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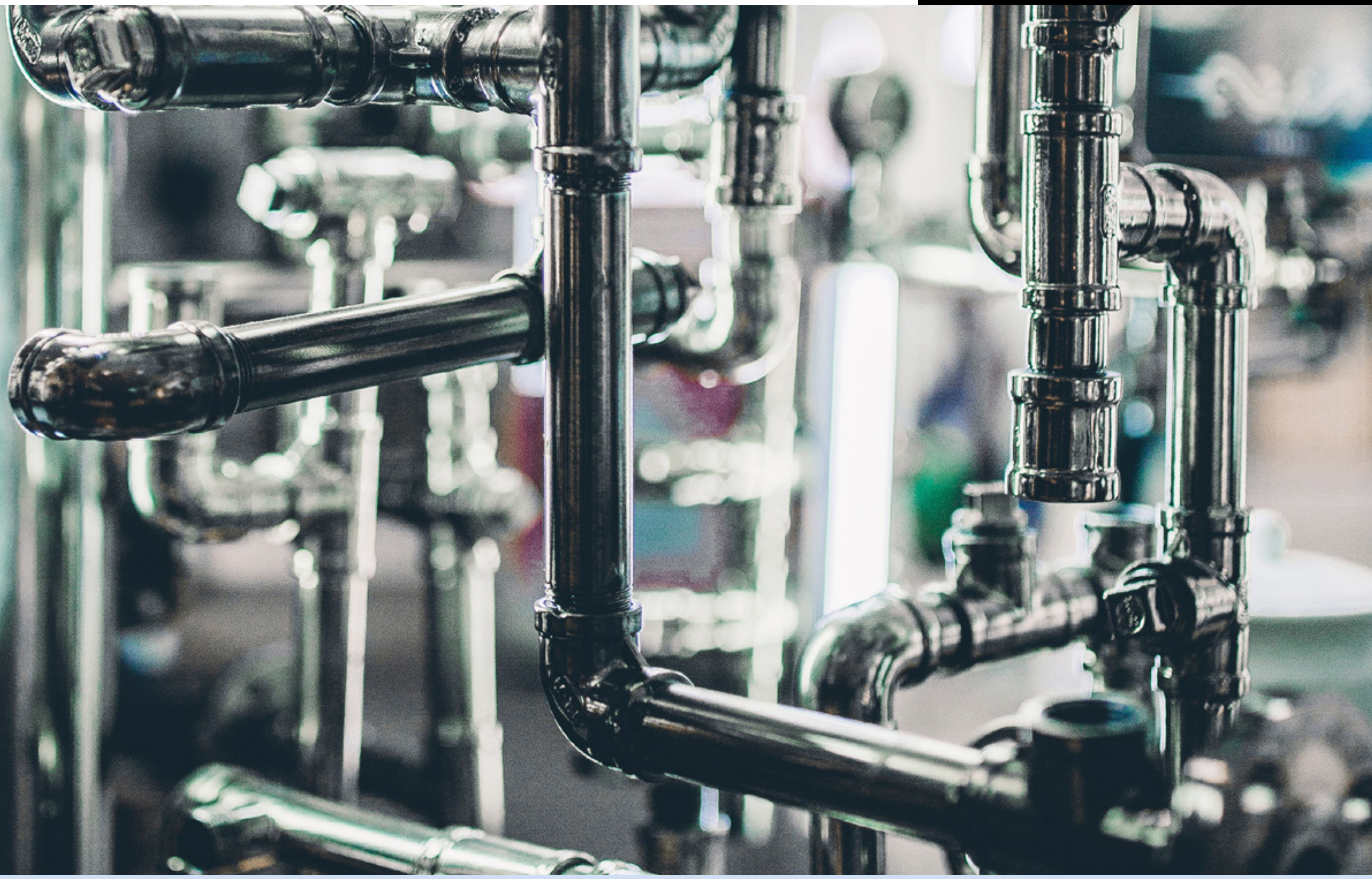


ISSUE BRIEF

Water-energy Nexus in Urban Water Supply Systems

KEY MESSAGES

- Water and energy are closely interlinked and highly interdependent, especially in urban areas and climate change contexts.
- Due to urbanization and population growth, the urban demand for water and energy is expected to increase substantially in the coming decades.
- There is a great need to tap into the water-energy nexus in urban planning, project designing, implementation, and the formulation of integrated water and energy policies.
- Multiple international initiatives are supporting cities and countries to unlock opportunities to address the water-energy nexus in the urban context.

1. INTRODUCTION

Access to clean water and modern energy supply are key preconditions for modern life. Water-energy nexus refers to the tight interlinkage and high interdependence between water and energy demand and supply (WWAP, 2014). Energy production, especially hydropower and the cooling of thermal and nuclear power generation, depends on water. Reallocating water to different uses and places might increase the value per drop but increase energy use. Water supply, including water extraction, treatment, and distribution, requires significant energy use. In 2014, the global water supply's energy use was 120 Mtoe, of which 60% was electricity, accounting for 4% of the worldwide electricity consumption (IEA, 2016).

In the urban context, water supply is typically sourced from groundwater or surface water from lakes or streams, treated, and distributed to end-users. Continued urbanization is driving both land area expansion and population increases in many cities, leading to increases in energy consumption and even energy intensity increase of urban water supply systems (Macharia et al., 2020; Huang et al, 2023).

The IEA projected a 16% increase in the global water demand of municipalities from 2015 to 2040. Such demand increase can lead to local water and electricity shortages, especially in developing country cities, due to ongoing climate change and its impacts on water availability, rapid urbanization, and per capita water consumption increase because of income growth (IEA, 2016).

As water is heavy, energy expenses are often a major operating cost component of urban water supply systems (UWSS) (Limaye & Jaywant, 2019). Leakage because of poorly maintained or not appropriately managed systems often incurs substantial water losses and, therefore, wastes the energy used for water supply. Applying the most efficient energy equipment in water supply systems and minimizing leakages are fundamental pillars to saving water and energy.

Table 1. Water balance in an urban water supply system (UWSS)

System input volume	Authorized consumption	Authorized billed consumption	Billed metered consumption	Revenue water
			Billed unmetered consumption	
		Unbilled authorized consumption	Unbilled metered consumption	Non-revenue water
			Unbilled unmetered consumption	
	Water losses	Apparent losses	Unauthorized consumption	
			Consumer meter inaccuracies	
		Real losses	Leakage on transmission and distribution mains	
			Leakage and overflows at storage tanks	
			Leakage and service connections up to consumer meters	

Source: Alegre et al., 2000

This issue brief focuses on the energy-water nexus in urban water systems, including urban water collection and supply systems. It will start with the opportunities for energy and water conservation in urban water supply systems, assess the challenges and options, and describe existing international support.

2. THE POTENTIAL OF WATER AND ENERGY SAVING IN URBAN WATER SUPPLY SYSTEMS

In many developing countries and emerging economies, the existing urban water supply systems are often very old or poorly maintained, therefore incurring high non-productive energy uses and water losses (Liu et al., 2012). Below are some examples of current conditions for water and energy savings.

2.1 The potential of water-saving

Twenty-five to fifty percent of all distributed water worldwide is either lost or never invoiced (State of Green, 2020). The rates of water loss vary a lot between different systems. Non-revenue water (NRW) is the difference between the amount of water a utility supplies to the distribution system and the amount of water billed. The NRW consists of three components: Physical losses, commercial losses, and authorized consumption not billed. Physical losses are the losses due to filtrations during the whole cycle (see Table 1). The main cause is the lack of proper operation and maintenance. Commercial losses are the losses that reach a lack of accurate consumption metering, census inaccuracies, and illegal connections. Authorized consumption not billed are those catering to firefighting, watering gardens, or given to certain social strata with risk of social exclusion. For growing cities, this is particularly problematic as expanding the water distribution networks without reducing urban water losses means expanding a cycle of inefficiency.

2.2 The high energy demand of urban water supply utilities

The energy intensities for water and wastewater utilities are variable and depend on the water source, water quality, topography, treatment requirements, distribution and/or collection pipe length, age, condition, and material (Ries, 2015).

According to a World Bank report (Limaye & Jaywant, 2019), electricity costs account for 33% to 80% of the non-labor operating costs of water utilities. Table 2 indicates the range of electricity costs for urban water and wastewater utilities in different developing countries based on data from the World Bank International Benchmarking Network for Water and Sanitation Utility database.

Table 2. Electricity costs for water and wastewater utilities in selected countries in 2019

Country	No. of utilities	Per m³ produced (US$)	Per m³ sold (US$)	As % of total operating costs	As % of non-labour operating costs
Albania	39	0.12	0.28	41	75
Bulgaria	30	0.07	0.20	19	33
Honduras	7	0.49	0.10	39	50
Iraq	10	0.09	0.65	55	82
Kazakhstan	14	0.09	0.11	24	38
Moldova	16	0.22	0.40	28	64
Nigeria	8	0.12	0.21	32	56
Ukraine	12	0.07	0.09	22	39
Vietnam	38	0.04	0.06	34	49

Source: Limaye & Jaywant, 2019

As most of the energy consumption by urban water supply systems is in the form of electricity, energy efficiency and conservation lead to electricity saving, reduced needs for primary energy consumption to generate the electricity, and reduced investment in power generation and transmission.

3. OPPORTUNITIES FOR ENERGY AND WATER-SAVING IN THE URBAN WATER UTILITIES

Water extraction and supply can represent up to 65% of the total energy consumption in the urban water cycle. They offer enormous opportunities for saving energy and water (Gustavo & Lentini, 2015). Below are described the opportunities around savings in the water-energy nexus.

3.1 The high energy consumption of urban water supply utilities

Many existing technologies can reduce leaks in the design, construction, operation, and maintenance of urban water supply systems, reducing water losses. Denmark has achieved a national average NRW of just 6% to 8%, one of the lowest in the world. Its technology solutions to achieve such a low NRW include smart meters, efficient valves, pumps, motors, and pipes, as well as tools and methods for planning, monitoring, and managing water losses, as well as economic incentives for water utilities and close public-private partnerships in water management (State of Green, 2016).

Moreover, there are many options to encourage water conservation on the demand side. The users can be motivated to save water through proper metering and water prices reflecting the total costs of water supply and wastewater treatment, standards and labeling for faucets, toilets, showerheads, washing machines, and dishwashers, as well as rainwater harvesting. Some behavior changes and solutions are cheap or involve no additional cost, such as stopping the tap when brushing teeth, and pausing the shower when applying shampoo and soap.

3.2 Opportunities for energy saving

Water provision and wastewater treatment comprise 30-50% of municipal energy costs, and there is often a high potential for energy and water-saving during both water production and distribution (see Table 3) (IEA, 2016). The World Bank, through its case studies, finds that energy efficiency investment in UWSSs can reduce energy costs by 25% to 40% globally and typically has a payback period between two months and five years (Limaye & Welsien, 2019).

Table 3. Potential for energy saving from UWSS by using the best technologies and solutions

Step	Water production	Water distribution
Potential for energy saving	20%-45%	20%-40%
Leakage reduction		30%-40%

Source: IEA, 2016

The energy efficiency and conservation opportunities in urban water utilities include three types: 1) equipment upgrades, 2) operational improvement, and 3) modifications to facility buildings. Equipment upgrades focus on replacing such equipment as pumps, electric motors, and drives with more efficient models. The operational improvement involves operation and system management changes, which can reduce energy use to perform specific functions, such as water treatment. Operational improvement may not require capital investment but can result in significant energy and cost savings. For instance, in some places, the peak electricity tariff can be more than double the off-peak electricity tariff. Water utilities can store water to avoid pumping at times of peak energy cost, thus dramatically reducing their electricity costs. Energy-saving measures for water utility buildings include efficient lighting, windows, ventilation, heating and cooling equipment, and building envelope insulation (see Table 4).

Table 4. Technologies and measures for energy efficiency improvement of urban water and wastewater utilities

Type	Technologies and measures
Pumps and pumping systems operations	• Replace inefficient pumps and inefficient electric motors; • Install variable speed drives; • Use gravity-fed systems instead of pumping, if possible; • Optimize pumping system operation; and • Improve predictive and corrective maintenance.
Water loss management technologies	• Reduce leakage (e.g. in pipes, valves, taps, toilet flushes, and shower heads) ; • Improve leak detection techniques and technologies; and • Manage pressure better.
Wastewater treatment	• Improve efficiency of anaerobic digestion and aeration equipment; • Use efficient activated sludge processes; and • Reduce wastewater with reuse and recycling.
Demand-side efficiency measures	• Reduce water consumption in municipal water systems (e.g. watering gardens and washing streets with rainwater, verifying control systems and leakage in garden watering systems) ; • Install water-saving and energy-saving home appliances (e.g. dishwashers and washing machines) ; • Install water-saving taps, short flush cycle toilets, and water-saving showerheads.
New technologies	• Implement supervisory control and data acquisition (SCADA-type) software; and • Install smart pumps, sensors, and meters.
Utility buildings	• Shift to efficient lighting; • Improve building envelope insulation; • Shift to efficient space heating, cooling, and ventilation.

Source: Rohilla et al., 2017.

4. CASE STUDIES

There are many examples of urban water projects that have resulted in significant water and energy saving, below are three of them.

Campinas (Brazil): In the City of Campinas, the utility SANASA implemented an energy management program to conduct the implementation of water efficiency measurements. SANASA was able to increase by 22% the water connections, reaching out to 98% of the population without any additional energy requirements. Capivari water treatment plant implemented new variable speed drives for a value of USD 1.03 million, achieving a 30% reduction in its energy consumption (1.4 GWh/year) and a 20% reduction on the contracted demand with a payback period of lower than four years.

In parallel, SANASA implemented a plan to reduce the Non-Revenue Water, optimize the system's operation, and energy efficiency actions on devices. The total energy savings are estimated at 200,000 kWh a year with a financial savings impact for the utility of 230,000 USD. 25% of the savings are due to a reduction in electricity intensity. The rest are due to NRW reduction that allowed increasing the number of people with access to water without increasing the generation (Initiative, 2011).

Guyana: The Inter-American Development Bank (IDB) and Guyana Water Incorporated (GWI) developed a series of pilot projects to improve the energy performance of water utilities in Guyana. In total, 34 projects to increase energy efficiency in the water sector were implemented, accounting for 25% of the energy consumption of GWI. The projects achieved a 29% energy efficiency increase through shifting to highly efficient motor-pump sets, reducing head losses by replacing suction/discharge pipes, and increasing the power factor with the implementation of capacitors. The total investment was USD 160,000 with an annual total savings of USD 640,000 per year and a reduction of the energy index from 0.28 to 0.20 kWh/m3 with an average simple payback period of 3 months (Pedraza, 2016).

Yerevan (Armenia): The city retrofitted the pumping stations by increasing the gravity-fed in the system and installing new pumps. An investment of USD 16.8 million led to USD 4.8 million of annual savings for the water utility, with a payback period of 3.5 years (Limaye & Welsien, 2019).

5. CHALLENGES AND TRADE-OFFS BETWEEN WATER AND ENERGY AND BARRIERS

In most countries, water and energy are administrated by different government agencies. The policymaking, planning, and investment of energy projects and supply systems and those on water supply and wastewater treatment often occur in isolation, without thinking about their synergies.

5.1 Assessing the energy and water efficiency of urban water supply systems

Energy and water efficiency audits are crucial to evaluate the overall energy performance of UWSSs (Pedraza et al., 2016). Assessing the performance of the water utilities by establishing a baseline can help municipalities understand, monitor, and manage the energy consumption of the utilities while tracking changes in their operation and maintenance (Plappally & Lienhard, 2012).

Key performance indicators are quantifiable measurements that the facility needs to know to create a working baseline and track progress toward the goals set by the facility. These indicators need to be easily accessible (extracted from energy bills, and reports on the utilities' operation) (US EPA, 2013).

The energy index or intensity of energy consumption (kWh/m3) links the total water produced with the specific energy consumption of the different technologies used at each stage of the water cycle. The Electromechanical Efficiency of Pumping Systems (%) is normally used to measure the efficiency of the motor-pump set by considering the joint efficiency of the different technologies involved (Pedraza et al., 2016).

The energy efficiency indicators may not reflect the energy performance of different water utilities. The operation conditions and related energy consumed at each of the different stages of the water cycle are highly dependent on the type of water source, location of the source and geography of the network, technologies implemented, and water-energy losses (Liu et al., 2012).

5.2 Difficulties in Water Planning

Water resources are often shared regionally and by different sectors and for different uses. Therefore, cities often lack control over water resource planning and face multi-level governance gaps in urban water governance. They can suffer from unstable and insufficient water revenue, face challenges in making water affordable for low-income groups, lack control of local water tariff levels, and lack the capacity to do long-term water resource assessment and planning (Romano & Akhmouch, 2019). Such strong interactions in urban water governance often make it difficult for a city to estimate the future volume of water resources at its disposal. Moreover, water prices and energy prices are sometimes beyond the control of local municipalities, making local governments unable to use price signals to stimulate energy and water saving. Energy and water infrastructure facilities often involve large investments, and once built, they have a use life of several decades or even longer.

5.3 Challenges - increasing complexity of urban water systems

Most cities handle three major water flows, rainfall, water supply, and industrial/household wastewater, through a myriad of pipeline networks and facilities. These networks and facilities vary dramatically between geographic locations. With increasing expectations on water quality and the use of unconventional water resources, the energy requirement of urban water systems may increase and subsequently raise greenhouse gas emissions.

Urban water infrastructure is growing increasingly complex, driven by factors including higher fluctuations in freshwater availability, increasingly strict quality and environmental requirements on water resources, and increasing water demand for different uses. Climate change affects water availability in many places and requires cities to adapt to new stormwater regimes. Developing country cities generally face greater opportunities and challenges in urban water-energy nexus (Fan et al., 2019).

6. HOW TO IMPROVE THE ENERGY EFFICIENCY OF URBAN WATER SUPPLY SYSTEMS?

Improvements in energy efficiency allow municipalities to achieve the same level of energy supply work with less energy and water needs. Key energy efficiency actions in potable water distribution and transmission systems include two types: 1) reducing Non-Revenue Water (difference between water produced and billed) and 2) equipment upgrades and technical performance improvements of the components to reduce the energy intensity through an optimization of the operation (US EPA, 2013).

Reductions in the NRW lead to better economic performance of urban water systems and can help lower the water costs for end-users. Actions to improve the technical efficiency of the systems through the minimization of the energy intensity of the different processes where energy is transformed (Gustavo & Lentini, 2015). Replacing inefficient components with efficient ones can save energy and operation costs. In countries where electricity is not highly subsidized, such energy efficiency investment is often with short payback periods. Components with a high impact on the energy consumption per cubic meter of water produced are by the order of energy transformation: transformers, power factor, variable speed drives, electric motors, and pumps.

Other measures to improve the operation of water utilities include using remote control systems to optimize water production, improving valves control, and avoiding the operation of the system during peak hours to reduce costs. The present and future of the utility should be reflected in a master plan to ensure the utility's financial viability, reduce the uncertainty towards financial institutions, and plan the future expansions and retrofits of the system (Japan International Cooperation Agency, 2017).

Box 1 Motor Savings in Context

Electric motors are very reliable equipment, with a minimum lifetime of 12 to 20 years depending on the power range (small: 1-7.5 kW to large: 75-375 kW motors). Such a long lifespan and the stocking of reserve motors have slowed the penetration of modern highly efficient technologies already available in the market. With motor-driven systems in the industry giving rise to more than 70% of electricity demand, which totalled more than 6 360 TWh in 2016[1] , and a transition to energy-efficient motor systems offering a reduction in electricity demand of 20 to 30 percent, this represents a huge unexploited potential for energy savings.

The international standards IEC 60034-30-1 and -2 define the motor efficiency by classes from IE1(Standard) to IE4 (Super-Premium) for line-operated motors and IE1 to new IE5 (Ultra-Premium) class for variable speed motors.

New technologies have led to the market introduction of high-efficiency motors reaching IE4 and IE5 efficiency levels, using standard induction motors (IE4) and other types such as permanent magnet synchronous motors, synchronous reluctance motors, copper rotor induction motors, of which some require the application of a variable speed drive.

Additional measures, such as addressing oversizing, using more sophisticated controls (variable speed driver/torque control), smart sensors/meters, digitalization of capabilities, and addressing the efficiency of the motors system components (i.e., transmissions, compressors, pumps, fan) can dramatically further improve the energy efficiency and thus savings figures.

For the water sector, it is estimated that using variable-speed drives with high-efficiency motors can lower energy use in clean water, desalination, and wastewater processes by about 25 to 30%. Furthermore, using digital solutions to optimise the control of pumping systems in wastewater treatment plants could result in energy savings of 10 to 20%.[2]

The UNEP United for Efficiency (https://united4efficiency.org/) Model Regulation Guidelines for Energy-Efficiency Requirements for General Purpose Electric Motors provide guidance to assist Governments in developing and emerging economies that are considering a voluntary, regulatory or legislative framework for use with incentive programmes, public procurements, minimum energy performance standards, energy labels and other such market transformation interventions for motors and motor systems.

The information on performance requirements may also be used as the basis for procurement specifications when tendering for bulk purchases of motors.

The guidelines are currently being updated to extend the range of motor sizes covered and to include specifications for pumps, fans, and air compressors.

The guidelines are available on the United for Efficiency website at: https://united4efficiency.org/resources/model-regulation-guidelines-for-energy-efficiency-requirements-for-general-purpose-electric-motors/

1 (IEA, 2017) IEA. World Energy Outlook 2017
2 (ABB, 2021) White Paper, Overcoming energy efficiency challenges in the water and wastewater industry. ABB 2021. https://library.e.abb.com/public/3a53fd503dc64f0ab0bd932665f23620/ABB_EE_WhitePaper_Water_and_wastewater.pdf

6.1 A holistic approach to water and energy conservation in urban water utilities

Many cities face water shortages and insecurity due to population increase, city expansion, climate change, and pollution. Integrated energy and water conservation measures can reduce water utilities' energy and water to serve the same population.

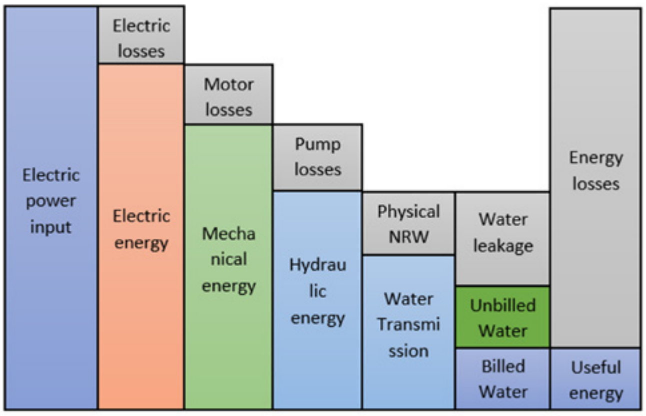
The World Bank summarizes the following benefits of holistic water and energy conservation measures for urban water utilities. Integrated water and energy conservation can improve the financial performance of urban water utilities and make it easier to access financial credits. It can help reduce the total demand for local water resources and energy from the grid. The energy-saving measures can also help avoid power shortages and investment in power generation and transmission capacity and reduce local air pollution and GHG emissions in places where electricity generation relies on fossil fuels.

6.2 Priority opportunities and actions

Municipalities have priority opportunities and actions when tackling the water-energy nexus in urban water supply systems, including strategy formulation and specific areas to focus on for energy efficiency improvement.

Strategy formulation. The governments need to develop a master plan to define clear goals and objectives and guide and prioritize actions and future expenditures. They also need to lower the uncertainty around the activities and reduce the risk to the financial institutions.

Figure 1. Opportunities for improving the energy efficiency of urban water supply systems



Source: drawn by the authors

The following technical areas, with their low costs and high impacts, need to be considered when planning actions to improve the energy efficiency of UWSSs: (1) reduce electric losses; (2) reduce motor-pump set inefficiencies; (3) reduce head losses in pipes; (4) lower the Non-revenue Water (NRW) rate; (5) optimize water supply operation (US EPA, 2013).

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6.3 Concrete recommendations from international organizations and initiatives

Urban water supply and treatment facilities, including the pipelines and networks for water supply, rainwater, and wastewater collection and treatment systems, are infrastructure facilities, and their construction involves high investment. Once they are built, they have a long use life. In the face of global climate change, including the more frequent occurrence of extreme weather events and their increasing impacts, cities need to consider the climate risks and future population and water demand change in their urban water system planning.

At the international level, many international and national organizations have studied the topic of water-energy nexus at the global, international, national, and local levels, including the International Energy Agency (IEA), UN Water and UNESCO (2014; 2020), the World Bank (2018), and GIZ.

The World Bank's 5-year initiative, Thirsty Energy, was implemented from 2014 to 2018. It helped countries improve their understanding of the interdependences of water and energy and learn how to address the interdependences in government policies and plans. The initiative carried 3 case studies in South Africa, China, and Morocco. Its main findings include: 1) water-energy nexus is context-specific, and solutions can't be generalized; 2) Win-win solutions are possible; and 3) Infrastructure investments made today are critical.

The German Agency for International Cooperation, GIZ, tackles the water-energy nexus in the urban water sector through its Water and Wastewater Companies for Climate Mitigation (WaCCliM) project. The WaCCliM is pioneering GHG reductions in the water sector in Mexico, Thailand, Peru, and Jordan. It offers utilities a roadmap to achieve energy and carbon neutrality (WaCClim, 2020).

The World Resource Institute has also carried out some case studies addressing the water-energy nexus in selecting urban water sources and long-term water planning (WRI, 2017). The main recommendations for policymakers from various international studies include:

- Adopt a Nexus approach will enhance understanding of the complex and dynamic interrelationships between energy, water, and food and facilitate more sustainable management of these resources.
- Implement integrated policymaking, resource planning, and investment project designing to maximize benefits both in terms of energy and water, instead of improving performance on one front at the price of the other.
- Act now, instead of waiting.

Box 2. Tool for Water System Efficiency Assessment

Developed by C2E2 with support from H2OPT (https://toolbox.unepccc.org/water-supply), the tool aims to help decision-makers to understand specific savings and financial opportunities of water distribution and consumption systems in their municipalities and cities.

Use
The tool has been designed as a self-assessment savings tool. Users need to provide some key local data inputs on their locality or the status of their water utility system.

Features

- The tool gives detailed categorizations on water and energy saving opportunities from such actions as metering, preventive maintenance, and efficiencies of electro-mechanical components.
- It also takes components of electrical systems such as power quality, variable speed drives, etc. and water billing components such as metering, fixed and variable tariffs, etc., to recommend potential water, energy, and CO2 savings.
- Scope for further calculating cost benefits using the tool results necessary costs of components and operations are available.

7. CONCLUSIONS

Water demand is in constant growth through the universalization of access to clean water. The growing urban demand will further intensify the water stress in many parts of the work and require the shift to more energy-intensive processes to obtain clean water. Water supply systems normally present the largest energy share in the water cycle. Many different technologies and measures can be adopted to benefit from large profitable opportunities for energy and water-saving in urban systems to decrease both water and energy consumption while improving the financial performance of the utilities. Considering the water-energy nexus in water supply systems ensures the sustainability of the water resources of the system, conserves energy, and minimizes related greenhouse gas emissions.

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UNEP Copenhagen Climate Centre is a leading international advisory institution on energy, climate and sustainable development.

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UNEP Copenhagen Climate Centre is actively engaged in implementing UN Environment's Climate Change Strategy and Energy Programme.

The centre employs 70 experts of 22 different nationalities working around the world from offices in UN City, Copenhagen and has more than 30 years of experience working with academia from leading institutions around the world.

UNEP Copenhagen Climate Centre was founded as the UNEP Risoe centre by UNEP, The Danish Ministry of Foreign Affairs and the Danish Technical University in 1990. From 2014 to February 2022, the centre was called UNEP DTU Partnership, until it became the UNEP Copenhagen Climate Centre.

For more information, please visit
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United for Efficiency (U4E) is a global initiative led by UN Environment (UNEP), funded by the Global Environment Facility (GEF), and supported by leading companies, expert organisations and public entities with a shared interest in transforming global markets for lighting, appliances and equipment, saving all electricity consumers, including governments, billions of dollars.

To learn more about U4E's work and to download the multiple tools and resources available (policy guides, Model Regulation Guidelines, Country Savings Assessments and guidelines for sustainable public procurement) , please visit www.united4efficiency.org

The Copenhagen Centre on Energy Efficiency is institutionally part of UNEP Copenhagen Climate Centre (UNEP-CCC). The Copenhagen Centre on Energy Efficiency functions as the global thematic Energy Efficiency Hub of Sustainable Energy for All (SEforALL), and accordingly works directly to support the SEforALL objective of doubling the global rate of improvement in energy efficiency by 2030.

The Copenhagen Centre on Energy Efficiency fulfills its mission through:
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- accelerating action through innovation in project development and finance
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