financing organisations. When the infrastructure investment produces co-benefits to the environment, economic growth or well-being of people, the financial gap is filled through public sector financing.

Any form of private sector financing needs a repayment, ensured through demonstrating a balanced budget between costs, tariffs, taxes and transfers, as well as projected cost savings. This type of financing requires that a bankable project proposal is presented (see section 4.1.2).

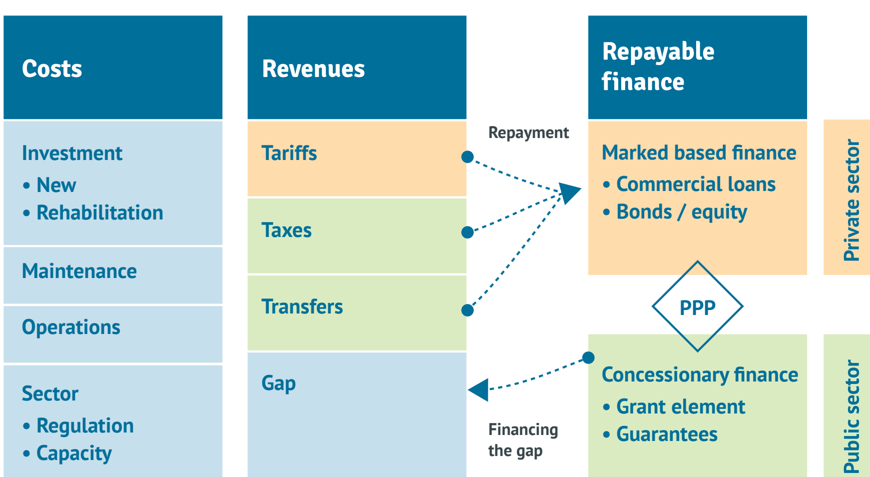


Figure 12. Pathways for water utilities to fill in their financing gaps.

4.1.2 Overview of mechanisms to fill the financing gap

There are a variety of instruments that can be used in the water sector to mobilise and leverage more financial resources and support utilities in achieving their coverage and quality of service targets. Being able to demonstrate how meeting the water utility's challenges also contributes to GHG reduction can lead the utility (or the government funding the utility) to apply for emerging financing mechanisms associated with the global climate mitigation targets. Table 3 provides a very general overview of the types of mechanism that exist at national and international levels. A more specific overview needs to be prepared for each country and cannot be included here. It is to be noted that international donors such as the Inter-America Development Bank, the Asian Development Bank, the African Development Bank or the World Bank, who often finance projects in developing countries targeted at infrastructure, are increasingly looking at including mitigation and adaptation to climate change in their project evaluation procedures.

What is important to highlight is that the financial strength of the utility is a key factor for accessing most of these funding mechanisms, which are provided in the form of loans and eventually need to be paid back.

Table 4 proposes examples of various funding mechanisms associated with GHG reduction measures. Note this is not an exhaustive list, and that utilities are encouraged to seek out further resources and guidance via the Knowledge Platform and independent assessments of individual financing mechanisms.

Water Infrastructure Funding From the state, regional or national levels	**Energy Efficiency Funding** From the state, regional or national levels
Development Bank Initiatives Large international development banks have funds available for projects which align with their goals, such as IDB	**Climate Change Adaptation Funding** From large independent international funds to governmental initiatives such as ESCO (European Comission)
Urban Stakeholder Partnerships Funding from partners on shared projects can expand the budget	**Corporate Social Responsability** Funding from policies or strategies for private utilities to incorporate more CSR

Table 3. General financing entities to begin the search for appropriate funders for adaptation projects. Relevant Acronyms: European Skills/Competences, Qualifications and Occupations (ESCO), Inter-American Development Bank (IDB), Corporate Social Responsibility (CSR).

GHG reduction measures	Potential actions	Potential financing mechanismst
Pumping station energy efficiency improvements	Optimise pumping, centralised/ supervisory control and data acquisition (SCADA) control and operation, replace pumps /motors/electrical, install variable frequency drivers (VFDs), upgrade instrumentation, fix power steering (PS) and system leaks/infiltration to reduce pumping volume	Utility budget, national energy efficiency financing European Skills/Competences, qualifications and Occupations (ESCO)
Drinking water treatment plant and WWTP energy efficiency improvements	Optimise pumping, replace pump/aerator /motors/ electrical, install VFDs, upgrade instrumentation, automatic control, clean or replace diffusers to increase oxygen transfer efficiency, optimise aeration	Utility budget, National energy efficiency financing, ESCO (see Glossary)
Increasing wastewater treatment/coverage	Increase proportion of wastewater treated at WWTP by expanding collection system, and minimising direct discharge to water bodies and related high indirect GHG emissions from water bodies	Utility budget, National infrastructure financing, Global Environment Facility (GEF) [16]
Biogas production using wastewater from septic/ onsite treatment systems	Collect wastewater from residences and businesses for anaerobic treatment/digestion and cogeneration at WWTP, use biogas for sludge trucks	GEF, Green Climate Fund (GCF) [17]
Rainwater harvesting	Rainwater harvesting at house and commercial levels to reduce wastewater flows and reserve capacity and reduce operating and capital costs, gain integrated energy/GHG benefits with drinking water and address climate change adaptation	GEF, GCF
Water reuse	Reuse at various scales (i.e. grey water treatment for irrigation and toilet flushing, WWTP effluent for irrigation, to reduce drinking water and wastewater flows and reserve capacity and reduce operating and capital costs, gain integrated energy/GHG benefits (drinking water and wastewater) and address climate change adaptation	GEF, GCF
Renewable Energy (solar)	Installation of solar panel at DWTP and WWTP sites to power facilities	National energy efficiency financing, ESCO

Table 4. Summary of GHG reduction opportunities and financing in the water sector.

[16] Learn more here: www.thegef.org
[17] Learn more here: www.greenclimate.fund

4.1.3 Qualities of a 'bankable' project

As mentioned earlier, financing a project through private sector involvement requires preparing a bankable project. The main elements of a bankable project are as follows.

- Financial viability of the projects – can you pay back, will it yield a return?
- Financial strength of the utility - cash flow, profitability, balance sheet.
- Management and technical capacity – project management.
- Trustworthiness of the figures provided – can we believe them?
- Risks – are they identified can they be managed? (e.g. tariffs, operating subsidies?).

The financial viability of the project is evaluated through the payback period, the net present value of the full project, the internal rate of return and increasingly often a cost–benefit analysis, which looks beyond pure financial elements to include benefits such as protection of the environment, economic growth of the city or the well-being of people. Table 5 provides further insights on each of these elements

After engaging in more detailed strategising, it is necessary to review the cost–benefit analysis and current capital/master planning, as well as opportunities that arise from shared initiatives with urban water stakeholders. Then a bankable project targeted at long-term improvements and tangible GHG reduction impacts can be developed. The project, when developed with these shared goals in mind, should have adequate data to comply with the criteria of prospective funding entities. Quality data determine the success of project proposals, which is why appropriate software tools such as ECAM are necessary to this process. When a new project proposal is presented, it should demonstrate clear and feasible objectives with corresponding planned activities, followed by the best available estimates of the following: GHG emissions reduction impacts, technical information of the equipment or infrastructure required for the project (at least pre-feasibility), financial information (investment needed, operation and maintenance costs), a contribution from the government or utility, sources of income, and savings. It is further recommended conducting a life cycle assessment of the chosen measure before implementation and during the planning stages, as this can strengthen the proposal. Other impacts that can be economically quantified, for example a project's contribution to the SDGs, Nationally Determined Contributions, or other global climate initiative and sustainable development initiative, are beneficial is unlocking climate and international development financing. Afterwards, the project can identify the mechanisms that are more suitable for their specific situation and pursue those practical pathways.

Financial Analysis	**Payback**	**Net Present Value (NPV)**	**Internal Rate of Return**	**Cost Benefit Analysis (CBA)**
What it means	Number of years to re-coup initial investment	Total value in today's currency	"Interest" yield during project lifetime	Balances all the benefits and costs
Example	1.5 years	Euro 800,000	12% IRR	CBA 1.2
Criteria	Payback < x < years (usually less than 5) for energy efficiency in W&WW utilities	If positive, it is profitable	IRR > hurdle rate (e.g. bank interest)	CBA > 1
Comment	• Easy •Can be misleading • Financing costs • Short time less risk	Need to select a discount rate	Easy to compare to an interest rate	Takes intangible benefits into account complex

Table 5. Some financial variables to consider in the planning of a bankable project over time. IRR stands for internal rate of return in this context.

4.2 Utility capacity: begin at the beginning

The current capacity of the utility refers to its pre-existing resources, processes, technology and relevant staff training at the beginning of the roadmap process. Staff training is a key component of the long-term success of the approach. Whether the current capacity is adequate to follow through with planned improvements, or whether more development is required, is a critical enabler for success. The ability to internally organise, strategise, assess GHG emissions, identify reduction opportunities and implement solutions effectively depends entirely on the capacity of the water utility. Having a multidisciplinary team with the right skill sets is a key goal. Beyond these skills, it is also necessary to develop bankable projects and further identify and secure financing to implement them. Each utility has a different starting capacity, so a main purpose of this roadmap is to help identify and fill gaps in capacity along this low-carbon, sustainability-oriented and holistic approach. The roadmap is designed so that utilities can begin with the minimum capacity necessary to understand what the areas for improvement are within their system, what the GHG emissions sources are, the scale of these emissions, and how to find and implement appropriate solutions. This process will also lead utilities to understand at which point consultant or expert support is needed to continue on this path.

4.3 Existing policies: what is already in motion to facilitate progress

There may be various policies or strategies at different governmental levels that are either directly or indirectly aligned with climate mitigation in the water sector. These policies can greatly assist a utility in reaching its internal improvement targets when the shared goals align. Referring to these policies will help in identifying whether the water utility is subject to meeting them, and, secondly, whether they can be referenced in support of the business case for financing new projects. These policies and strategies can be found at the city scale, as seen in case of New York City, or at the state, regional, and national scales. In the case of the Paris Agreement, this is an example of a policy drafted at the international level and promulgated at the national level. Some generic categories of policies or strategies that can assist GHG emissions reduction targets in the water sector are given below.

- Municipal, state, regional, and national GHG reduction policy or strategies from climate initiatives.
- Municipal, state, regional, and national energy efficiency policy or strategies.
- Corporate social responsibility policies or strategies (for private utilities).

These policies are in constant evolution and a champion to the low-carbon transition may drive new policies or revised policies that will support utilities in taking action towards a carbon-neutral future.

For example, in Peru, the WaCCliM team has worked towards including carbon mitigation as part of the mandatory climate plan that utilities need to submit to the authorities. More can be read on this case study in section 4.5, and a full version has been posted on the Knowledge Platform [18].

4.4 Stakeholder engagement

The engagement of key community stakeholders can facilitate improvements in the urban water sector through the development of lasting partnerships and support for specific projects. For example, if a wastewater utility needs to expand coverage, partnering with the neighbouring drinking water utility is beneficial for expanding both drinking water and wastewater services. In this scenario, the two utilities could apply for funding together with a stronger joint case. Many benefits and shared goals can be found through direct urban stakeholder engagement and it is strongly encouraged at all stages of the roadmap, especially where capacity gaps may take place. Everyone in the community has a stake in the success and development of their utility.

Many measures that result of holistic planning towards water and energy efficiency and towards reducing GHG emissions cannot be implemented in isolation by urban water utilities. Engaging all the stakeholders from other urban sectors as well as the various levels of administration and government institutions involved in water management is key to a successful transition to a low-carbon utility, and eventually a low-carbon urban water sector.

Active communication and empowering individuals to becoming champions of the low-carbon vision are two key overarching measures that will support the utility in implementing low-carbon technical measures in the long term.

As an example, utilities such as Waternet [19] in Amsterdam report that it has taken them many years to get the stakeholders' engagement to the level where carbon neutrality is now one of the objectives of the utility.

[18] Search for Peru Case Study on www.climatesmartwater.org
[19] Learn more here: www.waternet.nl

4.5 Project examples: the pilot utilities

WaCCliM is currently working in four pilot countries with partners and key utilities: in Peru with MVCS (Ministerio de Vivienda, Construcción y Saneamiento) and the utility of SEDACUSCO in Cusco; in Mexico with CONAGUA (Comisión Nacional del Agua) and the utilities of San Francisco del Rincón; in Thailand with WMA (Wastewater Management Authority) and the wastewater utility in Chiang Mai; and in Jordan with the Water Authority of Jordan and the water utility of Miyahuna-Madaba. In addition to the pilot utilities, the project reaches out to at least 10 follower utilities using the same approach as the pilots, with the goal of implementing measures resulting in 10% carbon reductions within the project timeframe. The project is being implemented from December 2013 to January 2019.The pilot utilities demonstrate the variety of challenges and opportunities faced by water utilities today, especially in the developing world. Each began involvement with the project under a different set of starting conditions. Some were able to plan and implement measures towards energy efficiency and increasing coverage, while others made progress towards higher awareness and policy influencing, both internally and externally. In all cases, building the capacity of the utility with a vision towards long-term progress was the goal of the changes initiated. The involvement of local stakeholders and knowledgeable experts becomes evident as a key success factor in all cases. The objective when becoming a utility 'champion' is to initiate progressive measures no matter what they look like, whether they be structural improvements such as in Mexico, Peru and Jordan, or critical policy and training updates, such as in Thailand. Highlights from each pilot country are listed below.

4.5.1 Mexico

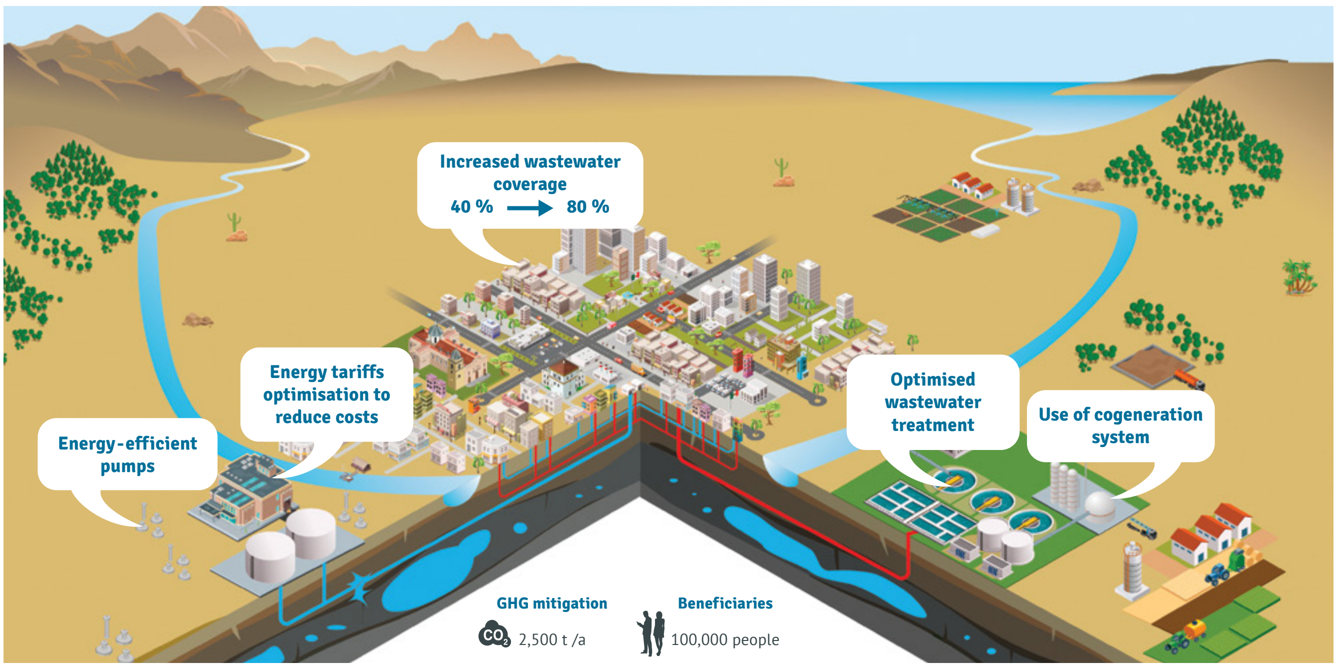


Figure 13. Potential GHG reduction through identified measures.

The implemented measures have allowed SITRATA and SAPAF to lower the operational costs and improve productivity. The immediate impact of increasing wastewater treatment coverage is a 40% reduction in GHG emissions, equivalent to 2500 tons of carbon dioxide per year. Financing for increasing wastewater treatment coverage (approximately €500,000) was raised using federal, state and the utilities' funds. The rest of the measures (€7,000) were implemented using savings the utilities gained through efficiency measures.

A full case study is available on ClimateSmartWater.org.

Measures implemented during the WaCCliM project	Success factors
• Increasing the volume of wastewater treated • Energy optimisation of pumps and treatment processes • Improving biogas and energy production in the plant	• Cooperation between the two utilities in the same city • Engagement, commitment, and interest from management during the process • Internal financing and allocation of funds based on progress of measures (generating more funds through offset costs) • Compliance with National Mexican Climate Mitigation objectives

Table 6. Measures chosen and implemented and the key success factors of the Mexican WaCCliM pilot utility

4.5.2 Peru

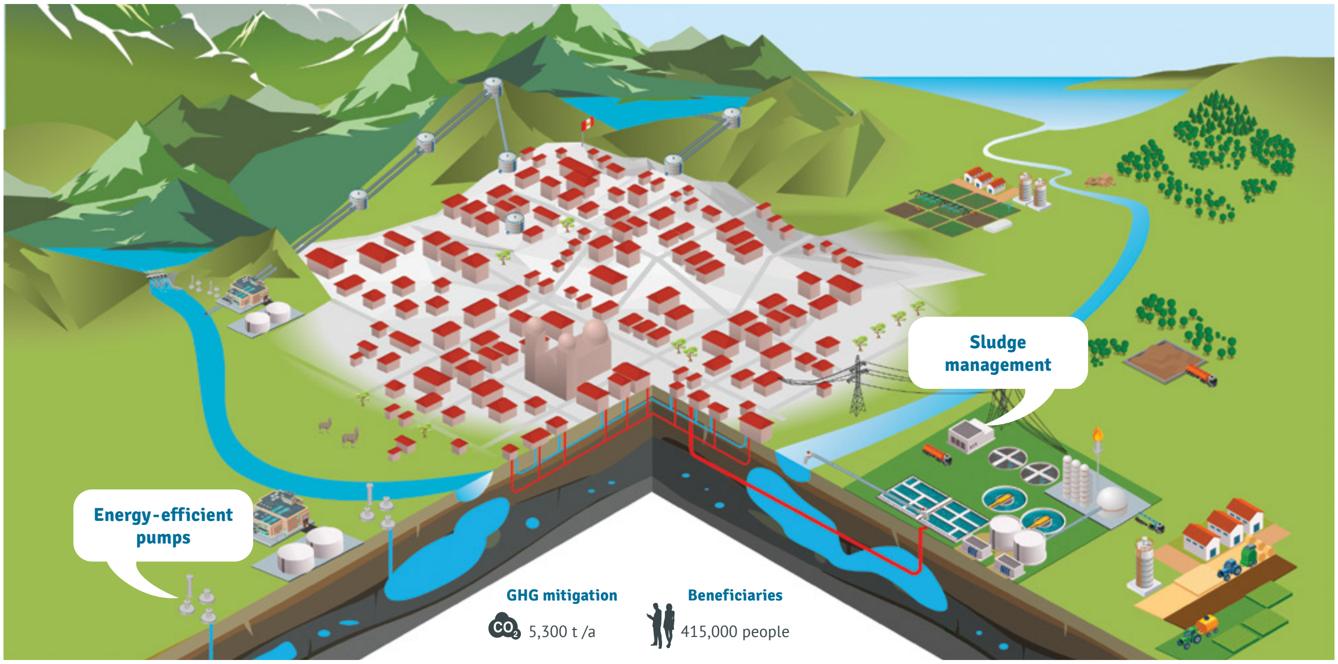


Figure 14. Potential GHG Reduction through identified measures.

To mitigate GHG emissions and counter climate-related risks and vulnerabilities, water utilities in Peru have drawn up their Climate Change Mitigation and Adaptation Plans (PMACCs for its acronym in Spanish), which are an important input for the optimised master plan, instruments that allow water tariffs to be determined. Acknowledging their importance, current water sector legislation established as mandatory that water utilities prepare PMACCs.

PMACCs offer a great opportunity to demonstrate how the water sector may contribute to meet the 2030 Agenda and the Nationally Determined Contributions. A successful example was implemented by the water utility of Cusco (SEDACUSCO), which faced the challenge of reducing its WWTPs' operating costs and odour nuisance along with the carbon emissions; to solve this, recovery of sludge and biogas has been shown to be promising: currently 5300 tons of carbon are saved every year, and future generation of electricity for internal use will allow savings of about USD290,000 per year and 650 tons of carbon per year.

A full case study is available on ClimateSmartWater.org.

Measures implemented during the WaCCliM project	Success factors
• Improved sludge management • Biogas optimisation production	• Commitment from the utility staff and board of directors • To achieve tangible and quick results to motivate water utility as energy cost reductions • Controlling odour nuisance

Table 7. Measures chosen and implemented and the key success factors of the Peruvian WaCCliM pilot utility.

4.5.3 Jordan

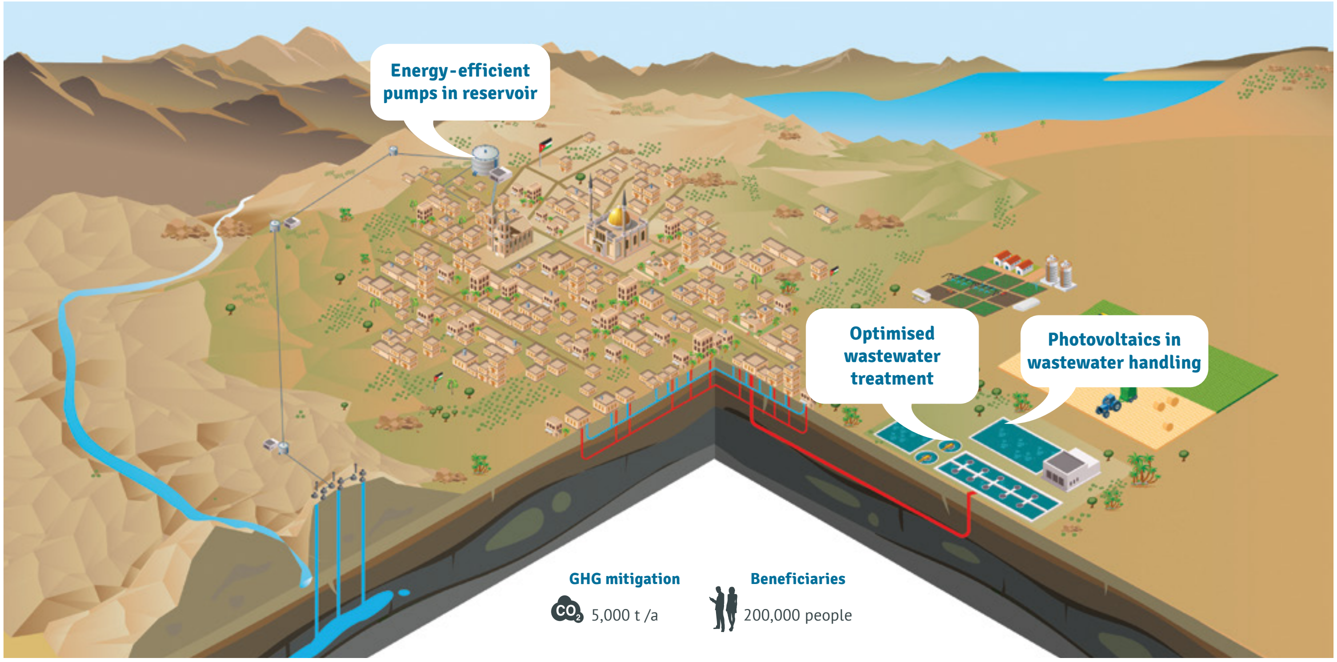


Figure 15. Potential GHG reduction through identified measures.

Under the guidance of the WaCCliM Roadmap, the Miyahuna-Madaba Company, with the help of the University of Jordan, conducted studies to determine its overall operational baseline GHG emissions throughout the UWC. This basic assessment was completed using the ECAM tool, a free software tool from the project. To address internal costs and water scarcity in the region, and as motivated by the national strategy, the utility decided to move forward with implementation of energy-efficient pumps, as well as water supply network maintenance and pressure management. The exact impact of the measures is to be assessed at the end of 2018, given the later start of this pilot project; however, early estimates indicate the potential GHG reduction is 1.2 million kilograms of carbon dioxide equivalent.

A full case study is available on ClimateSmartWater.org.

Measures implemented during the WaCCliM project	Success factors
• Energy-efficient pumps • Sludge digestion and biogas valorization • Water supply network maintenance and pressure management • Photovoltaic panels	• Detailed options study conducted first to help guide appropriate decision making • Continuous communication and coordination with the counterpart • Shared responsibility in procurement and monitoring • Adherence to national strategy • Strategy for continuing service improvements and climate mitigation

Table 8. Measures chosen and implemented and the key success factors of the Jordanian WaCCliM pilot utility.

4.5.4 Thailand

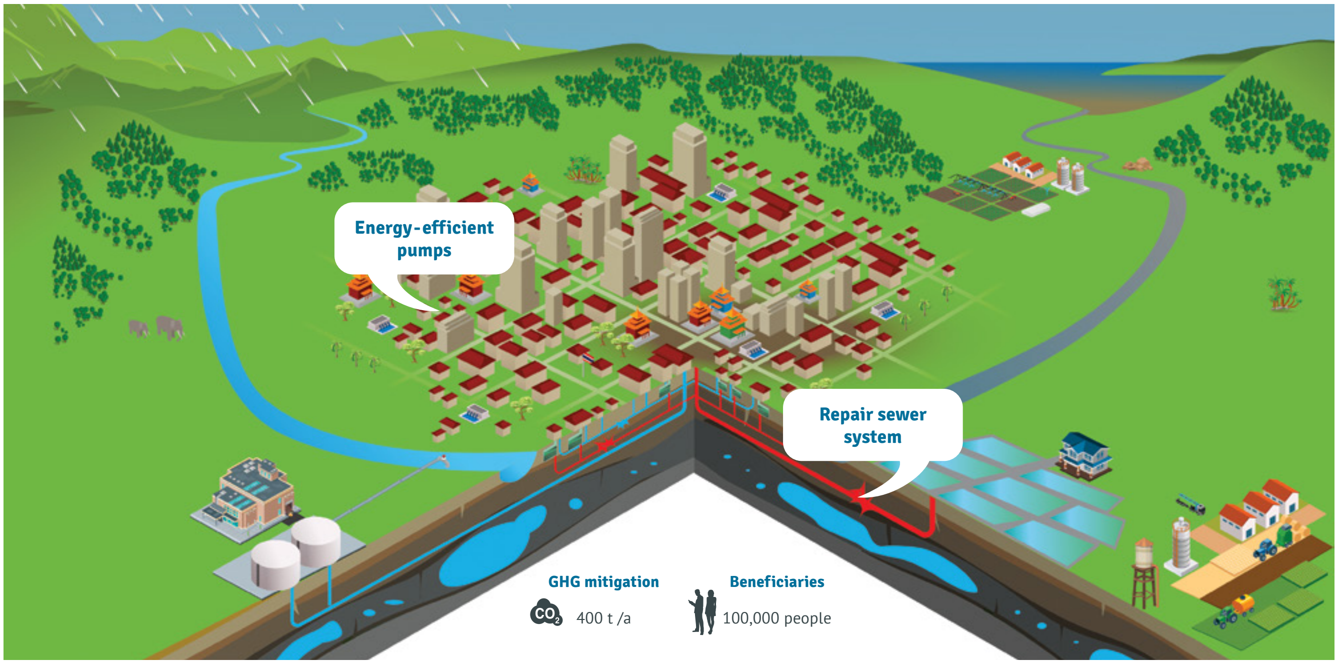


Figure 16. Potential GHG Reduction through identified measures.

The project developed a training programme for many utilities on emissions assessment methodology, a critical step in building the capacity necessary to have successful implementation of GHG reduction measures at a later stage. Initial GHG reductions were achieved in the Chiang Mai utility through sewer repairs and pumping cycle optimisation. More extensive measures required coordination with stakeholders beyond the utility: WMA are working closely with the municipality on planning this and it will be implemented after the project timeframe.

The development of a national policy to include GHG reduction targets for all domestic wastewater utilities is a main success of Thailand to meet climate objectives. The WMA also now develops sustainability reports. This demonstrates Thailand's continued commitment to improving services and becoming a regional leader in climate mitigation.

A full case study is available on ClimateSmartWater.org.

Measures implemented during the WaCCliM project	Success factors
• Policy development: 'Nationally Determined Contribution Roadmap on Mitigation 2021-2030' • Development of WMA Sustainability Report • Training workshops on key knowledge transfer topics to utility staff • Increase wastewater influent by cleaning sewer system	• Awareness Raising • Engagement of fellow utilities • Better understanding of how to carry out projects like this in the future • Assessment identified that repairs in the sewer system and implementation of energy efficient pumps would greatly enhance current operations

Table 9. Actions taken to support future implementation of measures and key success factors of the Thai WaCCliM pilot utility.

Step 5. Monitoring success

This step is about visualising the impact of the measures implemented. It requires collecting adequate data used with the same tools as for the assessment. Monitoring is used to verify and measure emissions reductions after implementation, which is key to accessing climate financing. This step determines the success of a project over time.

Following the successful implementation of several solutions, the path to better urban water management does not stop there. Progress is a continuous road to a higher state of capacity than before. The most innovative and adaptable actors in the water sector are constantly pushing themselves further than their current perceived limits. Monitoring the continued performance of the water utility is critical for understanding how previous decisions have contributed to the overall capacity and GHG emissions reduction impacts over time. Monitoring must be conducted regularly to be useful, otherwise the ability to identify problems and opportunities becomes limited to only a few points in time. Furthermore, the objective is not to implement a solution once and leave the project there, but to think about the long-term outlook for the utility and society. As research and development progress globally, the technologies used today in the water sector will improve and adapt; therefore the utility should be open to the new possibilities that anticipated technological advancements could bring as well.

This involves not only engaging in the beginning with the mind-set shift approach, but truly incorporating this new perspective at every level of internal planning, to expand the relevance of local actions to meeting global sustainable goals. Making the permanent shift requires thinking that has a broad vision for the utility's sustained and improved services, the natural resources maintained in the community, and global water supplies. Moving towards this vision involves monitoring, which is programmatic, meaning it is done repeatedly and compared constantly with previous results. The GHG data management and assessment framework presented in section 2.2 is developed mainly for this purpose, making it an important tool in the process. The objective is always to conduct a high-quality baseline assessment and to continue monitoring frequently. The data process flow for monitoring is shown in the recommended GHG data management and assessment framework [20]. For more information on how to use the ECAM tool for monitoring success, refer to the Monitoring Fact Sheet [21].

[20] Search for Data Management and Assessment Framework on www.climatesmartwater.org
[21] See From Data Management to Greenhouse Gas Monitoring on http://climatesmartwater.org/library/from-data-management-to-greenhouse-gas-monitoring/

Part 3:

The Urban Water Utility of the Future: Low-Carbon, Holistic and Sustainable

1. Water utilities are the champions for securing the collective water future

The WaCCliM roadmap is the first guide of its kind to demonstrate a clear and practical approach towards low-carbon, holistic and sustainable urban water management. Becoming a part of this initiative is one step along the global water sector movement to a better urban water management future for water utilities, their communities and the world. A low-carbon, holistic and sustainable urban water future is not simply an ideal fantasy or pipedream: it is a real future that can be practically achieved and is already in motion in some parts of the world. This is a future where water utilities are no longer vulnerable and unprepared for urbanisation pressures and climate changes; where renewable energy sources can offset both emissions and costs, and resource recovery can contribute to a circular economy; where service performance is not suffering from deteriorating infrastructure, but is modernising and expanding simultaneously. In this scenario, the residents of the community work together to support their utilities in providing an excellent and sustainable service, while ensuring that their water supplies are secure and beneficial for the local environment. This roadmap introduces helpful steps so that any utility can begin to strategise and plan future improvements that have lasting value to both the utility itself and the global climate agenda. However, the immediate benefits to the utility and initial GHG emissions reduction results are only the initial goal of this roadmap. The ultimate goal is to kick-start this transition and steer water utilities worldwide towards a greater future.

2. Continuing to improve

The mind-set shift that has spread into a sector-wide movement can shape how the urban water management of the coming decades will look. Closing water loops, integrating urban water management, increasing wastewater treatment coverage, resource recovery, water and energy efficiency, engaging the public and efficient treatment are all trends that will push the movement forwards. Creating real and lasting change is not something that can happen by one actor alone in a month or even a year. This will be a group effort, with relationships building and lasting the lifetime of a utility, and longer.

The roadmap presents an approach through one completed cycle of implementation; however, it is up to utilities to repeat the cycles into the future. In the next cycles, water utilities will again assess new drivers, cultural changes and revised priorities as capacity and circumstances change. Repeating the process means incorporating lessons learned from the first projects into future ones, while increasing the capacity for better decision-making and involvement of other stakeholders. The overall roadmap approach can improve over time, and critical components such as the framework for GHG data management and assessment will need to be updated as new data become available, improved data management and technology is implemented, and utility drivers change. Every part of the framework will develop and become fluid and adaptable to the many conditions a utility will work within.

3. Planning future assets that are low-carbon and adapted to climate change

The ultimate success of this low-carbon transition process goes beyond the optimisation of existing infrastructure. It is about building future assets in a way that considers all urban waters holistically, and ensures that urban water systems are fully regenerative, using the least amount of resources possible, and only discharging to the environment what it is able to be absorbed, including reduced carbon emissions.

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The Roadmap

to a Low-Carbon Urban Water Utility

Annexes

Annex I:

Project Background

WaCCliM, which stands for Water and Wastewater Companies for Climate Mitigation, is a joint initiative between the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and the International Water Association (IWA), acting on behalf of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) as part of the International Climate Initiative (IKI). The WaCCliM Project advocates for carbon neutrality of water utilities through the introduction of measures that can simultaneously enhance utility performance and reduce greenhouse gas (GHG) emissions. These measures are practical and contribute to common utility challenges, such as increasing energy efficiency, reducing water loss, increasing coverage areas, as well as recovering water, energy and nutrients from wastewater. To work towards this carbon neutrality goal, improvement measures must be both economically viable and effective at reducing emissions. The roadmap is targeted at water utilities in developing countries, but it is also intended to be applied universally at the local, national and international levels since climate change is a global problem.

WaCCliM is currently working in four pilot countries with partners and key utilities: in Peru with MVCS (Ministerio de Vivienda, Construcción y Saneamiento) and the utility of SEDACUSCO in Cusco; in Mexico with CONAGUA (Comisión Nacional del Agua) and the utilities of San Francisco del Rincón, SAPAF and SITRATA; in Thailand with WMA (Wastewater Management Authority); and in Jordan with the Water Authority of Jordan and the water utility of Miyahuna Madaba.

In addition to the pilot utilities, the project reaches out to at least 10 follower utilities using the same approach as the pilots, with the goal of implementing measures resulting in 10% carbon reductions within the project timeframe. The project is being implemented from December 2013 to January 2019.

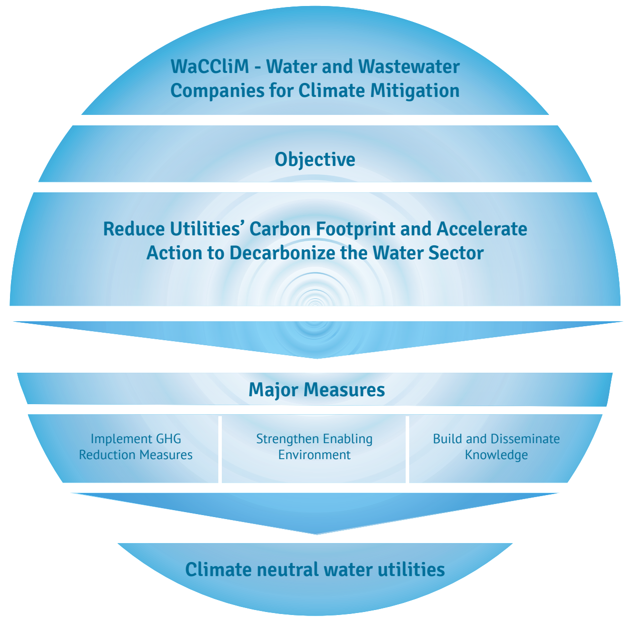

Figure A. The WaCCliM project objective.

Figure B. The four pilot utilities of the WaCCliM project and their GHG emissions reduction potentials and impacts.

Annex II:

Data Management Framework Extended

The steps for building the overall data management framework presented here are uniform for each utility; however, in actual application customized data processes will be required to support implementation. The initial data processes are dependent on the individual utility's current data management, resources and overall capacity. The recommended framework in the end, together with the customized data processes, can be refined, adapted and improved as the utility's capacity (i.e. hardware, software, staff expertise, etc.) increases over time. For example, a utility initially without a SCADA system and manually entering flow data into a spreadsheet can later begin to export the data from the SCADA system directly into the central data repository after upgrading. Therefore, the framework is flexible and is intended to facilitate and reduce the effort for continuous use of the ECAM tool and other tools, conducting GHG reduction studies and ultimately implementing corresponding reduction measures.

Data quality / Data process review

The first step in constructing the framework is performing a data quality and process review. **The WaCCliM Data Quality / Process Matrix** is a complete template that helps in evaluating what are the current GHG reduction opportunities, data owners (if specific owners assigned), data category (i.e. for baseline/monitoring and/or GHG reduction analysis), general data quality and current data processes for extracting the data for various purposes. The idea is to complete the matrix based on direct input from the utility's operations and engineering staff, which can be provided in a data management workshop with relevant utility staff. A sample of a completed data quality/process matrix and results can be found in the Knowledge Platform [1].

Data priority / Quality survey

The next step in developing the data management and assessment framework is performing a data priority/quality survey. This is done to check any pressing data limitations, as identified in the data quality/process matrix, versus the daily operational priorities of the utilities. If there are any critical data flaws (with a data quality score of 1) corresponding to high-priority items (with a data priority score of 3), then they are flagged by the survey to prioritize data improvements. The data priority/quality survey should result in identifying the most pressing data gaps and improvements, and where the utility should direct attention to better data management over time. A sample data priority/quality survey can be found in on tab 5 of the WaCCliM Data Quality/Process Matrix the Knowledge Platform.

GHG Reduction Analysis Data Requirements

Data required for GHG reduction studies are generally more detailed and collected at a higher frequency than for other studies, as they are intended to give some insight into the dynamics of the urban water system that impact GHG emissions. The data may also not directly relate to variables used for estimating GHG emissions. For example, pumping station or treatment plant flows do not correspond directly to GHG emissions, whereas electricity use is a key variable in GHG emissions calculations: for example finding kilograms of carbon dioxide per kilowatt hour (kg CO2e/kWh). However, flow variables are sometimes critical in determining whether pumping or treatment operations can be modified to reduce energy consumption. Similarly, process water quality data can signal process inefficiencies and possibly identify opportunities to optimize the overall process. Optimization usually reduces energy consumption and/or improves treatment, which reduces GHG emissions in receiving waters. A comprehensive summary of data that can be used in GHG reduction analysis can be found in the Knowledge Platform [2]. It is not anticipated that utilities will have all of these data available at the start, so the summary can be used as a working checklist to identify where data gaps might still exist and what data are available on a regular basis.

[1] Search for WaCCliM Data Quality/Process Matrix on www.climatesmartwater.org/assess
[2] Search for Summary of GHG Reduction Analysis Data on www.climatesmartwater.org/assess

Central Data Repository

The recommended processes for integrating data sources and linking data to a central data repository within the framework are listed in the last column of the data quality/process matrix above. In general, the recommended course of action is to leverage existing data processes, and either enter the pre-existing data saved in existing places or electronic files, such as Microsoft Excel files, into a central data repository, or import entire Excel sheets directly into a central data repository if this is in the form of a central Excel file. When the existing Excel sheets are imported, it is further recommended to begin maintaining and managing the existing Excel sheets within a central data repository, as this avoids confusion between different versions of the same Excel sheets. To create a successful central data repository, it is recommended maintaining it within a central Excel file (Central Excel), compiling any existing and new Excel sheets and data needed for the baseline/monitoring and GHG reduction studies here in one streamlined format. It is up to the utility to decide which of the data required for the GHG reduction studies can be directed into the Central Excel, or saved outside the Central Excel until conducting the studies requires extracting the data from their original source. Data can be extracted from original sources such as the SCADA historical data, operational logs or scanned performance curve sheet files. Storing any data that are not frequently required for baseline/monitoring or GHG reduction studies outside the Central Excel helps to minimize the file size. The central repository can always be more sophisticated than a central Excel file depending on the utility's resources.

Recommended framework construction

Once the recommended data processes are identified, it is recommended implementing the framework as illustrated and described in the examples on the Knowledge Platform [3].

[3] Search for Recommended GHG Data Management and Mitigation Framework on www.climatesmartwater.org/assess

Annex III:

Utility Roadmap Scenario

Starting conditions

This is a wastewater utility in rural Argentina servicing a growing population. Recent rapid housing developments are increasing the wastewater coverage demand in the area. Likewise, tourism is growing in the region, and the public authorities are putting pressure on the local utilities to increase the sanitation and safety level of the water to support the local tourism industry. Adding to this pressure, in an unusually strong rainy season in the area, some abnormal flood events are expected during the rest of the season. It is clear that the wastewater utility must take some level of action, but the question is, with a limited budget, what are the best options to proceed?

Options to approach the situation

Increasing coverage can be a costly investment, depending on the size of the area that needs to be covered as well as the current capacity of the utility. It is possible to seek out additional funding by engaging with local stakeholders. However, this too may be limited given the resources of the urban area. Instead, one approach can be to assess what volume of GHG emissions are avoided by increasing wastewater coverage, and to propose a project that can demonstrate clear contributions to the global Sustainable Development Goals and nationally determined contributions through improving community health, biodiversity and climate change mitigation. This can move a project up the financing scale, from a purely local issue to one that can successfully move forward contributions to global agendas. This opens up a utility's options in terms of unlocking climate financing and potential collaborators who can address knowledge gaps.

Starting with one small step

By honing in on one critical issue, such as increasing wastewater coverage, an individual utility can begin the process to link its own planned actions with reduction of GHG emissions, thereby dually purposing projects and expanding their reach and usefulness. The roadmap is useful when developing a project, as critical data needs and considerations along the utility pathway are considered. For example, to assess how much GHG emissions could be reduced and/or avoided by implementing increased wastewater coverage, the utility will first need a tool with which to assess these emissions.

Finding the right resources

The roadmap is not about starting costly projects which are beyond the scope of a utility's current capacity; it is simply to facilitate the progress that the utility is already planning with access to better information and tools. In this way, the benefit of choosing measures that also align with global GHG reduction goals becomes clear, especially when the opportunity to bring in additional knowledge, tools and resources is unlocked by following this path. In this scenario, the utility in Argentina can simultaneously address its need for increased wastewater coverage, which helps the new housing developments, the booming tourism industry and the safety of the general population in regards to their water quality, as well as minimizing wastewater which can overflow during a flood event. The demonstrated contribution of the project to lowering GHG emissions has won the project climate financing from the International Development Bank, and attracted expert collaboration from the networks of IWA and GIZ over implementation queries. The utility has also been able to train its staff in carbon-neutral approaches and will be kicking off a new strategy plan and sustainability report this year.

The next steps

After successful completion of the coverage project, the utility is able to monitor its progress and finds that it has offset its overall carbon emissions by 10% in just one year after the baseline assessment, by avoiding emissions from untreated wastewater and reduced pumping from water reuse. The success of the project has brought praise from local stakeholders and the municipal authority owing to the higher standard of sanitation in the area. They would like to see the utility build on this success and the capacity-building initiatives started during this project. The next year, the tourism sector joined the utility as a local stakeholder and together they planned a joint project that set up a nature reserve to benefit both ecotourism and the quality of the local water supply. This project is planned in coordination with the international partners and wins funding from the Global Environment Facility. Soon the low-carbon and sustainable approach is built into the new utility strategic master plan, with improvements planned for every year thereafter.

Annex IV:

Overview of Opportunities and Solutions to Lower the GHG footprint of Urban Water Utilities

The Climate Smart Water Knowledge Platform (ClimateSmartWater.org [4]) has been developed under the WaCCliM project. This platform offers utilities free access to relevant resources such as case studies, technical documents, problem solutions, inspiring stories and more, which can support them on their journey through any phase of this roadmap and towards a low-carbon, low-energy future.

The 'Step 3 – Opportunities' section of the platform presents an inventory of potential solutions to lower GHG emissions while optimizing water and energy efficiency across various stages of the urban water cycle (UWC). These are already presented in Part 2, section 3.1 of this document, but more detail is available online, with solutions presented for many of the potential areas of improvement. This online inventory is continuously being updated and further documented. It is structured in a way that highlights the interconnectivity between different stages of the UWC, by identifying how one stage is impacted and impacts other stages of the water cycle. Under each stage of the UWC, several areas of improvement are identified, which may lead to a reduction in GHG emissions. Under each area of improvement, specific solutions are described, along with the points to consider and benefits while implementing them. The intention is to start to build an authoritative reference for utilities ready to begin the strategic planning and implementation of solutions as the lasting legacy of this project. The basis of the inventory is built on water utility expert knowledge and experience from previous projects. As experience in the sector over these types of low-carbon project grows, so too will the available solutions; thus the WaCCliM project explores the current opportunity to create a living inventory through this Annex.

This information is also available in a downloadable version, which will capture the solutions inventory as shown on the online Knowledge Platform as of August 2018. As this is intended to be a living inventory of solutions, it is recommended regularly visiting the online portal and exploring the latest resources and solutions that might have been added since the original publication. If there are any verified technical solutions you would like to share to increase the value of this inventory to a diverse range of utility users, please send suggestions to **info@wacclim.org**.

[4] www.climatesmartwater.org

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