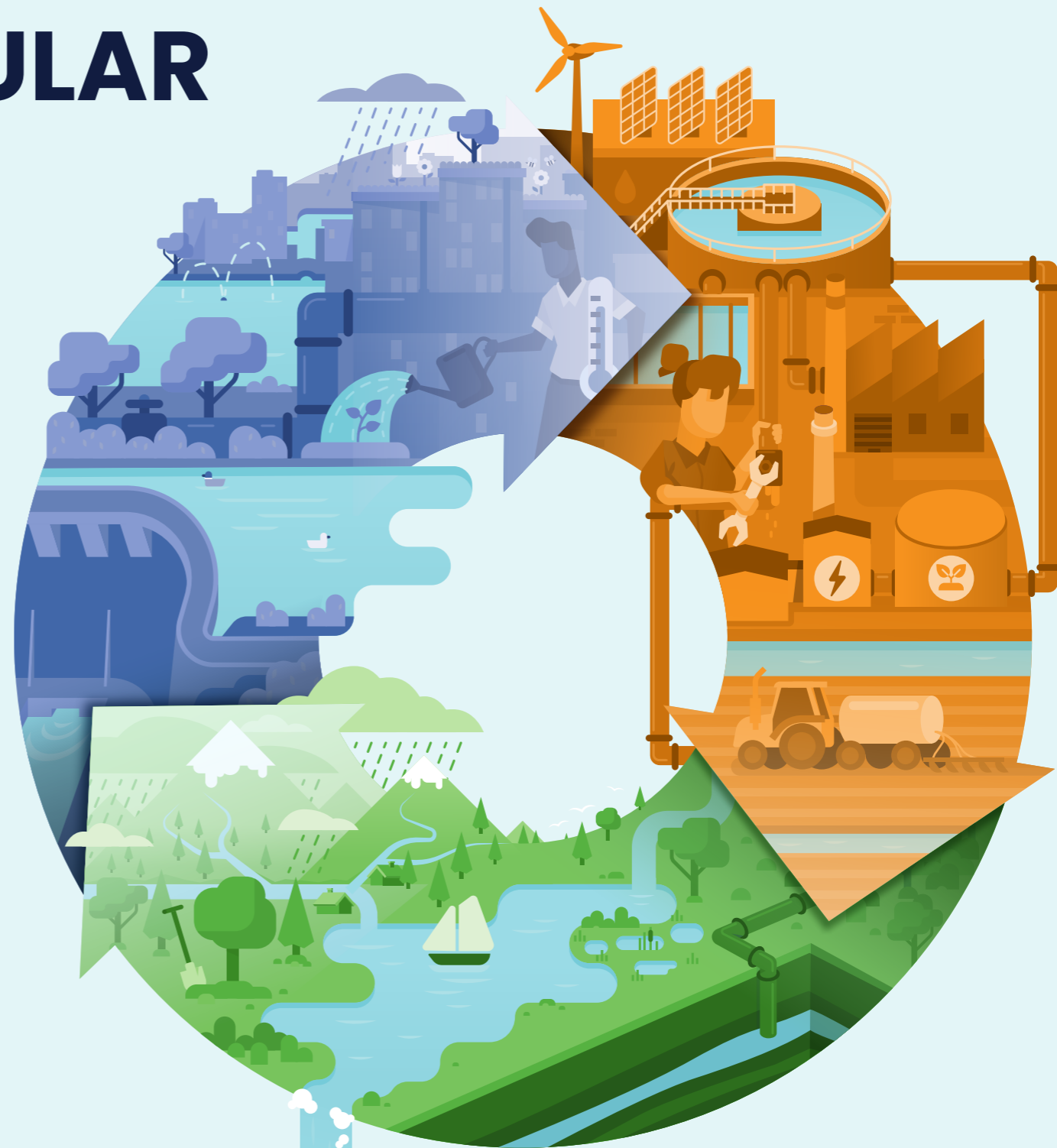


WATER IN CIRCULAR ECONOMY AND RESILIENCE (WICER)

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As cities grow, so do urban water challenges. It is estimated that the urban population worldwide will nearly double by 2050, an increase that has serious implications for urban water demand. Rising urban water use will also lead to more wastewater and more water pollution. Climate change further exacerbates pre-existing water stresses and is already having a measurable effect on the urban water cycle, altering the amount, distribution, timing, and quality of available water.



Circular Economy has emerged as a response to the current unsustainable linear model of “take, make, consume, and waste”. Yet so far, the water sector has not been systematically included in high-level circular economy strategy discussions. But interest in the water sector is growing.



Circular economy offers an opportunity to recognize and capture the full value of water – as a service, an input to processes, a source of energy and a carrier of nutrients and other materials. In a circular economy, water is seen as the finite resource it is. Using water is avoided wherever possible and water and other resources are reused. In a circular economy, negative externalities are designed out, impacts on natural resources are minimized, and watersheds and other natural systems are restored.



To achieve its full benefits, a circular water system needs to embrace resilience and inclusiveness. Resilience should be integrated into any circular strategy to prepare cities for uncertain shocks and stressors in order to avoid the undesired impacts of a disruption or failure of water services. As developing countries continue to grow and urbanize, they must be supported as they transition to a circular economy so vulnerable groups also benefit from those interventions.

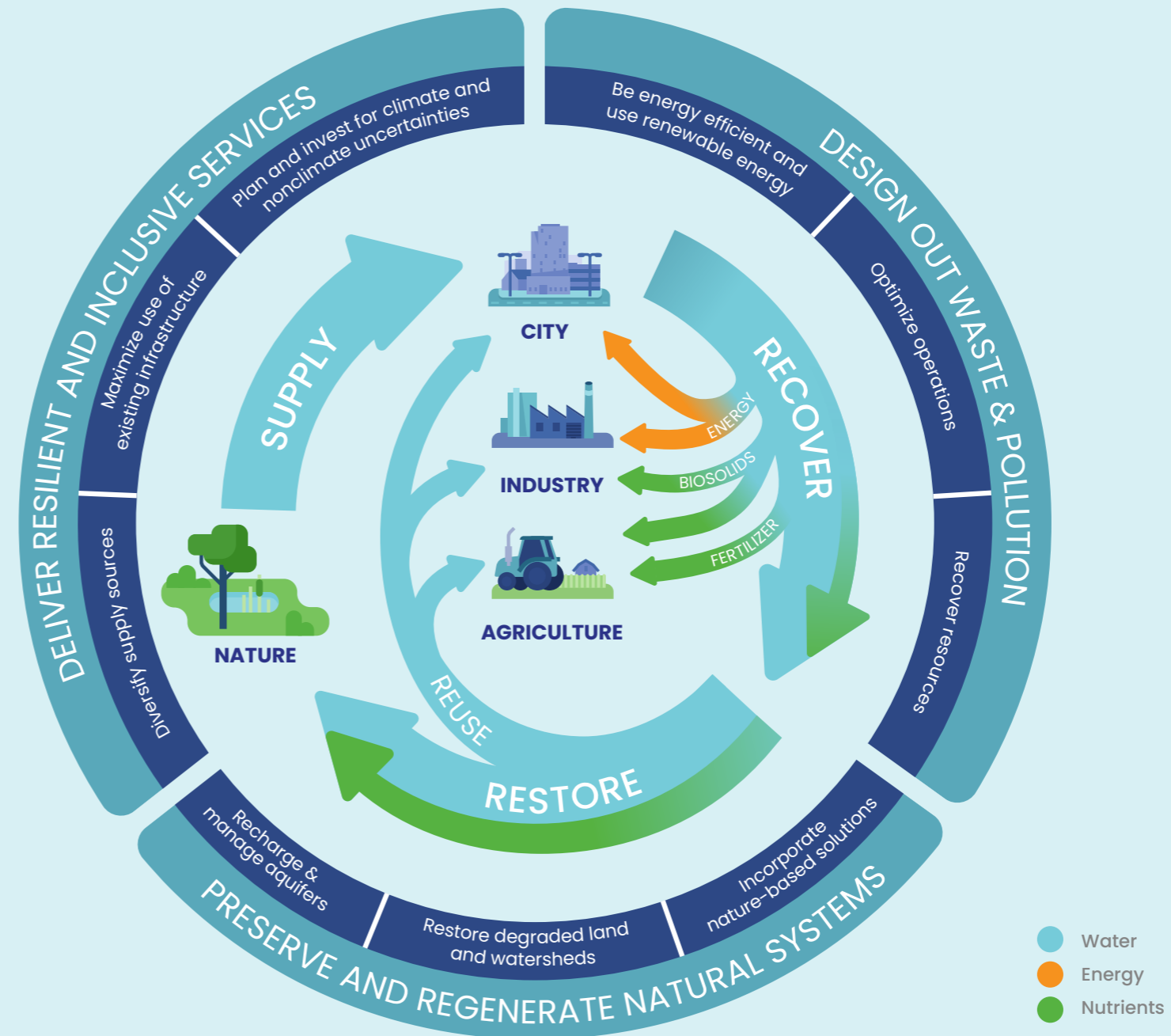


The objective of this report is to establish a common understanding of circular economy and resilience in the urban water sector. The report presents the Water in Circular Economy and Resilience (WICER) Framework (figure ES.1), which grew out of a literature review, complemented by lessons learned from case studies and World Bank experience.

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The proposed WICER framework should serve to guide practitioners who are incorporating the principles in policies and strategies, planning, investment prioritization, and design and operations. The report also provides case studies, examples, guidelines, and other relevant materials. The report describes the key actions (in dark blue in Figure ES.1) to achieve three main outcomes: 1) deliver resilient and inclusive services; 2) design out waste and pollution; and 3) preserve and regenerate natural systems. These will ultimately improve livelihoods while valuing water resources and the environment.

Figure ES.1 Water in Circular Economy and Resilience (WICER) Framework



EXECUTIVE SUMMARY



Applying the framework provides not only environmental benefits but also social, economic, and financial ones. The WICER framework can contribute towards the achievement of several Sustainable Development Goals (SDGs) and is also in line with the climate agenda. At the same time, examples provided in the report show that investments in circular and resilient systems yield economic and financial payoffs.



Adopting the WICER framework could help utilities attract the private sector and improve access to various forms of finance. A circular and resilient water system can lower capital and operating costs and increase revenues, creating a more attractive environment for the private sector. Because the financing required to achieve the SDGs is substantial, and public funding alone will not suffice, enabling conditions are essential, because the private sector is often reluctant to invest in water and sanitation projects.



The WICER framework brings out the importance of cross-sector linkages and multi-scale issues of water. Although most of the actions described in this report can be carried out by service providers, for the whole water sector to be fully circular and resilient, changes are needed at the river basin, city, and household levels and in other sectors, such as agriculture, energy, industry, and environment.



Cities and water utilities will not achieve a fully circular and resilient water system without the proper policy, institutional, and regulatory framework in place. The WICER framework can be adapted and raised to the policy level in government and deployed to assemble relevant stakeholders for collaborative work across sectors.



To avoid being locked into linear and inefficient systems, low- and middle-income countries can leapfrog and apply the WICER framework to design and implement circular and resilient water systems from the outset. The paper sets out to demystify the circular economy by showing that both high-income and low-income countries can benefit from it. They are not “all or nothing” propositions, and cities should not be reluctant to implement them—especially in view of the benefits they can bring.

Summarizing, rethinking urban water through the circular economy and resilience lenses offers an opportunity to tackle urban water challenges by providing a systemic and transformative approach to delivering water supply and sanitation services in a more sustainable, inclusive, efficient, and resilient way.

CONTEXT AND CHALLENGES



1.1 KEY CHALLENGES OF THE CURRENT WATER CRISIS

Rising populations, growing economies, and shifting consumption patterns have intensified the demand for water resources at a time when 36 percent of the world's population lives in water-scarce regions. More than 2 billion people live in highly water stressed countries, and about 4 billion people experience severe water scarcity for at least one month of the year (*WWAP 2019*). Water stress will continue to intensify as demand for water grows. Global consumption has increased by a factor of six over the past hundred years and continues to mount (*UNESCO and UN-Water 2020*). Projections suggest that by 2050, global demand for water will increase by 20 to 30 percent (*WWAP 2019*) unless consumption patterns shift dramatically. By then, more than half the world's population will be at risk of water stress. Intense water scarcity could displace as many as 700 million people by 2030 (*HLPW 2018*).

Water is essential for socioeconomic development and is a contributing factor in nearly every Sustainable Development Goal (SDG).

Access to safe water and sanitation is vital for healthy and prosperous societies. Water supports healthy ecosystems and biodiversity. It is also crucial in producing food and energy and in most industrial processes, so the lack of access to water translates into slower economic growth. Some regions could see their growth rates decline by as much as 6 percent of GDP by 2050 because of water-related losses in agriculture, health, income, and prosperity (*World Bank 2016a*).

Nevertheless, water is undervalued, and proper incentives are not in place to use water resources efficiently.

The inability to recognize the value of water is the main cause of its waste and misuse (*United Nations 2021*). While water stress and scarcity are intensifying, water utilities around the world still have massive water losses in their distribution systems, with non-revenue water (water in the distribution system but not billed because of physical leaks or commercial fail-

ures) accounting for 25 to 50 percent of the total water supply and, in some emerging markets, up to 75 percent (*IWA 2015*). At the same time, farmers, industries, businesses, and households often have few incentives to consume less water or to become more efficient. In fact, water is used more wastefully and inefficiently in water-scarce areas than in areas with abundant water resources, often because of inappropriate policies, pricing, and incentives (*Damania et al. 2017*).

Water pollution caused by human activities damages health, the economy, and the environment, while further endangering the sustainability of water supplies. Water quality is declining in natural bodies owing to inadequate sanitation, lack of wastewater treatment by residential and industrial users, and polluted runoff from farmland and storm drains. Unregulated discharges add to the pollution. Around 80 percent of the world's wastewater—more than 95 percent in some developing countries—is still released untreated into the environment (*WWAP 2017*). Humankind is polluting water resources much faster than nature can recycle and purify them (*UN n.d.*). Rich and poor countries alike face water-quality challenges, with the range of pollutants – and challenges – usually expanding with prosperity. Water quality has an impact on health, agriculture, and the environment, outcomes that are more serious than previously understood and that cause observable economic slowdowns (*Damania et al. 2019*).

Climate change is straining water resources worldwide. Climate change has a measurable effect on the water cycle, altering the availability, quantity, and quality of water. Climate change has altered hydrological cycles and increased the timing, frequency, and intensity of water-related extremes, such as floods and droughts, making water availability more unpredictable and unreliable. These events aggravate conditions everywhere—in both water-stressed regions and regions with abundant water resources (*UNESCO and UN-Water 2020*). Since 1990, water-related catastrophes have accounted for almost 90 percent of the top thousand most devastating natural disasters, causing damage amounting to 15 to 40 percent of annual GDP for some countries (*HLPW 2018*). Water quality is also affected by climate change. For example, higher water temperatures and lower dissolved oxygen levels have reduced the self-purifying capacity of freshwater bodies (*UNESCO and*

UN-Water 2020). Polluted runoff during floods and higher pollutant concentrations during droughts further contaminate water resources. Water-related climate risks cascade through food, energy, urban, and environmental systems, causing major socioeconomic damage.

1.2 WATER CHALLENGES IN URBAN AREAS

Projections show that by 2050, two-thirds of the world's population will live in urban areas, creating an unprecedented demand for reliable, safe, and sustainable urban water supply and sanitation services. Much of this transition will occur in developing-country cities with populations of at least 1 million (*UNESCO and UN-Water 2020*). Many countries already face challenges in meeting the needs of their growing urban populations. The situation is particularly difficult in low- and middle-income countries, where urbanization is occurring more rapidly, often with less planning. Even though water and sanitation access rates are generally higher in urban than rural areas, planning and infrastructure have not kept pace in the cities (*WHO and UNICEF 2019*). There is still a lack of adequate and inclusive water and sanitation infrastructure and services for all, especially in informal settlements.

Water-related challenges in urban areas can have wide-ranging effects, which often propagate through the economy. Cities play a critical role in global economics, with some economists estimating that they account for 80 percent of the world's gross domestic product (*Damania et al. 2017*). Although home to over half the world's population, cities are sited on less than 3 percent of the world's land surface (*Akbari, Menon, and Rosenfeld 2009*), creating an intense concentration of assets and people. The economic performance of firms, businesses, and industries in cities is affected by water availability. Already, one in four cities, registering USD 4.2 trillion in economic activity, are classified as water stressed (*Damania et al. 2017*). The difficulties in securing reliable water supply are accompanied by the growing need to sustainably manage sanitation and stormwater (*Varis et al. 2006*). Continued urbanization and land-use changes often encroach on drainage capacity, increasing flooding risks. Cities and their residents (households, industries, businesses) are one of the main causes of water pollution, through discharges of

untreated wastewater, sewer overflows, and polluted stormwater runoff. More flooding and a multitude of adverse human and economic consequences follow, compromising growth and welfare and directly impairing human health (Haddad and Teixeira 2015; OECD 2015; Huntingford et al. 2007).

The urban water supply and sanitation sector is also affected by the variability, seasonality, and extreme weather events aggravated by climate change. More frequent natural disasters bring too much or not enough water and damage water infrastructure. Effluent discharge in floods can contaminate soil, ground water, and surface water. In severe droughts, water availability and sources can disappear or be made more vulnerable to pollution. During droughts, to compensate for the loss of surface-water supply, groundwater is overextracted. Water scarcity reduces the self-cleaning capacity of sewers, while flooding exacerbates stormwater overflows and pollution. Future climate change and various natural hazards will put additional stress on water systems and damage the quality and delivery of services, with the greatest effects falling on the poor.

Urban water supply and sanitation service providers, which are often public entities, face the brunt of these challenges, on top of existing performance and funding issues. Poor performance is usually caused by complex and multidimensional problems that stem from a vicious cycle of dysfunctional political environments, inefficient practices, and a lack of dedicated leadership (Soppe, Janson, and Piantini 2018). Low operating efficiency (such as high non-revenue water and low energy efficiency, usually linked to aging infrastructure), inefficient investments, and low tariffs make it difficult for water utilities to recover costs and improve service sustainability. This has resulted in the water supply and sanitation sector relying on public sector financing and subsidies for its investment, operations, and maintenance needs. Despite large investments in the sector by governments and development agencies over the past 10 to 15 years, the sustainability of water supply and sanitation services in developing and emerging economies has not improved significantly (Soppe, Janson, and Piantini 2018). Moreover, subsidies are often poorly targeted and fail to reach the poor, disproportionately benefiting upper-income groups. Fifty-six percent of subsidies end up in the pockets of the richest 20 percent of the population, while only 6 percent go to the poorest

20 percent (Andres et al. 2019). The level of investment needed in the water supply and sanitation sector to meet the SDGs ranges from USD 74 billion to USD 166 billion annually (Hutton and Varughese 2016), but estimates show that governments and development agencies have insufficient funds to meet these requirements (Kolker et al. 2016).

Circular economy and resilience principles offer an opportunity to tackle these urban water challenges by providing a systemic and transformative approach to delivering water supply and sanitation services in a more sustainable, inclusive, efficient, and resilient way. The circular economy shows how to address the increasingly complex challenges associated with finite water resources and growing urban demand, undervalued water, financial and operational inefficiencies, pollution and degraded ecosystems, equity, and sustainable urban water supply and sanitation services. Circular economy initiatives can also help attract the private sector by creating new business models, adding new funding sources and helping to close the existing funding gap. In the face of highly uncertain events such as the COVID-19 pandemic and climate change, it is also crucial for urban water systems to be resilient. A system that mainstreams circularity approaches should also incorporate resilience metrics and approaches. A resilient city and its water utilities can adapt to changing conditions and withstand shocks and stressors (climate and nonclimate) while still providing essential services. As countries embark on initiatives to recover from the pandemic, there is an opportunity to build back better and greener for a resilient, inclusive, and sustainable recovery (World Bank 2020). Cities are strategically positioned to be change leaders, and they have a critical role to play to reduce environmental pressures, provide for equitable distribution of benefits, ameliorate risks and uncertainties, and improve sustainability (UNEP 2017). In cities, the density and proximity of people and economic activities reduce the economic and environmental costs of providing most infrastructure and services. Circular economy and resilience actions taken by cities can have huge beneficial outcomes, both in urban areas and elsewhere through a ripple effect (UNEP 2017).

EMBRACING CIRCULAR ECONOMY AND RESILIENCE IN URBAN WATER



2.1 WHAT IS CIRCULAR ECONOMY, AND WHY DOES IT MATTER?

Circular economy provides a framework for redefining growth and designing an economy that is restorative and regenerative by design, bringing benefits for society and the environment. There is no standardized definition for circular economy (Kirchherr, Reike, and Hekkert 2017; Kalmykova, Sadagopan, and Rosado 2018; Korhonen et al. 2018). But the competing definitions all emerged in response to the linear “take, make, consume, and waste” industrial model. Based on the unsustainable assumption that “resources are abundantly available, easy to source, and cheap to dispose of” (European Commission 2014), the linear model has resulted in environmental degradation and pollution. Circular economy principles draw and build on concepts developed years ago. Notable among them are the spaceman economy (Boulding 1966), limits to growth (Meadows et al. 1972), performance economy (Stahel and Reday-Mulvey, 1976; Stahel 2006), industrial ecology (Frosch and Gallopoulos, 1989; Graedel and Allenby, 1995), “cradle-to-cradle” (Braungart and McDonough 2002), “planetary boundaries” (Rockstrom et al. 2009), and the behavioral “Rs” (reduce, reuse, recycle, recover, refurbish, repair). All feature the principle of maximizing the value of resources recognizing that the Earth’s resources are limited¹, and that the planet itself has a limited capacity for managing and assimilating pollution (Kalmykova, Sadagopan, and Rosado 2018). Although most of the strategies grouped under circular economy are not new in isolation, the concept offers a new framing under a useful conceptual umbrella (CIRAIG 2015; Blomsma and Brennan 2017). A comprehensive and widely used definition is the one developed by the Ellen MacArthur Foundation (box 2.1).

¹ Should the global population reach 9.6 billion by 2050, the equivalent of almost three planets could be required to provide the natural resources needed to sustain current lifestyles (UN, N.D.)

Box 2.1 Defining Circular Economy

A circular economy is restorative or regenerative by intention and design. It entails gradually decoupling economic activity from the consumption of finite resources and from environmental degradation. As an economic system, it seeks to minimize waste and make the most of resources. The circular economy approach replaces the end-of-life concept with restoration, eliminates the use of toxic chemicals that impair reuse and return to the biosphere, and aims to eliminate waste through superior design—of materials, products, systems, and business models. Underpinned by a transition to renewable energy sources and a more sustainable use of biodiversity and ecosystems, the circular model builds economic, natural, and social capital. A circular economy not only reduces waste and resource needs but also unlocks additional value from natural resources and supports the development of an ecosystem in which innovations in sustainability create new arenas for economic activity. It is based on three principles:

- Design out waste and pollution.
- Keep products and materials in use.
- Regenerate natural systems.

Source: Adapted from the Ellen MacArthur Foundation.

A circular economy is fully aligned with the UN 2030 Agenda, which recognizes that objectives of environmental, social, and economic sustainability can no longer be met separately, in isolation from each other. In 2017, the World Economic Forum, in cooperation with the United Nations Environment Programme (UNEP), launched the Platform for Accelerating the Circular Economy. The platform encourages and enables public and private sector leaders to commit to accelerate collective action. In 2018, UNEP also entered into an agreement with the Ellen MacArthur Foundation to scale up and accelerate the shift toward circular economy. In 2019, UNEP launched the “circularity platform” to provide an understanding of the circularity concept, its scope, and how critical it is for achieving the targets of the Paris Agreement and the

2030 Agenda for Sustainable Development. In 2017, the World Business Council for Sustainable Development published a report for CEOs on the importance of circular economy in businesses (*WBCSD 2017*) and has since launched a program on circular economy, recognizing it as a key element in mitigating climate change, biodiversity loss, and resource scarcity.

In 2019, the Organisation for Economic Co-operation and Development (OECD) launched the Programme on Circular Economy in Cities and Regions, acknowledging that “transitioning to a circular economy is key for a prosperous, inclusive and sustainable future.” In 2020, the United Nations Development Programme (UNDP) and UNEP published a joint guidance note on circular economy and climate change mitigation. The note calls for circular economy strategies to be included in revisions of Nationally Determined Contributions under the Paris Agreement, given that circular economy could help reduce the current emissions gap by half (*UNEP and UNDP 2020*). Business and corporations around the world are also taking concrete actions and implementing circular business models (*EMF 2020*). The World Bank has hosted a series of learning events on [Circular Economy and Private Sector Development](#) and is launching a Global Program for Pollution Management and Circular Economy.

Many governments and international organizations are promoting and embracing circular economy principles to achieve the SDGs. At the country level, China introduced its Circular Economy Promotion Law in 2009 to improve resource efficiency, protect and improve the environment, and achieve sustainable development; it has since included circular economy in its five-year plans. After high-level discussions around circular economy in 2011, the European Commission recognized the need to move toward a circular economy and announced its ambitious Action Plan for the Circular Economy in 2015 (*European Commission 2015*). Since then, several member states have unveiled their own circular economy strategies. In 2020 the EU adopted a new Circular Economy Action Plan (*European Commission 2020*) to “achieve climate-neutrality by 2050, to preserve the natural environment, and to strengthen the economic competitiveness” as part of the European Green Deal, Europe’s new agenda for sustainable growth. In Latin America and the Caribbean, the circular economy concept has gained high-level political

attention. More than 80 public initiatives related to circular economy have already been launched in the region (*Schröder et.al. 2020*). Policy makers in many other countries are giving the circular economy principles increased priority.

A circular economy not only creates benefits for society and the environment but also makes economic and financial sense. Estimates show that moving toward a circular economy could unleash USD 4.5 trillion of global economic growth by 2030 by avoiding waste, making businesses more efficient, and creating new employment opportunities—all while helping achieve the Sustainable Development Goals, regenerate and protect our ecosystems, and enable a sustainable post-COVID recovery (*UNEP FI 2020*). These virtues are also in line with the Green Resilient Inclusive Development framework presented at the 2021 spring meetings of the World Bank and the International Monetary Fund. In Europe, estimates show that a circular economy could represent a 7 percent increase in GDP by 2030, compared with the present development scenario, with additional positive impacts on employment (*EMF 2015*).

Economic and financial benefits of implementing circular economy principles can also be seen at a smaller scale. There are many cases (including the ones in this report) where, for example, investments to improve resource efficiency were recovered in less than two years due to operational savings (see the case of Monclova, Mexico, [box 3.5](#)) or where resources were recovered and sold, creating a revenue stream for the utility (see the cases of Chennai, described in [box 3.1](#), and San Luis Potosi, in [box 3.8](#)). Circular economy could therefore also reduce the financial risk of infrastructure projects, improve the rate of return, and create a more attractive environment for the private sector. Because the financing required to achieve the Sustainable Development Goals is substantial, and public funding alone will not suffice, enabling conditions are essential, because the private sector is often reluctant to invest in water and sanitation projects.

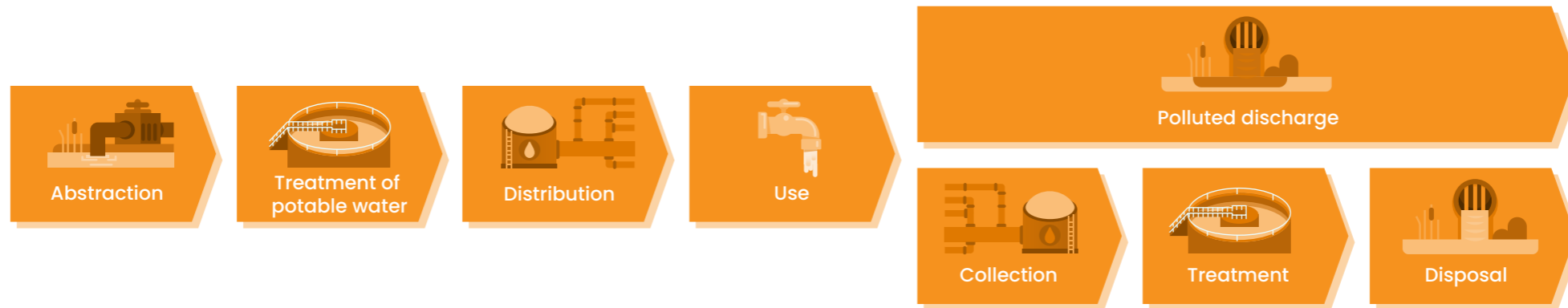
2.2 APPLICATION OF CIRCULAR ECONOMY PRINCIPLES IN THE WATER SECTOR

Left alone and undisturbed, water is a sustainable and circular resource. Yet so far the water sector has not been systematically included in high-level circular economy strategy discussions. Many circular economy initiatives and policies have focused on the manufacturing and solid waste industries – due to the origins of the concept. But interest in the water sector—one of the largest untapped sectors for the circular economy (*IWA 2016*)—is growing given its potential. Circular economy offers an opportunity to imitate and restore the natural cycle of water, where nothing is considered a waste but an input to another process. Circular economy can be used to transform consumption patterns and help decouple economic growth from water use and water pollution (*UNEP 2015*). Circular economy is an alternative to business as usual, which, if it persists, could lead by 2030 to a 40 percent shortfall between forecasted demand for water and its available supply (*UNEP 2015*). [Annex B](#) summarizes some key resources on circular economy and water.

In a circular economy, the full value of water is recognized and captured. Water offers value in several ways, and it can play a number of roles in a circular economy: As a service (for example, it provides access to water supply and sanitation, it is used for cooling and heating purposes and it is needed to maintain and recover natural ecosystems), as an input to processes (in industry and agriculture, for example), as a source of energy (kinetic, thermal, biogas) and as a carrier of materials such as nutrients and chemicals (*IWA 2016; EMF, ARUP, and Antea Group 2018*). Instead of the current linear approach to the management of water ([figure 2.1](#)), circular economy identifies opportunities within three interrelated “pathways” (water, energy, and materials) (*IWA 2016*), leveraging and using all valuable resources in water and ideally providing additional revenue streams for the water sector (*Rodriguez et al. 2020*).

Circular economy recognizes water as the finite resource it is. By adopting a systems perspective and mimicking the natural water cycle, circular economy avoids using water when possible and closes loops at several levels by improving water (and other resources) efficiency, minimizing waste, and

Figure 2.1 The linear approach: Freshwater abstraction, treatment, use, and disposal (treated or untreated)



focusing on the behavioral Rs—reduce, reuse, recycle, replenish, recover, and retain. (Jeffries 2017; WBCSD 2017; EMF, ARUP, and Antea Group 2018; ING Bank 2018). Moreover, in a circular economy, a systems thinking, especially at the basin level, is used to identify and leverage opportunities within the sector and with other systems and sectors (notably industry, energy, and agriculture) (EMF, ARUP, and Antea Group 2018). Circular economy provides a framework that builds on already established water-sector concepts such as integrated water resources management (IWRM), integrated urban water management (IUWM), energy efficiency, reduction of non-revenue water (NRW), nature-based solutions, and resource recovery from wastewater. It also fits and builds on ongoing initiatives of the World Bank, such as [Utility of the Future](#) and [Citywide Inclusive Sanitation](#).

In a circular economy, negative externalities are designed out, the impact on natural resources is minimized, and watersheds and other natural systems are restored. A circular economy acknowledges the economic importance of rivers, lakes, oceans, wetlands, and groundwater. It values water as natural capital. A circular economy preserves and enhances this natural capital instead of degrading it, by embracing regenerative practices (Jeffries 2017). Water resources are conserved and pollution minimized by, for example, expanding wastewater treatment and avoiding discharges of industrial pollutants. Watersheds and natural ecosystems are restored through initiatives that maximize environmental flows, replenish aquifers, manage and preserve

natural capital, and curtail human disruptions to natural water systems (EMF, ARUP, and Antea Group 2018). Interventions are designed as part of river basin planning frameworks to safeguard watersheds, maximize environmental and economic benefits, improve efficiency and resource allocation, and boost inclusive practices (Rodriguez et al. 2020). In a circular economy, the water sector also mitigates its emissions of greenhouse gases with improved and energy efficient operations. It promotes the use of renewable energy, ideally self-generated (biogas, thermal energy sourced in wastewater, small hydro-power, and so forth), in line with climate change goals.

2.3 RESILIENCE AND INCLUSIVENESS IN CIRCULAR ECONOMY SYSTEMS

A planning exercise or investments prioritized around circular economy principles should foster efficient and sustainable outcomes; but these do not always translate into resilient water systems. Some circular trends might even compromise resilience (Circle Economy 2020). For example, a resource-efficient system that focuses only on eliminating supply redundancies could become less resilient. But if instead resource efficiency is achieved by reducing water losses and increasing energy efficiency (using fewer resources to obtain the same outputs), it could help make the system more

Box 2.2 What is resilience?

Resilience is the ability of individuals, communities, institutions, businesses, and systems to survive, adapt, and thrive in the face of stress and shocks, and even to transform when conditions require it. Three capabilities characterize a resilient system: persistence, adaptability, and transformability.

- **Persistence** refers to the ability of a human or a natural system to maintain coherent function under changing conditions and disruption without altering its identity. The existing components, configuration, and interactions of the system enable it to return to its prior function under the exogenous stresses and shocks to which it is exposed.
- **Adaptability** refers to a system's ability to maintain coherent function by modifying its identity to accommodate change. Adaptability is about continually adjusting responses, innovating, and reorganizing system parts and relationships relative to changing external conditions and internal interactions. Adaptability allows for system development and realignment within its current equilibrium—adjusting to sustain its present function.
- **Transformability** refers to a system's ability to change its identity and to establish a new function in a novel equilibrium when pushed beyond the threshold of its present state. It is the ability to change from one type of system to another in the presence of different controlling variables, structures, functions, and feedbacks. Transformation results in a change in both system identity and function. Transformability is the capacity to create a new system when ecological, economic, or social conditions make the existing system untenable.

Source: World Bank 2016b, Rockefeller Foundation et.al. 2019, Boltz et al. 2019

resilient and more circular. Resilience (defined in box 2.2) should therefore be integrated into any circular strategy to prepare the cities for uncertain shocks and stressors (climate and nonclimate, such as changes in demand, land use,

extreme weather events, demographics, and pandemics) in order to avoid the undesired impacts of a disruption or failure of water services (Rockefeller Foundation et al. 2019). Risk assessments and resilience planning for contingencies ensure that when failures do occur, they can be addressed in a way that limits adverse events. Resilient water utilities, networks, and systems anticipate, absorb, adapt, and recover from disruptive events and continue delivering essential services to populations.

A circular economy needs to be inclusive to achieve its full benefits for all. If inclusiveness is not explicitly included and carefully integrated in circular economy plans and actions, there is a risk that poor countries and vulnerable groups will not reap the benefits enjoyed by others. Developing countries—especially the least-developed countries—may struggle to access the resources, knowledge, and technologies to transition toward a circular economy (UNIDO n.d.). Additionally, if circular economy is implemented only in high-income countries (in part to reduce their dependency on imported raw materials), producers and exporters in developing countries could face adverse outcomes (UNIDO n.d.; Preston et.al. 2019). Evidence shows, however, that developing countries can also benefit from implementing circular economy principles. For example, estimates show that developing countries possess up to 85 percent of the opportunities to improve resource productivity (McKinsey Global Institute 2011). At the national scale, it is also important to integrate inclusiveness in circular solutions to avoid unwanted consequences and ensure that key users and stakeholders, regardless of income levels, are properly identified and participate in key consultation and decision-making processes. For example, initiatives to reuse wastewater for sale to industrial users should consider impacts on—and provide solutions for—small farmers who might have been using that wastewater for irrigation. Initiatives to improve resource efficiency, such as reducing non-revenue water – which includes reducing physical leaks and illegal connections – should also assess why those illegal connections are happening and provide solutions to connect everyone. An inclusive agenda should be visible at the utility level and in the utility's strategic plans. As developing countries and their cities continue to grow, it will be vital to support middle- and low-income countries as they transition toward a circular economy and ensure that vulnerable groups benefit. For example, the World Bank's [Citywide Inclusive Sanitation](#) initiative

supports governments and offers resources, good-practice documentation, and other materials to advocate for, design, and implement sanitation solutions for all, especially the poor, ensuring that services are inclusive. Multistakeholder platforms, such as those promoted by the 2030 Water Resources Group, ensure that key stakeholders, including the poor, participate in the creation of plans and investments to build resilient water systems.

Section 3 presents a framework for water in circular economy and resilience to guide practitioners that want to incorporate the principles into water sector planning, policies and strategies, investment prioritization, design, and operations.

THE WICER FRAMEWORK



3.1 WHY, HOW, AND FOR WHOM?

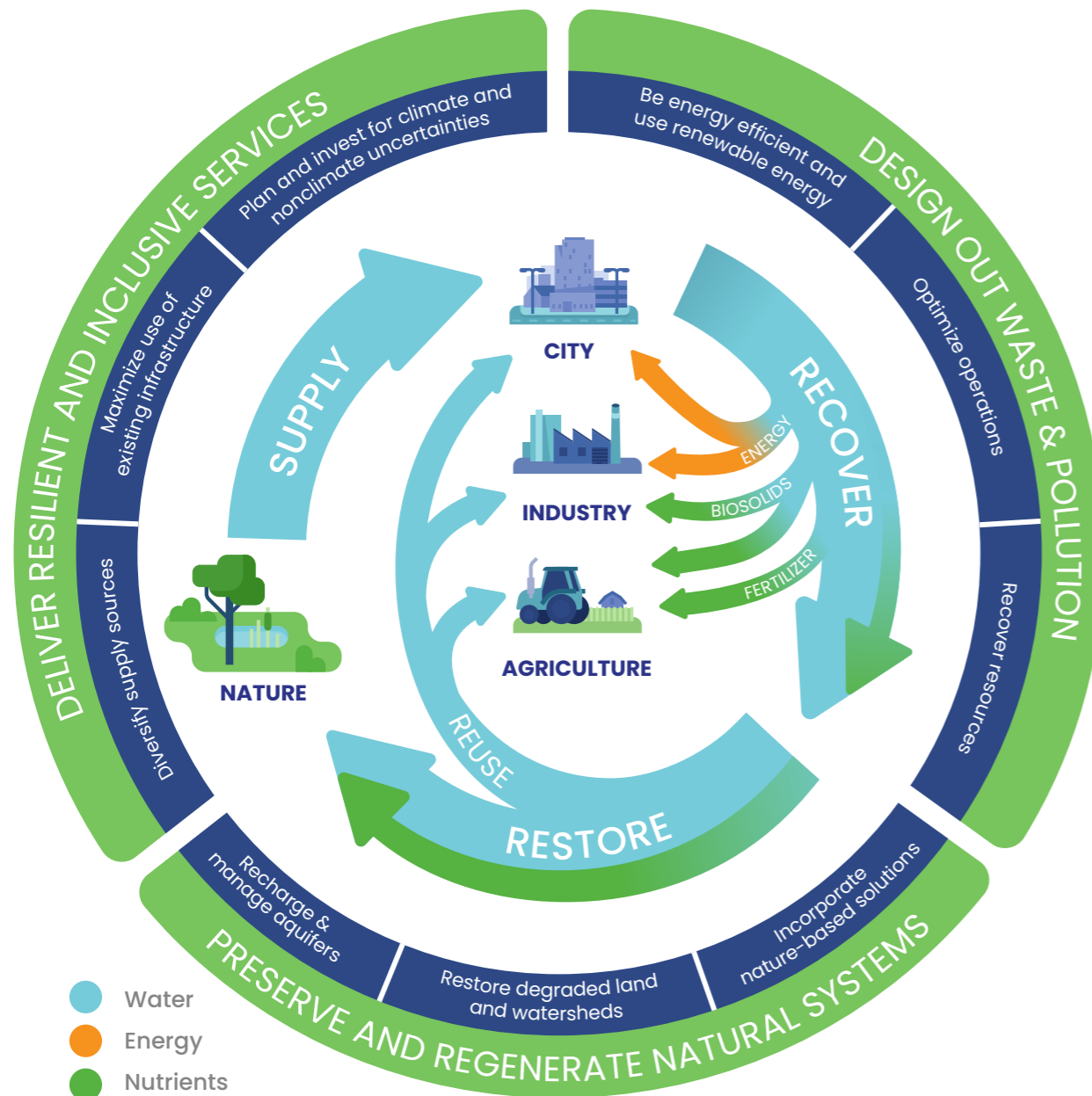
The WICER framework sets out the core elements of a circular and resilient water system. It builds on the literature review presented in section 2, folds in lessons from existing projects and case studies (see boxes and [Annex A](#)), and draws on World Bank knowledge and expertise. The framework was developed with three distinct outcomes in mind: (1) to deliver resilient and inclusive services; (2) to design out waste and pollution; and (3) to preserve and regenerate natural systems. Each of the outcomes depends on three actions, as shown in the two outermost circles of [figure 3.1](#). The outcomes and actions can be considered in any order, since the system described is circular and all outcomes are interlinked.

The outcomes and actions are examined in detail in sections 3.2 and 3.3. Cross-cutting actions that complement the framework are explained in 3.4. The rest of this section surveys the framework's context.

Within international organizations and client countries, extensive discussions are taking place on how to mainstream and operationalize circular economy and resilient approaches. The proposed framework brings forward the latest thinking on the subject. It is informed by practical examples from around the world in an effort to support the Bank and client countries as they incorporate circular economy and resilience in their policies, strategies, plans, investments, and operations. Although many World Bank initiatives and projects are already contributing to the achievement of a WICER system, the framework structures and frames them under a comprehensive umbrella.

The WICER framework is highly relevant to the world's Sustainable Development Goals (SDGs). It contributes directly to the achievement of SDG 6 (availability and sustainable management of water and sanitation for all) and is linked to several other SDG targets: SDG 1.4 (achieving universal access to basic services), SDG 3.9 (reducing water pollution-related deaths), SDG 7.2 (increasing the share of renewable energy), SDG 7.3 (improving energy efficiency), SDG 8.4

Figure 3.1 The WICER framework



(improving resource efficiency to decouple economic growth from environmental degradation), SDG 9.1 (developing quality, reliable, sustainable, and resilient infrastructure), SDG 9.4 (increasing resource-use efficiency and

adoption of clean and environmentally sound technologies), SDG 11 (making cities inclusive, safe, resilient and sustainable), SDG 12.2 (sustainable management and efficient use of natural resources), SDG 12.4 (environmentally sound management of chemicals and waste, and significantly reduce their release into the air, water and soil), SDG 12.5 (reducing waste generation through prevention, reduction, recycling and reuse), SDG 13.1 (strengthening resilience and adaptive capacity to climate-related hazards and natural disasters), SDG 14.1 (reducing marine pollution), and SDG 15.1 (ensuring the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services).

WICER offers a long-term vision for countries planning their urban water supply and sanitation services. This report intends to demystify circular economy (it is not, for example, an all-or-nothing proposition) and to show that the WICER framework can be applied worldwide. In fact, many water supply and sanitation utilities are already implementing projects that contribute to a WICER system. Sometimes one encounters reluctance to focus on circular economy initiatives, especially in low- and middle-income countries, because they seem impossible to achieve—too complex and overwhelming, or too expensive. Some may feel WICER should be implemented only by high-income countries or only once “the basics” are met. It is true that it would be unrealistic to demand the application of all the concepts in the framework in the short term. In fact, most high-income countries are not even close to be completely circular and resilient. However, with the right enabling conditions, low- and middle-income countries could leapfrog high-income countries, which are mired in linear systems, and develop circular systems at the outset, from scratch. The framework aims to provide guidance on how to get there, at each country’s pace, depending on the local conditions and the current baseline. Where infrastructure and projects remain to be designed and built, there are opportunities to embrace the WICER framework and develop infrastructure that sidesteps linear, inefficient assumptions. Where systems are already in place, planners will need to assess and prioritize which WICER interventions would have the greatest impact, retrofitting where appropriate. There are few prerequisites for applying the framework, as it is adaptable to local conditions and can be used to identify pathways toward circular economy and resilience that make sense in all contexts. Moreover, the WICER framework is fully aligned

with – and would contribute to meet the requirements of –the World Bank’s Environmental and Social Standard 3 (ESS3) on resource efficiency and pollution prevention and management.

Although the WICER framework was developed to be used primarily by city planners and decision makers in urban water supply and sanitation utilities, it can also be used to link the urban and rural worlds. For the reasons noted in the context section, including the potential for cities to be leaders of change, the target audience of this report are city planners and decision makers in urban water supply and sanitation utilities. However, circular economy and resilience principles can also be applied in rural and peri-urban settings. Peri-urban areas and small towns can play a critical transition role in connecting the rural and urban worlds—for example, by being the end users of treated wastewater and other by-products of wastewater for agricultural purposes. By using the framework to connect urban and rural worlds, opportunities and synergies can be identified, tradeoffs mitigated, and relevant stakeholders brought together.

The WICER framework can bring together and influence change across sectors. Because water is a resource for many sectors, achieving full circular and resilient water systems also depends on pursuing in parallel circular and resilient actions in other sectors. For example, improved practices should happen in agriculture (such as the implementation of efficient irrigation techniques, efficient rainwater harvesting, agricultural land management and efficient use of fertilizer (UNEP, 2015)), in the industrial sector (such as water reuse and recycle in industrial operations and the adoption of waterless and zero discharge processes), and at the household level (such as the adoption of water efficient appliances, recovering heat from wastewater and harvesting rainwater). The WICER framework acknowledges these cross-sectoral and intra-regional issues, and can be used to engage with stakeholders across sectors. WICER also emphasizes the need to analyze, plan, and invest in water interventions using a systems perspective, one extending beyond city boundaries to take into account river basins and watersheds and all relevant stakeholders. The framework can be applied to retrofit existing infrastructure, plans, and actions, or to design new plans and investments. The framework can also be adapted for use by stakeholders at all levels (river basin, region,

ministerial, federal) and by multiple economic sectors (industry, agriculture, energy, and environment) at different entry points.

3.2 OUTCOMES OF THE WICER FRAMEWORK

As noted, the three main outcomes for the urban water sector and cities are to (1) deliver resilient and inclusive services; (2) design out waste and pollution; and (3) preserve and regenerate natural systems. The outcomes are summarized below; the actions required to achieve them are treated in detail in section 3.3 and 3.4, which constitutes the bulk of this report.

Outcome 1. Deliver resilient and inclusive services. Water supply and sanitation services are designed, planned, and implemented in a way that ensures their long-term resiliency and inclusiveness. Resilient utilities, networks, and systems anticipate, absorb, adapt, transform if needed, and rapidly recover from a disruptive event. Inclusive services ensure that everyone, regardless of gender and social and economic class, has access to water supply and sanitation and that vulnerable groups are not negatively impacted by circular economy and resilient interventions. Instead, they are included and participate in strategy development, and they also reap the benefits of circular economy and resiliency.

Outcome 2. Design out waste and pollution. Water supply and sanitation utilities transition toward resource efficiency and effectiveness, producing more output (water, energy, nutrients and other resources and services) with less input (less energy, less chemicals), closing the loops of materials and resources as much as possible and keeping resources in use, while minimizing the impact on the environment. At the same time, interventions also contribute toward improved resilience of the system.

Outcome 3. Preserve and regenerate natural systems. A circular and resilient water sector not only minimizes waste and negative environmental impacts, but also actively restores precious natural systems, recognizing their economic value and their importance for a sustainable future. The value of water resources is fully recognized, and aquifers and watersheds are carefully man-

aged, preserved, recharged, and restored. Nature-based solutions are integral to the solution.

3.3 KEY ACTIONS TO ACHIEVE A WICER SYSTEM

The following sections provide concrete examples of the actions needed to achieve the three key outcomes of the WICER framework. The references and resources cited in the report and in [Annex A](#) cite additional reports, guidelines, and case studies on each action. The boxes show concrete examples of the implementation of these principles. The listed actions are not in any particular order, since most of the elements of WICER are interconnected. The actions to focus on will depend on the context and available resources in an individual case, but ideally the framework should be used to create a holistic long-term strategy. Cross-cutting issues are presented in section 3.4.

3.3.1 Actions to deliver resilient and inclusive services

This outcome hinges on three actions: (1) diversifying supply sources; (2) optimizing the use of existing infrastructure; and (3) planning and investing for climate and nonclimate uncertainties.

Action 1. Diversify supply sources

Actions must be planned and implemented using a systems approach. Specifically, interactions should be considered at the basin level because cities are part of catchments and have, in most cases, multiple water-supply sources. Taking a basin-level approach makes it possible to do several important things: (1) to identify, optimize and protect conventional and unconventional sources of water—including surface and groundwater, rainwater, treated wastewater, and seawater (*World Bank 2018a; UN Water 2020*); (2) to identify polluting sources and optimize wastewater interventions and investments, including nature-based solutions (*Browder et al. 2019*), in view

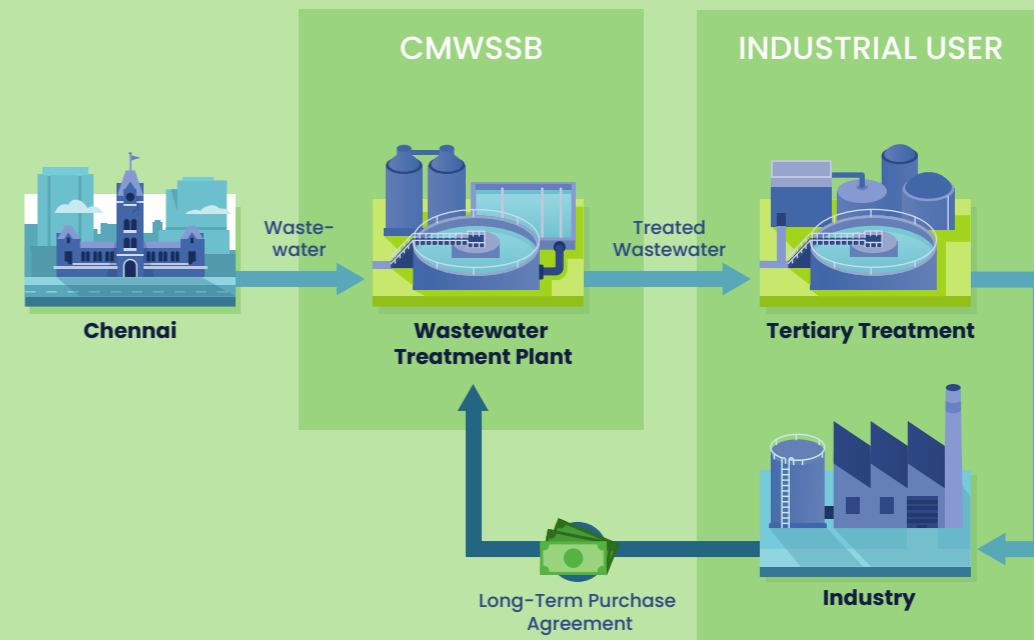
of the conditions of the receiving waterbody — minimizing treatment needs (upstream and downstream) (*Rodriguez et al. 2020*); (3) to protect the city from floods and implement integrated water storage solutions (*GWP and IWMI 2021*), including nature-based solutions (*Browder et al. 2019*) and natural and artificial aquifer recharge (*Clifton et al. 2010*).

This systems approach must also be inclusive, engage all relevant stakeholders, and take into account, during planning and implementation, the benefits and potential impacts for everyone. In order to be fully inclusive, off-grid supply solutions also need to be considered in the planning exercise to ensure that all urban dwellers receive an affordable service that meets basic needs and is safely managed (*Misra and Kingdom 2019*). Urban water and sanitation utilities must shift from a linear thinking that focuses on achieving service standards in a financially sustainable way to an integrated approach that secures reliable and sustainable water supplies now and into the future for everyone, including vulnerable groups. [World Bank \(2016c\)](#) further explores how to mainstream water resources management in urban projects.

Diversifying and protecting water supply sources support utilities and help cities hedge against risks. Utilities and cities must build diversified and dynamic water resource portfolios, making sure to protect and explore the use of all available water sources and, whenever possible, to use fit-for-purpose approaches to minimize treatment costs. Ideally, to ensure resilience and flexibility of systems, the diversified water portfolio should include sources having different risk and cost profiles (for example, combining surface and groundwater – see also [Outcome 3. Action 3.](#)), sources that respond to stress at different time scales, and, if possible, sources that have low vulnerability to shocks and stresses, such as desalination and treated wastewater ([box 3.1](#)). [World Bank \(2018a\)](#) offers different examples of cities with diversified water portfolios such as the case of Windhoek, Murcia and Singapore. By combining the concepts of fit for purpose and security through diversity, all potential water sources can be taken into account, thereby maximizing end use and system efficiency (*Jacobsen et al. 2013*). As part of their water security strategy, cities and water utilities can become the stewards of their upstream and downstream watersheds, whether through catchment management, lobbying efforts, or other means (see [Outcome 3. Action 1](#) and [2](#)).

Box 3.1 Applying circular economy principles in Chennai, India

To protect against the vagaries of nature, build resilience, and increase water availability, the Chennai Metropolitan Water Supply and Sewerage Board (CMWSSB) in Chennai, India, embarked on several projects and investments to diversify water supply and to become more circular and resilient to droughts. Chennai was the first city in India to mandate rainwater harvesting. CMWSSB is also the only utility in India with two large-scale desalination plants and the first to reuse 10 percent of collected wastewater, with plans to achieve a reuse rate of 75 percent. Since 2005, CMWSSB has been implementing several projects to treat and reuse wastewater for several purposes. As part of this effort, CMWSSB sells treated wastewater to industrial users and with the additional revenues, it can cover all operating and maintenance costs (see figure on the right). The capital investment in the reuse project has been recovered in less than five years. CMWSSB also retrofitted seven of its wastewater treatment plants to recover energy from wastewater and to supply more than 50 percent of the energy needs of all the plants, saving on energy costs and helping sustain operations financially. The energy generation investment had a payback period of 2.8 years. CMWSSB is also investing in indirect potable reuse and is exploring the possibility of selling most of the biosolids generated in the wastewater treatment plants as manure for agricultural use. Read the full case study [here](#).



Source: World Bank 2021a.

Note: CMWSSB = Chennai Metropolitan Water Supply and Sewerage Board.

Integrated water storage can help diversify supply sources and shift resource availability across time to help navigate future uncertainties.

There are different types of water storage (natural, nature-based, and gray infrastructure) each with different characteristics. All types of storage should be considered and combined as part of an integrated, codependent storage system to hedge against potential risks and increase the resiliency of the system (*GWP and IWMI 2021*). In the face of shifting rainfall patterns and growing uncertainty, integrated water storage will be critical to guarantee numerous water-related services (such as water supply for households, industries, irrigation, and energy security) and to manage water resources to protect communities, including the most vulnerable groups, and the environment

(ecosystem functions; flood and drought protection) (*GWP and IWMI 2021*).

An integrated water storage plan with multiple storage solutions can also be more flexible and adaptive to external shocks.

Rainwater harvesting should be considered as a valuable complementary intervention to enhance water security.

Rainwater can be collected and stored in tanks in private and public buildings or in private homes and harnessed for domestic use (for example, for toilet flushing) and irrigation (*World Bank 2020b*). It can be stored in reservoirs or used to recharge groundwater aquifers for use in times of scarcity (see [Outcome 3. Action 3](#)). Rainwater harvesting can be part of an adaptation strategy, providing a way to store water

in the face of growing variability in rainfall (UNEP 2019), and to help with flood management in cities. Water utilities can play a role in rainwater harvesting by providing equipment, technical support, installation, and maintenance. Rainwater should be included as part of every city's water balance.

Managing stormwater adequately is key to capturing the potential of this valuable resource. Urban development is usually done in a way that it negatively affects the permeability of surfaces, thereby amplifying stormwater runoff and reducing groundwater recharge (World Bank 2018a). Rapid urbanization often brings about informal settlements in areas with high flood risk, such as floodplains and riverbanks (World Bank 2019c). Stormwater run-off can also carry sediments, nutrients, chemicals, and other pollutants that can affect the quality of water sources. As urban population grows and climate change intensifies the frequency and intensity of heavy rains, cities need to adapt and prepare for these events to protect their inhabitants and the ecosystem. At the same time, stormwater presents quality characteristics different from those of wastewater and usually requires less treatment before being fit for reuse. In water scarce cities, especially, managing stormwater goes beyond flood protection, since rainwater can be a powerful resource (as noted in the discussion on rainwater harvesting above). Therefore, managing stormwater offers opportunities for cities to capture these resources through aquifer infiltration and other methods, closing the circle from flood mitigation to resource utilization (World Bank 2018a). In flood prone cities, it is also important that stormwater be managed as part of an integrated approach to managing flood risks (Jha, Bloch, and Lamond 2012) and combining gray with green infrastructure (see [Outcome 3. Action 1](#)).

Action 2. Maximize the use of existing infrastructure

Infrastructure already in place is a valuable resource. Rather than building new infrastructure, existing or damaged infrastructure can be rehabilitated to function as it did in its original design. Infrastructure can be retrofitted or optimized to increase the returns on the initial investment, provide additional services, or maximize service delivery without making costly investments.

Existing water and wastewater treatment plants should be used efficiently and effectively. This seems obvious, but too often valuable and costly infrastructure is not used to its fullest potential. For example, in water and wastewater treatment plants, international experience and advances in operational efficiency have shown that the actual treatment capacity of certain plant processes is greater than the nominal capacity foreseen in the original design. Utilities often assume that the real capacity of all plant processes is equal to the nominal one and, when more capacity is needed, they tend to “mirror” the plant without taking the real capacity of each plant process into account. This results in underutilization of the potential capacity and overexpansion (and depreciation) of the existing infrastructure, with its high capital costs. Analysis or audits of existing treatment plants can reveal excess capacity in some treatment processes (Nolasco, Stephenson, and DeAngelis 1994; Environment Canada 2006). Armed with that knowledge, expansion can focus first on processes that present a bottleneck, thus yielding considerable savings ([box 3.2](#)). Optimizing the performance of conventional wastewater treatment also makes it possible to postpone the need for immediate investment in physical expansion of facilities or in tertiary treatment systems; hence resources can be reallocated to other purposes, such as the expansion of the water supply and sewerage networks. Evaluating existing infrastructure and utilizing modern design methods (e.g., dynamic simulation) can maximize the use of existing infrastructure and enhance its sustainability, thereby avoiding unnecessary infrastructure expansions that waste valuable resources, raise costs, and enlarge the carbon footprint. Process evaluation techniques are not necessarily complex or expensive. [Rodriguez et al. \(2020\)](#) and [World Bank \(2019a\)](#) further explore this topic.

This principle can be applied to all water infrastructure. For example, in stormwater-retention infrastructure, existing infrastructure can be optimized instead of adding new storage capacity. Data-driven technologies such as continuous monitoring and adaptive control can enable the optimization (Garder 2019). By combining weather data, data on water levels in holding basins, and smart control valves, it becomes possible to plan for, observe, and respond to storm events predictively, avoiding the need for additional capacity. Similarly, assessing rainfall characteristics and hydrological conditions at the catchment level can help determine whether upstream actions might

Box 3.2 Maximizing the use of existing infrastructure: the case of Buenos Aires and São Paulo.

Maximizing the use of the existing infrastructure in Buenos Aires, Argentina.

AySa, the water and wastewater utility in Buenos Aires, was planning to expand its wastewater treatment plants in order to increase capacity. But the application of process audit techniques allowed the utility to find ways to exploit the full potential of its existing facilities, resulting in cancellation of the expansion plans and savings of USD 150 million in capital expenditures.

Optimization of existing wastewater treatment plants in São Paulo, Brazil.

In 2019, the World Bank's 2030 Water Resources Group for Brazil, in partnership with the utility's metropolitan sewage unit, began implementation of a program to optimize the performance of four major wastewater treatment plants. Instead of investing in expanding or building new plants to increase capacity, the program is conducting a series of audits to define priority actions and investments to eliminate bottlenecks and maximize the efficiency of the treatment process at each plant. Optimization of the plants will allow the utility to postpone investments in tertiary treatment and reduce investments in physical expansion. Preliminary results show that the program will result in enormous savings for the utility, SABESP. Read the full case study [here](#).

Source: World Bank 2019a, 2021b.

be more cost-effective in managing flows into an urban area (depending on flood characteristics). Nature-based solutions such as groundwater or aquifer water storage should also be considered as ways to maximize the value of existing gray infrastructure.

Exploiting the full potential of existing infrastructure also means connecting all households originally included in its design. Failing to achieve full water and sewerage connections leads to the underutilization of water infrastruc-

ture and lower-than-expected revenues. Low household connection rates can adversely affect the performance of treatment facilities, both from operational and financial perspective, reducing plant efficiency and returns on investments. A recent report by the World Bank "[Connecting the unconnected](#)" (Kennedy-Walker et al. 2020) has studied why so many households remain unconnected and shares global best practices in sewerage connection programs. One key message is the importance of engaging the community from inception through operation and management. For example, local cooperatives can be employed to connect households. Ensuring the connectivity of all households is not only essential for the efficient and optimal use of existing infrastructure but also crucial to ensure that water supply and sanitation services are inclusive, deliver satisfactory water quality, and are sustainable.

Action 3. Plan and invest for climate and nonclimate uncertainties

A circular approach promoting efficiency and sustainability should also focus on increasing resilience at the urban level. As cities grow rapidly and climate change affects the availability and distribution of water resources, meeting urban water demand will become ever more difficult and energy intensive. These entwined problems make it harder and harder for utilities and municipalities to provide services, ensure adequate resources (food, water, energy), protect public health, and preserve the environment. Careful planning promotes long-term water security and resilience to climate and nonclimate uncertainties and can mitigate some of these risks.

The traditional approaches to planning, design, and investment are not suited for addressing the growing challenges posed by climate change risks and threats to public health. In the traditional predict-then-act approach, decision makers attempt to predict the future and select interventions and investments to produce the desired outcomes under the chosen scenario. In most cases, the portfolio of investments is compiled by applying criteria such as cost effectiveness, cost minimization, cost-benefit ratios, or maximization of net present value. But the future is highly uncertain and cannot be predicted, and a failed prediction generally leads to a portfolio of inefficient investments, unnecessary projects (stranded assets), a high opportunity

Box 3.3 Improving the resilience of urban water supply in Mexico

The Cutzamala Water System, which carries water from the Balsas basin to the Valley of Mexico and Mexico City (a distance of 126 kilometers and an elevation of 1,200 meters) was assessed to improve its resiliency. First, trust was established among stakeholders and users while coming to understand the physics of the system, its operation, its benefits, and the precedents for emergency response. Then, as a simulation model was developed and tested, the potential for increasing the reliable yield through reservoir reoperation was discovered. New “rule curves” (how to operate the dams) for El Bosque, Valle de Bravo and Villa Victoria reservoirs were derived by maximizing the reliable yield of the existing system without additional investments. Still, very small changes in precipitation and temperature were found to cause the system to perform unsatisfactorily.

This suggested the need to evaluate options to improve the system’s performance. Accordingly, the performance of all investment combinations relative to the current performance of the system was assessed. The system was analyzed considering its robustness (meeting the target yield across a range of climate scenarios) and its resilience (or recovery) relative to current operations and optimized operations. The result of the multi-dimensional analysis showed that large capital investments do not yield large performance payoffs in isolation. Additionally, while some investments may exhibit similar yields and costs, they may differ in their ability to improve recovery after failure and robustness to future climate conditions

Based on these evaluations, the government will decide on potential investments to make the Cutzamala Water System more resilient.

Source: World Bank 2017.

cost, and unmet goals for the water system. Furthermore, “predict then act” does not explicitly assess social equity, environmental considerations, or the impacts of climate change.

This has fueled a paradigm shift to bottom-up, flexible, and robust decision-making approaches. Analytical approaches have been developed (*Garcia et al. 2014; Ray and Brown 2015; World Bank 2018b; Brown et al. 2020*) to examine the intrinsic characteristics of a water system or project and describe is in terms of exposure, sensitivity, and capacity to adapt to and withstand stress. These approaches can be broken down into three phases: (1) know and assess the characteristics of the existing system; (2) assess the sensitivity of that system to a wide range of future scenarios characterized by uncertainty, identifying the most vulnerable parts of the system and the specific attributes of those vulnerabilities; and (3) choose actions centered on robust and flexible strategies and examine the trade-offs involved in meeting the agreed objectives under the scenarios identified. [Box 3.3](#) offers an example of this process.

These bottom-up approaches can analyze the impact on systems of a range of risks and uncertainties such as climate change, population dynamics, pandemics, or economic conditions. In these approaches, the level of complexity, as well as the resources needed to make decisions are scaled and adjusted according to the unique characteristics of a project and other relevant factors, as well as the issues and decisions that may be raised by stakeholders at each step in the process (*Ray 2015*). By enabling diagnosis of the potential impacts of climate and other variables on a water project, plan, or strategy, this approach brings to the surface ways to reduce the effect of stressors on the system. Often, it permits water planners to assess the chances of success or failure of a specific application under current or plausible future conditions. From that point, water managers can propose modifications and gauge the resulting response of the system to the stressors. At this stage, decision-makers and stakeholders, through an inclusive process, should be able to formulate and design more cost-effective, resilient, and robust solutions for the application. This method also allows for more flexible solutions under future scenarios. For example, a new water supply or wastewater treatment facility can be built in a modular way, so that capacity can be added later as demand increases. The World Bank report “[Building the Resilience of WSS Utilities to Climate Change and Other Threats: A Road Map](#)” offers guidance on how to use a bottom-up approach to build resilient water supply and sanitation utilities (*World Bank 2018b*). The “[Resilient Water](#)

Box 3.4 Improving Resiliency, Sustainability and Efficiency in Uruguay's National Water Supply and Sanitation Company

With support from the World Bank, Uruguay's National Water Supply and Sanitation Company (OSE) improved resilience, efficiency, management capacity, and the reliability of its water supply and sanitation services. Under the project, the reliability and resilience of water supply and sanitation systems were improved by rebuilding two water treatment plants to protect against periodic floods and by enhancing the water intake at a third plant by increasing redundancy and incorporating preventive features into the existing system. These interventions have benefited around 433,900 households.

The project also focused on improving energy efficiency and reducing non-revenue water, which led to cumulative savings of 89.3 million cubic meters of water and energy savings of nearly 26,250 megawatt hours over the lifetime of the project. Moreover, 19 water safety plans were developed, responding to the government's innovative regulatory requirement that utilities develop water safety plans for each water supply system OSE operates. An asset management system was developed, as well as a prototype for biosolid drying and a process for applying biosolids to fodder crops. OSE also implemented a logistics management model and quality management software while building operational knowledge, innovation management capacity, and internal communications. The utility now incorporates risk management in its daily operations. Read more about this project [here](#).

Source: World Bank 2020d.

[Infrastructure Design Brief](#)" (World Bank 2020c) guides users on how resilience can be engineered into the design of projects.

Freshwater resilience needs to be quantified, as it is vital in urban settings.

Mainstreaming resilience in the planning and prioritization of investments is a condition for mitigating the vulnerabilities of urban water systems to shock and stress. [Box 3.4](#) illustrates how the resilience (and efficiency) of Uruguay's

water systems was improved, reducing losses in the process (by optimizing operations).

3.3.2 Actions to design out waste and pollution

This outcome depends on three actions: (1) being energy efficient and using renewable energy, (2) optimizing operations, and (3) recovering resources. These actions are detailed below.

Action 1. Be energy efficient and use renewable energy

Because energy is often the costliest component of water supply and sanitation operations, energy efficiency and renewable energy serve both to reduce emissions of greenhouse gases (GHGs) and strengthen financial performance. Electricity costs for water abstraction, production, distribution, and treatment range from 33 percent to 82 percent of nonlabor operating costs of water supply and sanitation utilities (*Limaye and Welsien 2019*). And rising energy costs have direct implications for service affordability, sustainability, and financing of water supply and sanitation services (*WWAP 2014*). Energy costs are tied to the type of water source, transport distance, and treatment standards (*Lackey and Fillmore 2017*). At the same time, energy is the largest controllable operational expenditure for most water supply and wastewater utilities. Making these utilities more efficient, or even transforming them into energy producers (of renewable sources), are some of the best ways to manage and reduce operational costs, hedge against fluctuations in energy prices, ensure long-term operational sustainability and increase the resilience of water systems. These benefits can be achieved while curtailing waste, curbing GHG emissions, and advancing climate goals. Moreover, energy-efficient facilities often reduce water losses, a double win for the utility.

For most urban water supply and sanitation utilities, investments in energy efficiency generate the highest returns. Each utility faces unique energy challenges and audits can ascertain the most appropriate solutions. Usually, energy costs are lowered through measures that address energy efficiency

and load management. Energy efficiency measures include improving the operation of pumping systems (such as replacing inefficient pumps, using smart pumps, converting to gravity-fed systems and upgrading maintenance), implementing water loss management technologies to detect and reduce leaks and manage pressure, boosting the efficiency of water and wastewater treatment plants, and implementing other innovations such as supervisory control and data acquisition (SCADA) software. Common and readily available technical efficiency measures can cut energy consumption by 10–30 percent, with payback periods as short as a year (ESMAP 2012). Load management is usually done by shifting pumping operations from peak to off-peak periods. In most countries, peak electricity tariffs are much higher than off-peak tariffs. Therefore shifting pumping operations can bring major cost reductions because they consume 70 to 80 percent of a utility's electricity use (Limaye and Welsien 2019). When utilities select and scale their treatment processes, they need to take such considerations into account at the design stage. Investments in energy efficiency and recovery activities should be based on analyses of the life-cycle cost, because investments that deliver over the long term will have a higher rate of return (Lackey and Fillmore 2017). Moreover, energy efficiency measures tend to be associated with water loss reduction—a win-win (box 3.5). A recent guidance note by the World Bank's initiative "[Mainstreaming Energy Efficiency Investments in Urban Water and Wastewater Utilities](#)" (Limaye and Welsien, 2019) provides further details on the typical energy efficiency and load management measures, how to identify, implement, and finance them, and a road map for mainstreaming energy efficiency in water sector infrastructure projects.

In combination with energy efficient measures, water supply and sanitation utilities can also become energy producers and achieve energy neutrality or even generate a surplus of energy to be sold to the grid. Worldwide, the water sector's electricity consumption is around 4 percent of total global electricity consumption (IEA 2016). In some countries, water supply and sanitation utilities are the most intensive energy consumers. By 2040, the sector's consumption could rise by 80 percent (IEA 2020). To minimize the sector's impact on the environment, mitigate climate change, and become more resilient to energy price fluctuation, utilities should transition to renewable energy. The good news is that renewable energy can be recovered in water streams.

Box 3.5 Improving energy efficiency, reducing energy costs, and saving water. The cases of Mexico and Bosnia and Herzegovina.

The example of Monclova, Mexico. With support from the World Bank, the city of Monclova optimized its water distribution network by changing zoning patterns; regulating water pressure and flows with hydraulic models; creating network sectors; addressing non-revenue water (detecting and repairing leaks); installing variable speed drives; improving pumping efficiency by introducing more energy-efficient pumps; and optimizing pumping operational schedules. The project boosted operations and water supply from 10 hours a day to 24. Water flow and pressure were improved so that an additional 40,000 customers gained access to water, while total energy consumed and non-revenue water dropped. Monclova saw energy savings of 4.75 million kWh (a 27 percent reduction) and water savings of 1.94 million cubic meters, resulting in annual cost savings of USD 380,000. The utility's greater operational efficiency increased revenues that repaid the investment in 1.9 years. Read the full case study [here](#).

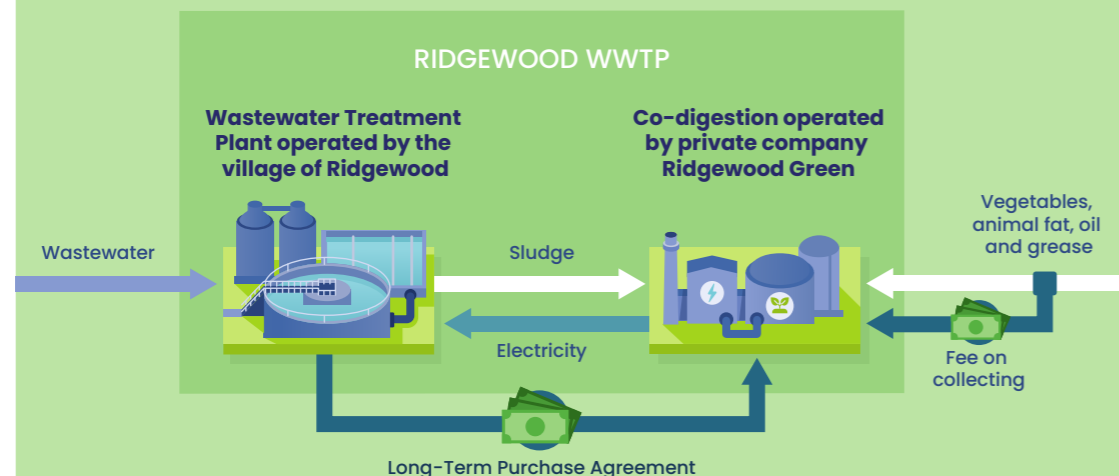
The example of Mostar, Bosnia and Herzegovina. With support from the World Bank, the town reduced its energy use by 40 percent with pump upgrades and replacements, more gravity-fed water, and improved water-leakage detection and repairs, reducing energy consumption by 40 percent, from 9.4 megawatt-hours in 2001 to 5.6 megawatt hours in 2004. These energy savings have brought annual savings of USD 128,400 for the town. Read the full case study [here](#).

Source: ESMAP 2010, 2011.

For example, most wastewater treatment plants generate biogas, which can be used to produce electricity and heat on-site to meet some of the plant's energy needs (see [Outcome 2. Action 3](#), and *Rodriguez et al. 2020*). Co-digestion—where an external waste source is injected directly into the anaerobic digesters—could increase biogas production and meet the entire

Box 3.6 Achieving energy neutrality in a wastewater treatment plant with co-digestion in Ridgewood, United States.

The wastewater treatment plant in the Village of Ridgewood, New Jersey (United States) was the largest energy consumer of the municipality, costing it more than USD 250,000/year for electricity. Ridgewood leveraged the potential of resource recovery and, under a public private partnership agreement, retrofitted its wastewater treatment plant for co-digestion, producing enough biogas to meet the plant's electricity needs. Ridgewood Green, the private operator of the co-generation facility, supplied all of the upfront capital investments, with minimum risk for the village of Ridgewood. The village purchases the electricity generated from biogas by Ridgewood Green at below-market prices under a power purchase agreement. Ridgewood Green obtains a return on its investment through a revenue model that leverages proceeds by (1) selling electricity to Ridgewood; (2) offering its renewable energy certificates to 3Degrees, a leader in the renewable energy marketplace under a medium-term agreement; and (3) collecting tipping fees for the organic matter collected for the anaerobic digesters to produce biogas and generate electricity. Read the full case study [here](#).



Source: World Bank 2018c.

energy requirements of a plant (Rodriguez et al. 2020; and [box 3.6](#)). Thermal energy from sewerage can be harnessed to heat offices and other buildings. Other World Bank reports (Vazquez and Buchauer 2014; Lackey and Fillmore 2017) offer further guidance on wastewater and energy generation, keying them to the size of treatment plants.

Another less-explored option is the installation of micro-hydro turbines in the water network to generate electricity (McNabola et al. 2014; Veolia 2020). Some municipalities are also installing solar photovoltaic (PV) on the land of their treatment facilities (TPO Magazine 2011) or using wind turbines to lower electricity costs while reducing their carbon footprint. Floating solar PV can be placed in large reservoirs. This type of energy projects is usually done through a third-party financing arrangement, where a private company finances, builds, and operates the energy-generation facility and sells the electricity to the municipality below market price, under a power purchase agreement (TPO Magazine 2011; [Box 3.6](#)). Using renewable energy also lowers GHG emissions and allows the utilities to benefit from carbon credits, renewable energy certificates, and other forms of climate financing (such as green bonds). In short, energy interventions in the water sector can also help countries achieve their climate goals.

Action 2. Optimize operations

Key to circular economy are operations optimized for efficiency, reliability, and performance. Poorly operated utilities jeopardize the sustainability of any other WICER solutions that may be deployed. But because performance issues are complex, this topic has been studied in depth. The [Utility Turnaround Framework](#) (Soppe, Janson, and Piantini 2018) is one of many World Bank reports offering guidance for poorly performing water supply and sanitation utilities. It identifies five elements that are critical to sound management and performance: technical operations, commercial operations, human resources management, organization and strategy, and financial management. The [Utility of the Future Framework](#) (Lombana Cordoba et al. 2021) builds on the Utility Turnaround Framework. Its methodology can help utilities improve performance and provide high-quality services in a highly efficient manner while

also being innovative, inclusive, market- and customer-oriented, and resilient.

Most utilities, especially in low- and middle-income countries, need to

reduce NRW. On average, water utilities lose a third of the water they spend so much money abstracting, treating, and supplying. In some cities, NRW rates can reach 80 percent. As the potential for developing new sources of water diminishes, water must be used efficiently to meet future demand. Given the challenges in the sector, and in line with circular economy, there is little benefit in investing in new water-supply sources if the current network system has a high levels of NRW. Moreover, managing NRW is often cheaper

than increasing supply (*World Bank 2016d*). NRW management helps utilities expand and improve service, boost their financial performance, lower energy consumption, and mitigate climate change while becoming more sustainable ([box 3.7](#)). The science behind, and the benefits of, reducing water losses is well known and extensively documented (*Farley 2001; Farley and Trow 2003; Liemberger and Farley 2005; Farley et al. 2008; WSP 2008, 2009; Liemberger 2010; Frauendorfer and Liemberger 2010*). But these benefits often remain unrealized because water service providers face massive political, financial, and technical hurdles. Two reports by the World Bank (*Kingdom et al. 2006; PPIAF 2016*) explore ways to tackle NRW, among them performance-based

Box 3.7 Two examples of optimizing operations in water utilities

Reducing non-revenue water (NRW) and increasing energy efficiency in Tirta

Tugu, the municipal utility of Malang in Indonesia. In 2009, Tirta Tugu's NRW rate was 42 percent, and the utility was able to serve less than 60 percent of the population of Malang Municipality. By 2019, Tirta Tugu successfully cut its NRW rate to 16 percent and became able to supply more than 95 percent of the population. The utility managed to improve its operational efficiency through the establishment of district meter areas, pressure management using pressure-reducing valves, active leakage control, and innovative technology (for example, control instruments and supervisory control and data acquisition systems). Tirta Tugu also improved energy efficiency through asset management, particularly for mechanical and electrical equipment. The utility installed capacitor banks in the main distribution panel and performed regular energy audits of all pumping stations. A dedicated team implemented the NRW reduction program and engaged all departments across the utility. To strengthen employee performance, it allocated an adequate budget for in-house training programs. With capital spending ascribable to NRW averaging USD 0.85 million per year, Tirta Tugu gained additional USD 2.5 million in annual revenue. Capital spending related to energy inefficiencies were USD 0.145 million in 2011. By reducing its energy costs by 21 percent, Tirta Tugu saved USD 0.57 million per year. Moreover, by making

optimal use of its limited water resources, the utility avoided the need for huge investments to increase its production capacity. Read the full case study [here](#).

Improving operational efficiency and reducing NRW in Phnom Penh, Cambodia.

In the early 1990s, the Phnom Penh Water Supply Authority (PPWSA), was a poor-performing utility. It supplied water intermittently to just 25 percent of the city's residents. Its treatment plants operated at 45 percent of their installed capacity, while revenue from tariffs covered only half of operating expenses. The NRW rate was as high as 72 percent because of leaking pipes, low collection rates, and illegal connections across the city. In 1993 the government introduced a utility improvement program. After bringing NRW down to 6.9 percent by 2013, PPWSA is now a world leader in efficiency, supplying water to 390,000 connections in the city, or 97 percent of the population of Phnom Penh. The drop in NRW from 1993 to 2013 produced savings of USD 150 million in deferred investment and USD 18 million in income. The stanching of water losses in the system has made PPWSA more resilient, as most of the water produced now reaches customers. Because Cambodia contends with frequent and prolonged droughts brought about by climate change, efficient management of water resources is crucial, especially as PPWSA relies on only one source of water—the Mekong River. Read the full case study [here](#).

Source: World Bank 2021c, 2021d.

contracts. The World Bank has also entered into a partnership with the International Water Association raising awareness about NRW, increasing recourse to performance-based contracts, streamlining the preparation of such contracts, and supporting their implementation in developing countries (*World Bank 2016d*). NRW interventions are usually done together with energy efficiency programs ([box 3.5](#) and [box 3.7](#))

Optimizing the operation of water and wastewater treatment facilities is equally important and can generate multiple benefits—notably greater energy efficiency and cuts in the resources required to achieve the same output, both of which lower operating costs. The first step is to plan and design treatment facilities correctly, with circular economy and resource recovery in mind. This implies projecting effluents accurately and selecting the best treatment processes, taking a phased approach when feasible to match local conditions and regulations. Rather than focusing on initial capital costs, utilities need to consider the costs of long-term operation and maintenance (see *World Bank 2019a* and [box 3.15](#)). Next, plant operations should be optimized with respect to treatment options and energy efficiency (*EPA, 1998; WEF 2016*). Comprehensive audits (*Environment Canada 2006*) identify measures that could mitigate or resolve inefficiencies through small-scale construction, automation using SCADA, and real-time monitoring using sensors and actuators for variable conditions. Investments to optimize operations can be recovered quickly due to the savings in energy and chemical costs and other operating savings such as effluent and discharge taxes and fees (*DHI n.d.*). Using less chemicals to achieve the same treatment levels also reduces the environmental footprint of the treatment plants. Moreover, optimizing operations often increases treatment capacity, resulting in additional savings due to postponed investments (see section 3.3.1, Action 2). Finally, energy efficiency measures (discussed in the previous section) should also be considered when optimizing operations.

Action 3. Recover resources

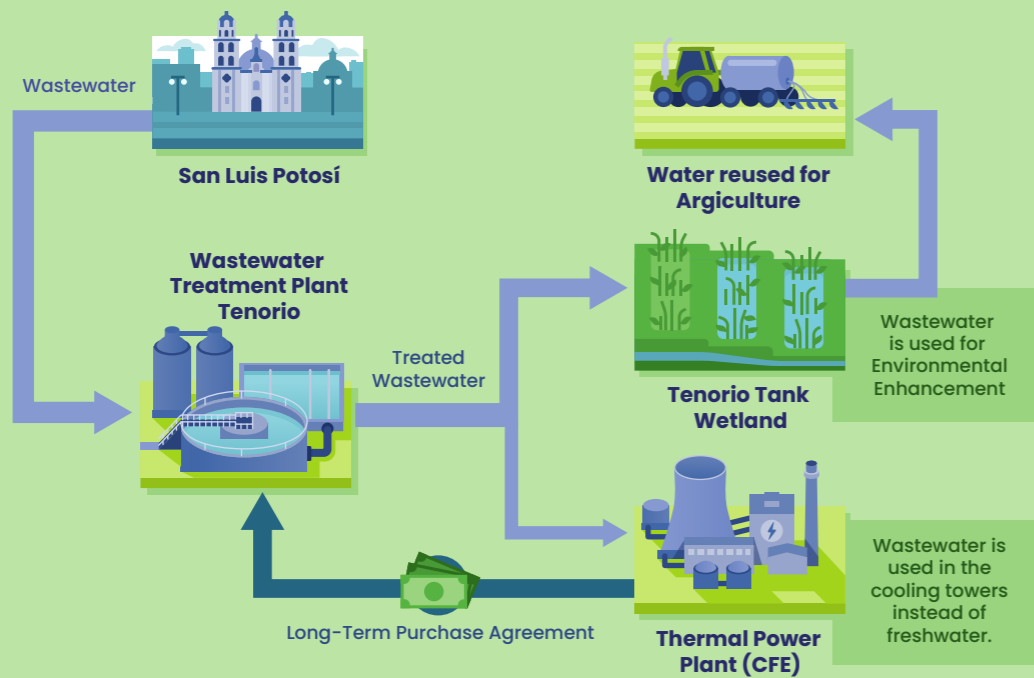
Resources can be recovered over the entire water cycle. Understanding the flow of resources in and out of their systems allows water supply and sani-

tation operators to identify opportunities to recover resources that are being underutilized or wasted at every phase of the water cycle. Ideally, a circular system is designed in a way that no resources are wasted. The recovered resources can provide an additional revenue stream for the utility or reduce the costs of operation and maintenance, making the utility more financially and environmentally sustainable (see [box 3.8](#) and [Annex A](#)). Resource recovery can be done at different scales and may include centralized and decentralized solutions. The right solution depends on the context (*Andersson et al. 2016; WWAP 2017; Chrispim, Scholz, and Nolasco 2020*). The World Bank's initiative "[Wastewater: from waste to resource](#)" published a report (*Rodriguez et al. 2020*) that explores the opportunities, market potential, and challenges to be overcome to recover resources from wastewater. WWAP (2017) also offers extensive guidance on recovering resources from wastewater. In fact, wastewater treatment plants (WWTPs) should be renamed as water resource recovery facilities (WRRFs), a term coined by the US (United States) Water Environment Federation. WRRFs can directly contribute to a circular economy by producing clean water, nutrients, renewable energy, and other valuable bio-based materials from wastewater (*WEF, 2020*).

Wastewater treatment for reuse is one solution to the world's water scarcity problems. Besides recovering water being wasted through the supply system (reducing NRW), wastewater can be treated and reused for multiple purposes. If planned with reuse in mind, wastewater can be treated to different quality levels and adapted to the requirements of each potential end user (a concept known as "fit for purpose"). Wastewater can be also sold untreated or partially treated, allowing the final user to treat the water to the desired standard (as in the case of Chennai, India - [box 3.1](#)). Treated wastewater can be used in industrial processes ([box 3.9](#), [box 3.13](#), *World Bank 2018e*); to cool power plants ([box 3.8](#)); irrigate crops (*World Bank 2018f*), public gardens, and parks; recharge aquifers ([box 3.15](#)); maintain environmental flows and restore ecosystems ([box 3.9](#)); or even to provide drinking water (directly or indirectly ([box 3.1](#))). Untreated wastewater is already being used in many parts of the world for irrigation purposes, with negative health and environmental consequences. Treating it for reuse avoids these negative consequences and frees scarce freshwater resources for other uses or for conservation. If sold, treated wastewater generates more revenue for the operator. World Bank

Box 3.8 Reusing treated wastewater for industrial purposes and to restore the aquifer as part of an integrated wastewater management plan in San Luis Potosi, Mexico.

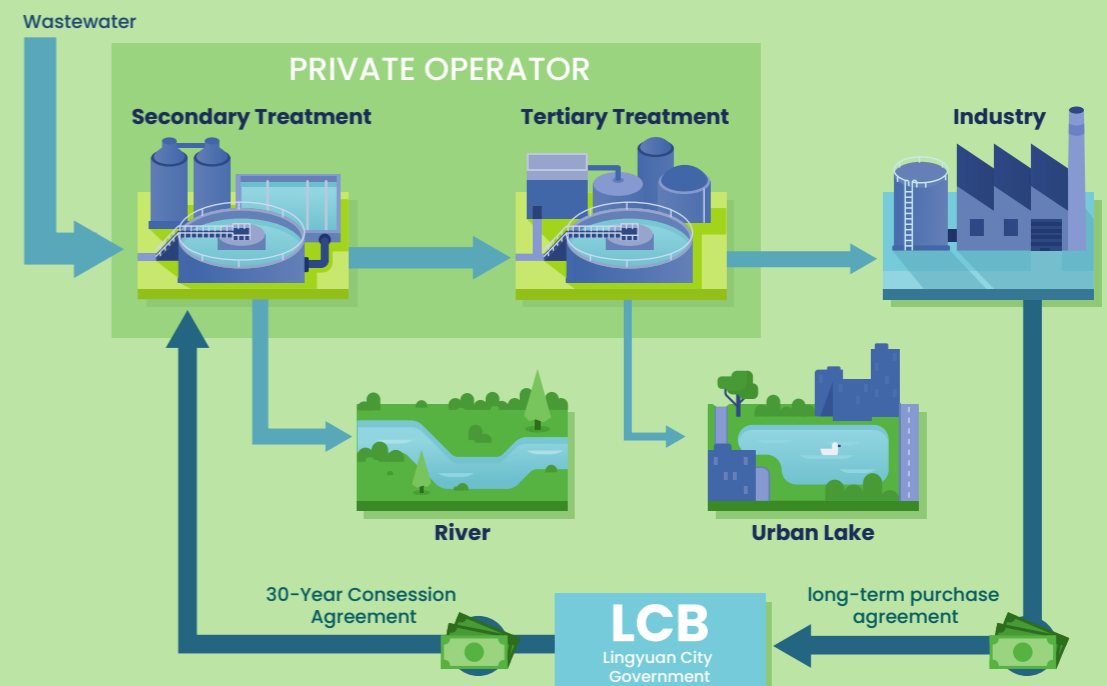
New water-reuse regulations and a creative project contract incentivized wastewater reuse in San Luis Potosi, Mexico. Instead of using fresh water, a power plant uses treated effluent from the nearby wastewater treatment plant (Tenorio) in its cooling towers. This wastewater is 33 percent cheaper for the power plant than groundwater and has resulted in savings of \$18 million for the power utility over six years. For the water utility, the additional revenue covers all operation and maintenance costs. The remaining treated wastewater is used for agricultural purposes and to restore nearby wetlands. Additionally, the scheme has reduced groundwater extractions by 48 million cubic meters in six years, restoring the aquifer. The extra revenue from water reuse helped attract the private sector to partially fund the capital costs under a public-private partnership agreement. Read the full case study [here](#).



Note: CFE = Comisión Federal de Electricidad (Federal Electricity Commission)
Source: World Bank 2018d.

Box 3.9 Reusing treated wastewater for industrial purposes and restoration of ecosystems in Lingyuan City, China.

To meet growing water demand resulting from rapid economic development and urbanization, the municipal government of Lingyuan City in China identified wastewater collection, treatment, and reuse as an opportunity to address the city's water scarcity and pollution problems while promoting circular economy principles. With the support of the World Bank and a supportive regulatory and policy environment, the city upgraded its wastewater treatment plant, increased the percentage of connected households to 90 percent, and built separate drainage systems for stormwater and wastewater. The city now sells part of its treated wastewater to industrial users, recovering operating costs and generating additional income for the municipality. The rest of the treated wastewater is used to replenish an urban lake to restore urban biodiversity and maintain the shallow aquifer around the lake. The project has also resulted in the replenishment of the aquifer, since industries no longer extract water from it. Read the full case study [here](#).



Source: World Bank 2021f.

(2018a) discusses treated wastewater reuse, focusing on water-scarce cities. And IWA (2018) illustrates the wastewater challenge and reuse opportunity in eight cities across the globe, presenting a reuse roadmap. The World Health Organization provides step-by-step guidelines to ensure the safe reuse of wastewater (WHO 2006). The World Bank is now collaborating with the International Finance Corporation on the “Re-Water” initiative, which aims to scale up IFC’s engagement in the municipal water and wastewater sectors and increase the number of bankable wastewater treatment and reuse projects in emerging markets.

The water cycle contains energy in different forms that can be harnessed and help cut operating costs and GHG emissions. Kinetic energy is found in flowing water, while thermal and chemical energy is found in organic matter found in wastewater. Microturbines deployed in the water system can produce electricity. Thermal energy can be recovered from water and wastewater using existing heat exchangers (pumps) to heat and cool residential and other buildings. Organic matter in wastewater can be captured as sludge and converted into biogas through anaerobic processes. Recovered biogas can be upgraded to natural gas-quality and sold to cities as gas for heating and cooking (World Bank 2019b), as vehicle fuel, or as fuel for a power plant; or it can be burned on site to cogenerate electricity and heat for the treatment plant, improving its energy efficiency. The heat can be used in the digester to dry sludge, while the power can be used to meet the plant’s electricity needs (box 3.10) or sold to the grid. All these energy sources in the water cycle are sustainable and green. Recovering and using them to generate power and heat/cooling reduces GHG emissions and other air pollutants to the extent they replace fossil fuels. In the process, they can qualify the plant for carbon credits. Renewable energy generation and energy efficiency investments are also explained in section 3.3.2, action 1.

Nutrients present in wastewater can be recovered and reused. Traditionally, sludge from wastewater treatment plants and fecal sludge from onsite sanitation solutions has been considered as a waste by-product to be disposed of at the lowest possible cost. But biosolids (sludge treated to levels that permit its beneficial use) can be used for many purposes by virtue of their nutrient content. For example, biosolids can be used to recover degraded

Box 3.10 Achieving 150 percent self-sufficiency by combining energy efficiency and energy generation measures in Aarhus, Denmark.

The water utility Aarhus Vand, Denmark, has implemented energy-saving technologies at its Marselisborg wastewater treatment plant, including an advanced SCADA control system, a new turbo compressor, and an optimized fine-bubble aeration system. These innovations have reduced electricity consumption by 25 percent, or approximately 1 GWh/year. At the same time, energy production has been improved with the installation of new, energy-efficient biogas engines (combined heat and power), yielding a gain in electricity production of another 1 GWh/year. A new heat exchanger was installed with the aim of selling surplus heat to the district grid—approximately 2 GWh/year. Between 2015 and 2019, the Marselisborg wastewater treatment plant produced an average of 9.6 MWh/year of energy and consumed an average of 6.4 MWh/year, equivalent to a net energy production of 150 percent. Most of the installed technologies have had a payback time of less than five years.

Source: Aarhusvand 2020.

land, as compost or fertilizer in agriculture, and as compost in gardens and golf courses (IEA Bioenergy 2015). Using biosolids for a fit purpose instead of disposing of them in landfills is not only more environmentally sustainable but also lowers or eliminates transport and landfill costs for the water utility while reducing GHG emissions. Nutrients such as phosphorous and nitrogen can also be extracted from wastewater to be used as fertilizer or for industrial processes (WWAP 2017; Waternet 2017, WEF 2020). Recycling and reusing essential nutrients in wastewater can lower the amount of fertilizer farmers must use, helping to mitigate water-quality issues, decreasing costs for farmers (Damania et al. 2019), and cutting GHG emissions. Box 3.11 contains an example of resource recovery from wastewater and fecal sludge.

Box 3.11 Making the most out of wastewater and fecal sludge. The case of Dakar, Senegal.

With its Sahelian climate, Senegal faces hot, arid conditions, compounded by variable rainfall and a changing climate that, without demand management, have come to threaten water security. Water stress at the national level has been intensified by droughts, floods, and threats to water quality. Meanwhile, Senegal's economic growth depends on water-intensive sectors like agriculture, mining, and tourism. In the face of competition and water stress, the Office National de l'Assainissement du Sénégal (ONAS) has been exploring several circular economy opportunities—and implementing some of them. Thanks to the co-location of wastewater treatment plants and fecal sludge treatment plants, ONAS has been able to recover resources that have led to (1) the sale and reuse of treated wastewater for irrigation purposes (horticulture) around the capital, Dakar; (2) the production of energy from biogas, saving 25 percent of energy costs; and (3) the recovery and sale of treated, dried sludge to farmers and for green areas. All these generate revenue, making services more sustainable, reliable, and resilient.

Source: World Bank 2021e.

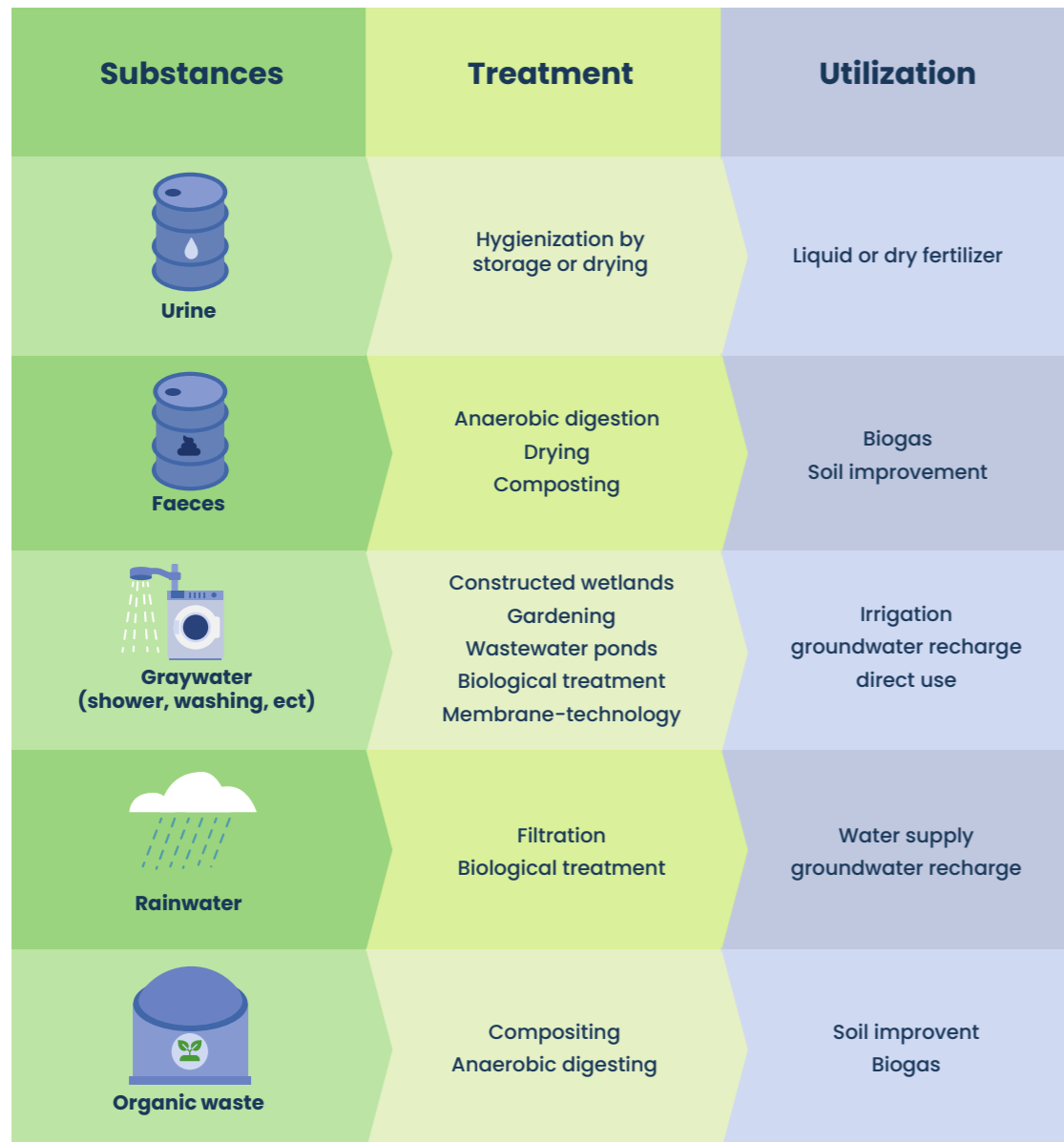
Water and nutrient reuse can be combined to irrigate and fertilize simultaneously. In some circumstances, it is not only possible but also advantageous to reuse wastewater together with some of its organic matter, thereby fertilizing and irrigating at the same time (*Andersson et al. 2016*). To be safe, wastewater must be treated. But depending on the end use, wastewater may require fewer treatment stages, lowering costs and leaving some of the nutrients in wastewater. For example, water-stabilization ponds offer a low-cost treatment that can bring pathogen and pollutant loads to within acceptable limits for irrigation (*Andersson et al. 2016*).

The potential to recover and reuse other materials is growing. Although not as well explored, other resources can also be recovered from water (*WEF*

2020). For example, sludge ash can be used in the construction industry to make bricks or tiles or incorporated as raw material for cement (*New Civil Engineer 2019*). There are also pilots to recover cellulose from wastewater. Underexploited resources like bioplastics, enzymes, metals, and minerals are also present in wastewater, but more work is needed to make their reclamation economically viable. On the supply side, limescale-forming deposits from calcite could be extracted from drinking water. Calcite-free water would be attractive to consumers, while extracted calcite could be used to make paper and plastic (*Waternet 2020*). The reuse of brine produced during desalination is also being explored, as it can become an environmental problem—and opportunity—as desalination capacity accelerates (*MIT News 2019*).

Separation of resources at the source offers opportunities to recover resources more efficiently and at a lower cost. If the different wastewater streams (urine, feces, graywater, rainwater, see [figure 3.3](#)) are kept separate, then more specific (and usually simpler) treatment can be applied for reuse (*Andersson et al. 2016*). Resource recovery consists of separating all the valuable resources from wastewater. If those resources are already separated, resource recovery becomes much simpler. For example, urine contains 88 percent of the nitrogen and 66 percent of the phosphorous found in human waste. It would be easier and more economical to recover these resources for use as fertilizer if urine were a separate waste stream (*WWAP 2017*). Graywater (from showering, washing, etc.) is usually less contaminated (compared with water with feces) and represents the larger volume of used water. Graywater usually requires less treatment to be reused than the combined wastewater stream, making reuse more economical. There are low- and high-tech solutions for source separation, but it is especially attractive in decentralized solutions (*WWAP 2017*). A good example is the case of El Alto in Bolivia, where urine, feces and graywater are separated at the household level (*Andersson et al. 2016*). The urine is reused as liquid fertilizer, composted feces are reused as solid fertilizer, and graywater is reused after treatment to replenish wetlands and irrigate greenspaces.

Figure 3.3 Waste separation and possible treatment and use options



Source: WWAP 2017.

3.3.3 Actions to preserve and regenerate natural systems

This outcome requires three actions: (1) incorporating nature-based solutions; (2) restoring degraded land and watersheds; and (3) recharging and managing aquifers.

Action 1. Incorporate nature-based solutions

Integrating nature into mainstream infrastructure systems can lower costs and contribute to more sustainable and resilient water systems while protecting ecosystems and mitigating climate change. Nature-based solutions are “actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits” (IUCN 2016). Natural systems have long been recognized for their ability to deliver or contribute to core infrastructure services while delivering many local ecological and socioeconomic benefits (Chausson et al. 2020). Emerging technology such as earth-based observations and advanced modeling make it even more cost effective and easier to design and implement green infrastructure (Browder et al. 2019). Combining green (natural) with gray (traditional) infrastructure offers an opportunity to deliver services at a lower cost while at the same time reducing risks related to extreme events, reducing pollution, protecting the ecosystems and contributing to the reduction of GHG emissions. Green infrastructure can boost infrastructure system resilience with its natural adaptive and regenerative capacity (Browder et al. 2019). Green infrastructure such as wetlands and forests act as carbon sinks, which can contribute toward climate goals if managed and protected correctly (Chausson et al. 2020; Seddon et al. 2021; Girardin et al. 2021).

Even so, nature-based solutions are not always considered when planning or building new infrastructure, and their benefits are often overlooked—sometimes because they are difficult to quantify. But sufficient evidence now exists to prove that nature-based solutions can meet the infrastructure investment gap in a cost-effective manner while benefiting local communities and the environment. For that reason it is crucial to assess and analyze their potential when preparing new projects.

Nature-based solutions need to be considered as a solution or complementary solution in all the WICER elements. Natural systems such as forests, floodplains, wetlands, urban parks, and soils can contribute to clean and reliable water supply, protect against floods and droughts and help restore degraded ecosystems while at the same time offsetting emissions of GHGs. For example, urban wetlands, green roofs, and green areas can diminish the

risk of floods (see [box 3.12](#) and Soz et al. 2016; World Bank 2019c; Oral et al. 2020), mitigate air pollution, provide recreational and health benefits, and help sequester carbon, contributing to climate goals (Seddon et al. 2021). Protecting and restoring natural ecosystems in upper catchments can contribute to climate-change adaptation by protecting communities and infrastructure from flooding and erosion, while also reducing costs for water treatment, contributing to carbon sequestration, and protecting biodiversity (Browder et al. 2019; Seddon et al. 2021). Rainwater harvesting and aquifer recharge can protect cities against droughts (Browder et al. 2019). Wetland and riparian ecosystems can provide wastewater and storm runoff treatment that can reduce the costs of investment in wastewater treatment facilities (UNEP 2015), provided these ecosystems are healthy, the pollutant load (and types of contaminants) in the effluent is regulated, and the ecosystem's capacity to assimilate pollution is not exceeded (WWAP 2017). Nature-based solutions can also enhance or enable resource recovery and the restoration

Box 3.12 Conserving wetlands to enhance urban flood control systems in Colombo, Sri Lanka.

In recent decades, rapid urbanization in the Colombo metropolitan area in Sri Lanka has caused degradation of the region's wetlands, which are essential for storing water during heavy rains. At the same time, climate change and sea-level rise are exacerbating the impacts of the region's vulnerability to flooding. Stormwater-management strategies in the city had conventionally been "gray" based. The World Bank's Metro Colombo Urban Development Project identified and implemented a mixture of green and gray infrastructure to reduce flood risks, improve drainage, and create recreation opportunities in the metropolitan region. Urban wetlands and flood-retention parks complement the gray stormwater system by allowing for the slow infiltration of stormwater into the ground, decreasing the volume of water that moves through the gray system.

Source: Browder et al. 2019.

of ecosystem services in urban areas (Kisser et al. 2020). For example, constructed wetlands offer effective, reliable, robust, and low-cost wastewater treatment and nutrient recovery (Kisser et al. 2020).

In most cases, combining green infrastructure with traditional gray infrastructure—such as dams, levees, reservoirs, treatment systems, and pipes—can provide the next generation of solutions that enhance system performance and better protect communities ([table 3.1](#)) (Browder et al. 2019). The mix of green and gray solutions must be appropriate for a region's socioeconomic status, development challenges, and the ecological context. The World Bank report "[Integrating Green and Gray: Creating Next Generation Infrastructure](#)" (Browder et al. 2019) offers guidance to developing country service providers and their partners on how to integrate natural systems into their infrastructure programs and provides examples of successful projects.

Action 2. Restore degraded land and watersheds

Wastewater needs to be treated, especially in heavily populated areas.

Currently most of the wastewater generated in the world is still released into the environment without treatment, polluting ecosystems and impacting human health. The problem is compounded in densely populated areas. Ideally, reversing this dire situation would be done in an integrated way by exploring nature-based solutions in combination with wastewater treatments plants, centralized and decentralized solutions, and interventions at the basin level that recover and reuse resources from wastewater.

Prevention or reduction of pollution loads must occur at the source.

Whenever possible, wastewater prevention and minimization should take priority over traditional end-of-pipe treatment (WWAP 2017). For example, regulations can prohibit or limit certain contaminants—like toxic chemicals that threaten human health and the environment—to keep them out of wastewater streams. Interventions to prevent pollution are usually much cheaper than reactive and remedial actions. Pollutant discharges to waterways need to be reported and monitored so interventions can be properly designed. Economic instruments such as discharge fees could also be implemented

Table 3.1 How green and gray infrastructure can coexist

Service	Gray infrastructure components	Examples of green infrastructure components and their function
Water supply and sanitation	Reservoirs, treatment plants, pipe network	Watersheds: Improve source water quality and thereby reduce treatment requirements
		Wetlands: Filter wastewater effluent and thereby reduce wastewater treatment requirements
Hydropower	Reservoirs and power plants	Watersheds: Reduce sediment inflows and extend life of reservoirs and power plants
Coastal flood protection	Embankments, groynes, sluice gates	Mangrove forests: Decrease wave energy and storm surges and thereby reduce embankment requirements
Urban flood protection	Storm drains, pumps, outfalls	Urban flood retention areas: Store stormwater and thereby reduce drain and pump requirements
River flood protection	Embankments, sluice gates, pump stations	River floodplains: Store flood waters and thereby reduce embankment requirements
Agriculture irrigation and drainage	Barrages/dams, irrigation and drainage canals	Agriculture soils: Increase soil water storage capacity and reduce irrigation requirements

Source: Browder et al. 2019.

to control and reduce pollution (Blackman 2005). It is vital to understand the absorptive capacity of river streams so treatment plants can be designed and sited to maximize treatment and the quality of water bodies.

Industrial discharges must be addressed. Inadequate legislation, enforcement, regulation, and monitoring of industrial discharges result in pollutants being discharged, untreated, into waterways or left to already overburdened wastewater treatment plants. In cities where industries generate copious amounts of wastewater, authorities must enforce programs for pretreatment and control of industrial pollutants. These are essential for curtailing the risks of chemical pollutants and ensuring the successful operation of wastewater treatment plants and effluent reuse irrigation schemes. Industries should either pay for treatment (in USD per kg treated, reflecting the true costs of cleanup) or reduce their discharges to set concentrations through in-house treatment. In some cases, strict zero-discharge policies for industries could incentivize industrial reuse and circular economy solutions. Economic instruments can play a critical role in incentivizing the “polluter pays” principle. Under the right conditions, leveraging the industrial sector could finance wastewater treatment and restoration projects (box 3.13).

Degraded land and watersheds can be restored using resources recovered from wastewater. The nutrients, organic carbon, and water found in wastewater can be used to restore and remediate ecosystems. They can also bolster ecosystem services in ways that bring major benefits for economies and communities (WWAP 2017). Partially treated wastewater can be used to recharge depleted groundwater and aquifers with various beneficial end uses or to restore wetlands, lakes, and other watersheds. In fact, in water-scarce areas, treated wastewater has even been used to create artificial lakes or wetlands and to ensure that natural wetlands maintain healthy water levels even during periods of drought (WWAP 2017). Biosolids can be used to restore degraded land and to support reforestation. Treated wastewater allows environmental flows to be respected and maximized, ensuring that ecosystems are not adversely affected by water withdrawals or wastewater discharges, and that fisheries and other aquatic ecosystems thrive.

Urban expansion must preserve ecosystems and protect water resources. Permeable surfaces such as natural ground and green spaces need to be included in city planning to abate urban runoff and flooding. Forested areas and wetlands absorb excessive “nutrient loads” that would otherwise enter streams and groundwater. By protecting these natural buffers, or creating

Box 3.13 A win-win partnership between a water utility and industry to treat wastewater and restore a river in Arequipa, Peru

Cerro Verde, a mining company near Arequipa, Peru, was planning a large-scale expansion that required additional water supply. But increasing the water supply would prove difficult in view of the region's aridity and rising population. Meanwhile, the city's insufficient wastewater treatment capacity was contributing to the increasing pollution of the Chili River.

After discussions with regional and local governments, development agencies, and civil leaders, Cerro Verde and SEDAPAR, the municipal water utility, decided, under a PPP agreement, that the mining company would be responsible for designing, financing, building, and operating a wastewater treatment plant to handle about 95 percent of the city's wastewater. In exchange, Cerro Verde could use some of the treated water for its mining processes and discharge the rest into the river to be used downstream by farmers.

This win-win solution has allowed the mine to expand its operations, while the municipality has saved money (building and operating the wastewater treatment plant would have cost the city more than USD 335 million). The Chili River, meanwhile, has largely recovered, to the benefit of the city and its residents. Read the full case study [here](#).

Source: World Bank 2019d.

them artificially, municipalities can shield waterways from potential pollutants (*Damania et al. 2019*). Land-use policies must preserve forests, wetlands, and natural biomass—and create green spaces where needed—particularly near high-value waterways (*Damania et al. 2019*). These practices not only make systems more resilient; they also help cities adapt to climate change. Moreover, ecosystems that are protected and carefully managed can also store carbon and help to mitigate climate change (*Girardin et al. 2021*).

Natural capital is preserved, protected and restored, in recognition of its full value. Protected watersheds and related ecosystems lower the costs of providing services (for example, lowering treatment costs) and benefit people and their environment. Preserving and restoring natural capital makes economic sense (see section 3.3.3, action 1). [Box 3.14](#) describes how the State of Espirito Santo has implemented nature-based solutions to protect its water source.

Box 3.14 Targeted green infrastructure for source-water protection. The case of Espirito Santo, Brazil.

After investing for several decades in traditional gray infrastructure to provide potable water to its residents, the Greater Vitória Metropolitan Region in the State of Espirito Santo, Brazil, was contending with erosion and sediment pollution, which were spoiling the watershed. Working with the World Bank, the state identified nature-based upstream solutions. The Watershed Management and Restoration of Forest Cover project implemented a payment-for-ecosystem services (PES) scheme. At the cost of USD 16.2 million, the project paid upstream landowners to reforest, conserve, restore, and manage their land in ways that curbed erosion and kept sediment loads from being deposited into the watershed. The project also included a USD 7.4 million pilot project to reduce the silt loads hampering operations of the water treatment plant. This is an example of a holistic approach that combined reforestation with better land management. The estimated economic benefits of these interventions range from USD 13 million to USD 18 million, with an internal rate of return ranging from 12.7 percent to 16.8 percent. Estimates indicate that the water utility, CESAN (Companhia Espírito Santense de Saneamento), will save a total of R\$ 15.5 million over 30 years in avoided costs for new filtering equipment and maintenance. Landowners benefit from the PES, from regulatory compliance, and from higher income gained through productive practices. The port of Vitória downstream avoids the need for costly new dredging operations.

Source: Browder et al. 2019.

Action 3. Recharge and manage aquifers

Managing, recharging, and preserving aquifers properly is crucial for long-term water security and resilience because groundwater is more likely to be compatible with a variable and changing climate. Aquifers can store large volumes of water. They also react more slowly to changes in rainfall and temperature than does surface water. If managed well, aquifers can be resilient buffers during long periods of water stress (*Clifton et al. 2010*). Complementing surface with groundwater makes the water supply system more resilient to variability and water scarcity, since aquifers respond to stress on a different time scale (*World Bank 2018a*). To manage aquifers correctly, utilities need to monitor their water levels; regulate and set limits on extraction rates; and ensure that aquifers are not polluted. A World Bank report "[Water and Climate Change: Impacts on Groundwater Resources and Adaptation Options](#)" (*Clifton et al. 2010*) discusses the impacts of climate change on groundwater and adaptation options.

Recharged and restored, aquifers can become a sustainable source of water supply for cities. When developing an integrated approach to urban water security, cities should always consider aquifers instead of looking for alternatives. Given their potential to store large amounts of water, aquifer recharge is an economical alternative compared to expanding water production and surface storage infrastructure, or transporting water from distant reservoirs through massive conveyance infrastructure (*World Bank 2018a*).

Managing aquifer recharge (including building infrastructure and/or modifying the landscape to boost groundwater recharge) is one of the most promising adaptation opportunities, especially in developing countries (Clifton et al. 2010). Besides storing water for future use, aquifer recharge can stabilize or recover groundwater, manage saline intrusion or land subsidence, and enable reuse of wastewater or stormwater (*Clifton et al. 2010*). Moreover, aquifer recharge can be used as part of the nature-based solutions strategy because natural "soil passage"—such as riverbank filtration—can lower costs for treatment chemicals and energy (*Sharma and Amy 2010*). [Box 3.15](#) sum-

marizes the North Gazan experience with a wastewater treatment plant that recovers and reuses treated wastewater to replenish the aquifer and irrigate agricultural land in a water-scarce and conflictual environment.

Box 3.15 Wastewater treatment to recharge aquifers and reuse water in a context of water scarcity and conflict. The case of North Gaza.

Gaza is among the most water-stressed places in the world. Its main source of water is groundwater. With its rising population, Gaza and its wastewater treatment plants were further strained when approximately 1.5 million cubic meters of wastewater overflowed from an existing plant into the surrounding sand dunes, where it formed a 30-hectare lake. The wastewater eventually seeped into the aquifer, exposing the population to waterborne diseases and to the threat of floods of sewage. In 2004, the North Gaza Emergency Sewage Treatment Project, supported by the World Bank, addressed these problems through the construction of a plant that increased wastewater treatment capacity and then recovered and reused treated water to replenish the aquifer and irrigate agricultural land. The project depolluted the aquifer and improved sanitation services and health outcomes for residents. The operating costs of this solution were too high, however, to achieve cost recovery, in part due to the high cost of electricity. In the end, this led to a complementary solution—now being implemented—using solar panels together with biogas to cover the project's electricity needs. This case shows that it is crucial to choose technologies suitable for the local conditions, and that the costs of operation and maintenance—and the capacity to cover them—are as important as capital costs, if not more so. Read the full case study [here](#).

Source: World Bank 2021g.

3.4 CROSS-CUTTING ISSUES

The following four cross-cutting issues emerge as important factors in the successful adoption of the WICER framework: (1) policy, institutions, and regulations; (2) demand management; (3) digitalization; and (4) inclusiveness.

Cross-cutting issue 1. An enabling policy, institutional, and regulatory (PIR) environment is needed to achieve full circularity and resilience in urban water.

Even when progress is made at the utility or city level, regulatory and policy limitations may persist. For example, regulations should address resources recovered from wastewater. If they are nonexistent, lax, or prohibitive, municipalities may not develop projects or create markets for byproducts (*World Bank 2019e; Rodriguez et al. 2020*). If tariffs for freshwater or energy are too low, few entities will make efficient use of water, reuse treated wastewater, or generate energy in wastewater treatment plants. If wastewater discharge fees or pollution charges are too low, or enforcement is lax, industries have no incentives to minimize water pollution.

Water supply and sanitation utilities and cities cannot embark on this challenge alone. An enabling environment must be created to provide the right incentives to mainstream circular economy and resilience. Most of the case studies presented in this report showcase one or more aspects of the WICER framework (see also [Annex A](#)). All stem either from strong government support or a favorable environment. As noted above, an enabling PIR environment should encourage the use of recovered resources and enable a market for those resources. It should incentivize interventions in water and energy efficiency and foster renewable energy and nature-based solutions, while protecting natural resources. An enabling environment should also use the right economic and policy instruments to set adequate tariffs and prices so that circular alternatives can compete with traditional, linear alternatives, which frequently benefit from subsidies, externalities, and other market distortions (*Enriquez, Sánchez-Triana, and López 2021*). Clear environmental

regulations (on water rights, discharge standards, and pollution charges) should foster investments in pollution control and the regeneration of natural systems.

Institutional and regulatory capacity needs to be strengthened to enforce the regulatory frameworks and promote the adoption of circular economy approaches (*Caffera 2011; Blackman 2018*). Enforcement of regulations is indispensable and can take place only with adequately resourced agencies, administrative procedures for sanctions, and monitoring programs. Coordination with other sectors is also vital, especially with large water users or potential users of recovered resources such as agriculture and industry. Clarity about institutional functions is a great help. So is clarity regarding incentives for collaboration within government—specifying with what sectors and at which levels. The WICER framework can be used across sectors to identify synergies and collaborations. The framework can also be used as part of the PIR global initiative by the World Bank Water Global Practice.

Cross-cutting issue 2. Demand management is integral to WICER

The principles of circular economy include not only minimizing waste and recovering resources but also avoiding the misuse of precious natural resources. The first aim should be to minimize water use. It is unsustainable to invest and build infrastructure for water production and supply if water is being wasted. Actions and policies to increase water supply need to be paired with actions and policies that manage demand. Water conservation policies are usually implemented at the government level, and water supply and sanitation utilities cannot directly control water demand. But they can encourage responsible water use with awareness-raising and communication campaigns, monetary incentives, setting the right tariffs to recover full costs, progressive subsidies, and new water meters, among other measures (*World Bank 2018a*). Namibia's capital, Windhoek, has been implementing measures to become more resilient by diversifying supply, reusing wastewater, and other means. As part of those efforts, the city has included constant media communication with customers to maintain a low per capita consumption and to raise awareness about local drought conditions (*World Bank 2018a*).

Water needs to be priced correctly, reflecting the local opportunity cost of water use, when possible. An appropriate water tariff structure (which also ensures affordability for the poor) incentivizes the efficient use of water and makes wastewater reuse financially sustainable. For example, it is important not to set the freshwater tariffs too low, especially for industries and businesses, so there are incentives to reuse treated wastewater.

Reducing water consumption also reduces the amount of wastewater to be treated. By investing in water conservation measures, utilities can increase water availability without having to build more infrastructure, saving the costs of water supply and treatment and wastewater treatment and disposal (*WWAP 2017*).

Cross-cutting issue 3. The potential of digitalization

Digital solutions can contribute to greater resilience and better water supply and sanitation services. Digital solutions offer new ways to optimize, manage, and conserve water. Worldwide, the water sector is embracing digital solutions so it can better respond to customer demands and growing global pressures. Remote sensing, smart meters, big data, advanced simulation tools, and artificial intelligence enable utilities to manage and optimize a diversified water-supply portfolio. Digital solutions also help extend and improve the quality of water resources, expand infrastructure life cycles, optimize operations and maintenance, increase energy efficiency, reduce NRW, and help prepare for a changing environment or potential crisis (*IWA n.d.*). For example, hydrologic models paired with monitoring devices have allowed the water utility in Durban, South Africa, to optimize storage levels in dams and reservoirs, protecting its customers from scarcity events (*IWA n.d.*). Digital solutions in water distribution networks can detect pipe bursts in real time, helping reduce NRW (*IWA 2020*). The incorporation of external data sets such as weather and traffic data can help a utility adapt its operations to changing climate and demographics. Digital customer-engagement programs and analytic tools improve customer service and increase revenue collection, for example, by allowing customers to pay through a mobile phone app. In

fact, digital solutions can be integrated in every aspect of the water cycle; as such, they should be considered as an additional tool in every WICER action to improve efficiency and sustainability. The uptake of digitalization, however, requires data collection and monitoring and changes in organizational culture. Digitalization should therefore be seen as a journey, not an end in itself (*IWA n.d.*).

Cross-cutting issue 4. Inclusiveness—so all can reap the benefits of circular and resilient water systems

It is imperative that all WICER interventions be inclusive. Everyone must benefit. Stakeholder discussions need to include every group, considering a range of solutions tailored to the realities of cities in developing countries. By focusing on service provision and its enabling environment, utilities and municipalities can avoid the trap of building infrastructure in isolation from social needs and realities (*World Bank n.d.; Misra and Kingdom 2019*). A fully circular and resilient system should ensure that everyone has access to water services and is included in resiliency plans. At the same time, many elements of WICER already contribute to more inclusive services. For example, if less water is wasted through NRW, more people can be given access to water, as several of the case studies show. Moreover, recovered resources can offer an additional revenue stream, making the utility more financially sustainable and allowing subsidies to be redirected where they are most needed. The key issue (especially if public-private partnerships are involved) is to ensure that projects and contracts are well designed to address social needs.

3.5 PROMOTING AN INTEGRATED APPROACH TO CIRCULARITY

As we have seen, the WICER framework is a useful tool for cities and utilities seeking to incorporate circularity into their plans, strategies, designs, and operational practices. An integrated approach to circularity is facilitated by the natural interconnectedness of a number of WICER elements. For example, reducing NRW generally improves energy efficiency. Nature-based solutions

can help recover resources and restore degraded lands and watersheds. Some of the examples in the report highlight how WICER actions have been implemented in coordinated fashion to tackle several problems at once. Cities and urban water supply and sanitation utilities can incorporate the WICER approach into master plans, strategies, and long-term investments. New projects are best designed and planned with circularity in mind to ensure that resources are not wasted. The WICER framework can also be used to engage other sectors, especially with potential end users such as agriculture and industry. [Box 3.16](#) highlights some examples of water supply and sanitation utilities that have incorporated circular economy and resilience concepts into their business plans and strategies.

Box 3.16 Two utilities that are taking an integrated approach to circular economy principles

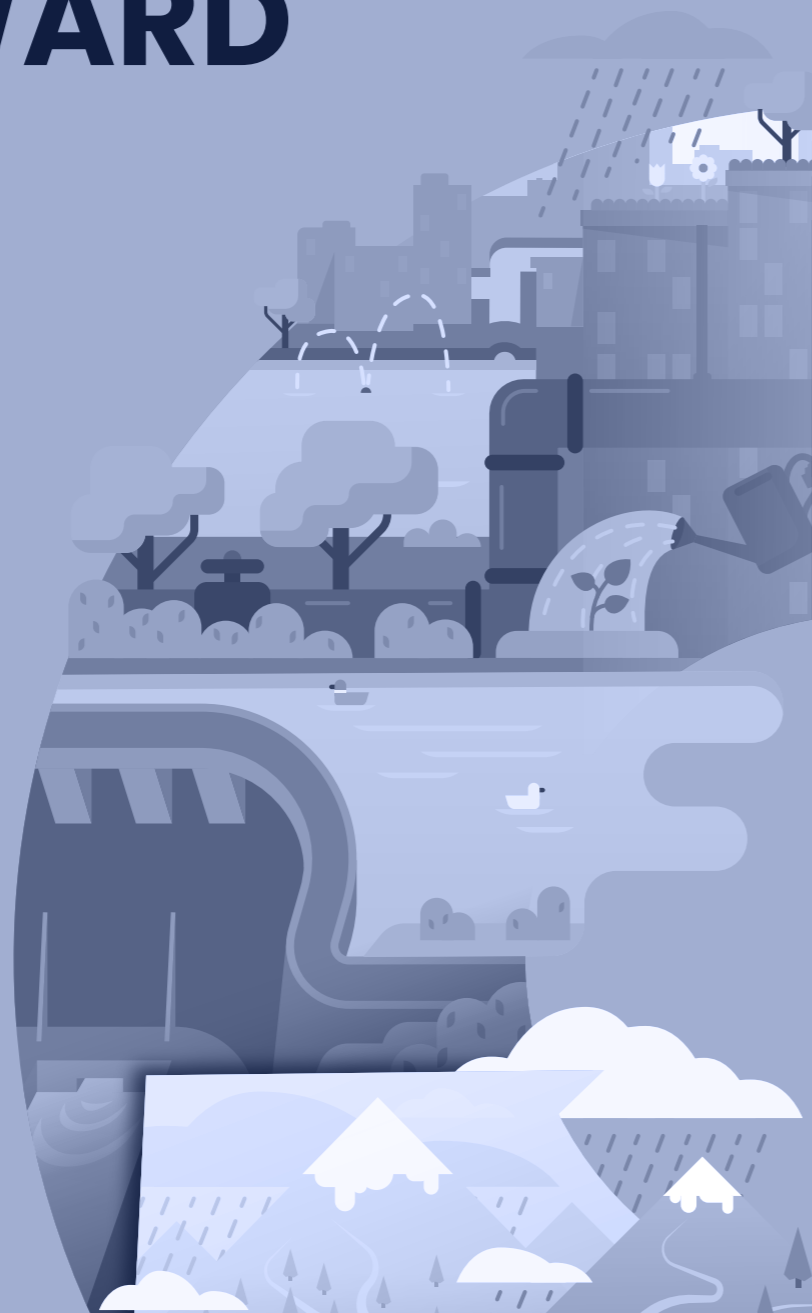
Aguas Andinas of Chile and the biofactory concept. Aguas Andinas is transforming its wastewater treatment plants into “biofactories”—which Aguas Andinas’s CEO defines as “business units that do not generate waste, have no environmental impacts, and do not consume fossil energy but produce their own energy to operate.” The biofactory project was launched in 2017 to pioneer circular wastewater treatment solutions in Santiago and in the sector more broadly. With this new concept, Aguas Andinas is promoting a paradigm change, moving from treatment to managing resources, from a linear to a circular approach in which biofactories extract and supply new, valuable resources, such as electricity, natural gas, agricultural fertilizer, or clean water from what used to be considered waste. The company’s goal is to be zero-waste, energy self-sufficient, and carbon neutral in its three wastewater treatment plants in Santiago by 2022. Read the full case study [here](#).

Águas de Portugal and circular economy principles in the long-term strategies of urban utilities. Presented with a favorable political and regulatory environment,

Águas de Portugal (AdP) seized the opportunity to carry out a paradigm shift by developing a strategic framework to become circular and resilient. The framework was developed through an open and inclusive internal dialogue involving everyone in the company. The process also engaged stakeholders from other sectors and from the government. AdP also created a new subcompany to assume responsibility not only for driving the change process but also for identifying and developing new circular business models. Under the circular economy pillar of the strategic framework, AdP developed several actions: i) Under its Energy Neutrality Plan, AdP intends to be energy neutral by 2030 through energy-efficiency measures and self-generated renewable energy; ii) Under its Action Plan for Water Reuse, the company aims to reuse 15 percent of wastewater by 2030 with a fit-for-purpose approach; and iii) Under its Sludge Strategic Plan AdP aims to cut the volume of generated biosolids in half, lowering management costs by 45 percent (for annual savings of EUR 7 million) and focusing on identifying and enabling various business models that reuse biosolids, recover materials from sludge, and generate additional revenue streams. Read the full case study [here](#).

Source: World Bank 2019b, 2021h.

CONCLUSIONS AND WAY FORWARD



This report aims to promote a common understanding on the definition and applications of circular economy principles and resilience in the urban water sector. Using the proposed WICER framework, it defines key elements in a circular and resilient urban water system, while making the case for implementing such a system. The report also provides examples, case studies, guidelines, and other relevant material to guide practitioners in implementing the WICER principles in policy, regulation, plans, investments, and designs related to water supply and sanitation systems. The report sets out to demystify circular economy by showing that both high-income and low-income countries can benefit from it, and that many water supply and sanitation utilities are already implementing solutions that contribute to an integrated WICER system. This report has framed these solutions under a comprehensive conceptual umbrella. They are not “all or nothing” propositions, and cities should not be reluctant to implement them—especially in view of the benefits they can bring.

Applying the WICER framework provides environmental benefits as well as social, economic, and financial benefits. It is also a condition for achieving several of the global Sustainable Development Goals (SDGs). A circular and resilient water system fosters the sustainable and responsible use of water, energy, and other resources; reduces waste and pollution (such as greenhouse gas emissions and wastewater); and delivers resilient and inclusive water services, ultimately improving livelihoods while preserving water resources and the environment. Implementing the framework is also in line with the climate agenda and can be an ally in achieving several climate-related goals.

At the same time, examples provided in the report (and in [Annex A](#)) show that investments in circular and resilient systems yield economic and financial payoffs. If projects are designed correctly, a circular and resilient water system reduces inefficiencies, recovers resources, uses nature-based solutions, reuses materials, and results in lower capital and operating costs and more revenue. These benefits make the system more financially robust—sometimes with

remarkably high returns on investment—and environmentally sustainable. Moreover, if all potential externalities and systemic effects are correctly accounted for, the economic outcomes of a circular and resilient system can be even greater. For example, the amenity value from available and resilient public services raises housing prices, while sustainable water-related services (supply, sanitation, and hygiene) have well-known benefits for human capital.

The WICER framework could help utilities attract private sector finance.

Applying the WICER framework can increase the operational and capital efficiency of utilities by, for example, creating new revenue streams and business models. These would in turn lower losses and costs, allowing utilities to leverage alternative financing mechanisms, such as those available to the private sector. Improved services can make utilities more sustainable and lower the financial risk posed by infrastructure projects. Improved rates of return create a more attractive environment for the private sector. Under the right conditions, the private sector can even be induced to cover most or all capital costs and risks (Box 3.13).

But cities and water utilities will not achieve a fully circular and resilient water system without the proper policy, institutional, and regulatory framework in place. Reforms are also needed in other sectors, like agriculture, energy, industry, environment—and at the river basin, and household levels. The WICER framework can be adapted and raised to the policy level in government and deployed to assemble relevant stakeholders for collaborative work across sectors.

To avoid being locked into linear and inefficient systems, low- and middle-income countries should consider applying the WICER framework to design and implement circular and resilient water systems from the outset.

This report sets out an array of options and opportunities appropriate for different budgets and capacities. Service providers and their partners must prioritize interventions and investments that maximize impact under given conditions. The WICER framework can be used in workshops with a city's major stakeholders—utilities, municipal government, city planners, and potential end users of water and recovered resources. WICER can and should be used in a cross-sectoral or multisectoral approach to guide assessments and identify

possible interventions. Then, the urban water sector should be evaluated through the WICER lens to calculate costs and benefits and prioritize interventions.

Using the WICER framework, the World Bank can support and collaborate with countries and cities to create a long-term plan that suits the community. Analyzed through the WICER lenses of circularity and resilience, plans, projects, and investments can reveal their synergies and opportunities. For example, if a utility is planning to build a wastewater treatment plant, the WICER framework can identify complementary solutions (such as upstream, nature-based investments and resource recovery-and-reuse) that will make the project more sustainable financially, environmentally, and socially. Supporting client countries design, plan and invest in water projects based on circularity and resilience contributes to the achievement of the SDGs.

Follow-up activities and future work to advance the WICER framework have been identified through consultations with World Bank task teams and clients:

- **WICER for decision making.** A how-to guide could operationalize circularity and resilience concepts, identify tradeoffs, and rank interventions and investments suitable for local contexts, different entry points, and key counterparts. This guide could also include a menu of financial instruments for WICER interventions.
- **Economic and financial analysis and prioritization of investments using the WICER framework.** To attract funding for WICER projects, the how-to guide could be complemented with future work on the financial and economic benefits of the WICER approach versus a linear system. Decision makers need to know that a circular and resilient future is not only essential—it is also the most efficient way to achieve the SDGs.
- **Policy, regulatory and institutional environment for WICER:** Using the existing framework for PIR by the Water Global Practice, the key enabling PIR conditions could be assessed, identifying necessary interventions and economic instruments to foster WICER interventions.

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ANNEX A

LIST OF WORLD BANK RESOURCES BY OUTCOME AND ACTION

Outcome 1 Deliver resilient and inclusive services

Action 1 Diversify supply sources and manage and optimize water resources and storage

World Bank. 2016. *Mainstreaming Water Resources Management in Urban Projects: Taking an Integrated Urban Water Management Approach*. Washington, DC: World Bank. <http://hdl.handle.net/10986/29613>.

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World Bank. 2018. “Wastewater: From Waste to Resource—The Case of Durban, South Africa.” World Bank, Washington, DC. <https://openknowledge.worldbank.org/handle/10986/29489>.

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World Bank. 2021. *Water in Circular Economy and Resilience (WICER): The Case of Chennai, India: Recovering Water and Energy from Wastewater*. Washington, DC: World Bank.

Action 2 Maximize the use of existing infrastructure

World Bank. 2019. “Wastewater: From Waste to Resource: Background Paper I: Efficient and Effective Management of Water Resource Recovery Facilities.” World Bank, Washington, DC.

Case studies

World Bank. 2021. *Water in Circular Economy and Resilience (WICER): The Case of São Paulo, Brazil: Optimizing Wastewater Treatment Plants in the Metropolitan Area of São Paulo*. Washington, DC: World Bank.

Action 3 Plan and invest for climate and nonclimate uncertainties

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Outcome 2 Design out waste and pollution

Action 1 Be energy efficient and use renewable energy

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ANNEX B

SUMMARY OF MAIN REFERENCES ON WATER AND THE CIRCULAR ECONOMY

Ellen MacArthur Foundation, ARUP, and Antea Group. 2018. "Water and Circular Economy."

This white paper explores the relationship between the principles of the circular economy and sustainable water management, identifying the opportunities that are offered through applying circular economy principles to water systems. [Table B.1](#), excerpted from the white paper with a few emen-

Table B.1 How circular economy principles apply to water systems

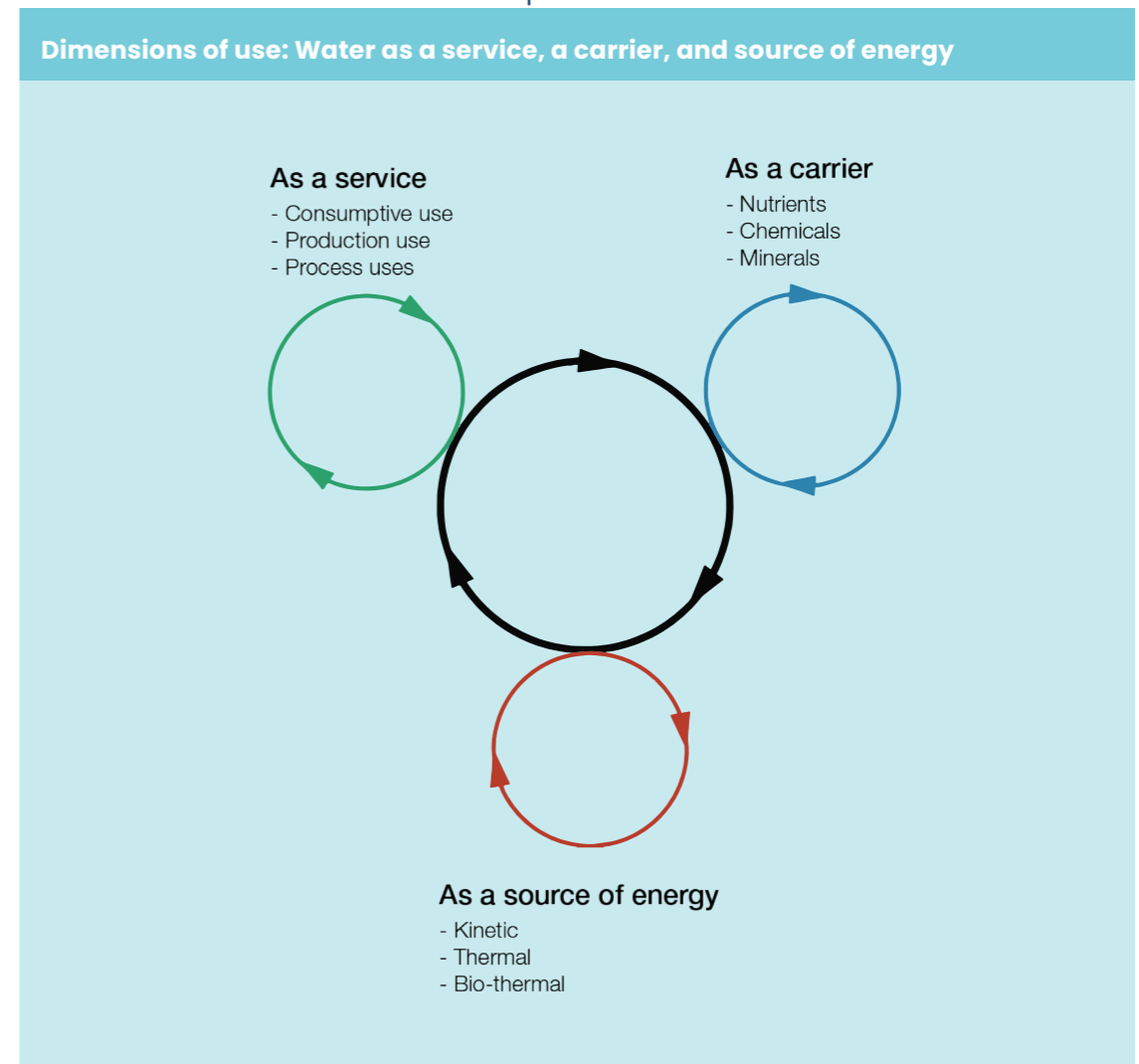
Circular economy principles	Gray infrastructure components
Design out waste and externalities	<ul style="list-style-type: none"> Optimize the amount of energy, minerals, and chemicals used in the operation of water systems in concert with other systems. Optimize consumptive use of water within a sub-basin in relation to adjacent sub-basins (e.g., for agriculture or evaporative cooling). Implement measures or solutions that deliver the same outcome without using water.
Keep resources in use	<ul style="list-style-type: none"> Optimize resource yields (water use & reuse, energy, minerals, and chemicals) within water systems. Optimize energy or resource extraction from the water system and maximize their reuse. Optimize value generated in the interfaces of the water system with other systems.
Regenerate natural systems	<ul style="list-style-type: none"> Maximize environmental flows by reducing consumptive and non-consumptive uses of water. Preserve and enhance the natural capital (e.g., river restoration, pollution prevention, quality of effluent, etc.). Ensure minimum disruption to natural water systems from human interactions and use.

Source: Ellen MacArthur Foundation, ARUP, and Antea Group 2018.

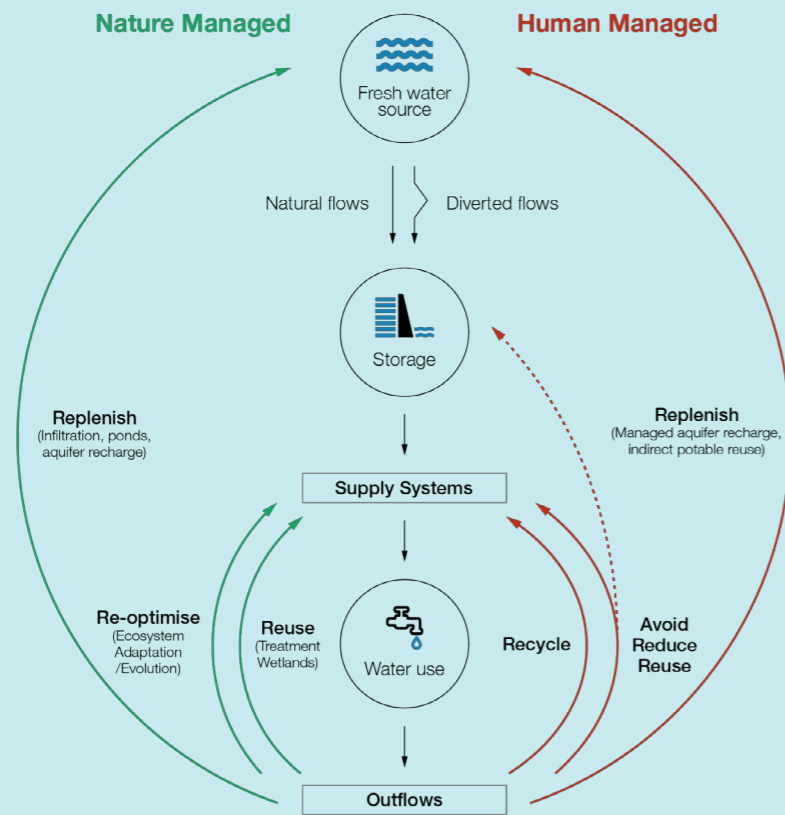
dations, describes how the circular economy principles relate and can be applied to water systems.

The paper also describes water systems from four different perspectives to establish a common understanding between circular economy and water cycle experts, and explores the opportunities presented by the circular economy from each perspective.

Table B.2 How circular economy principles benefit water systems from four perspectives



Systems perspective



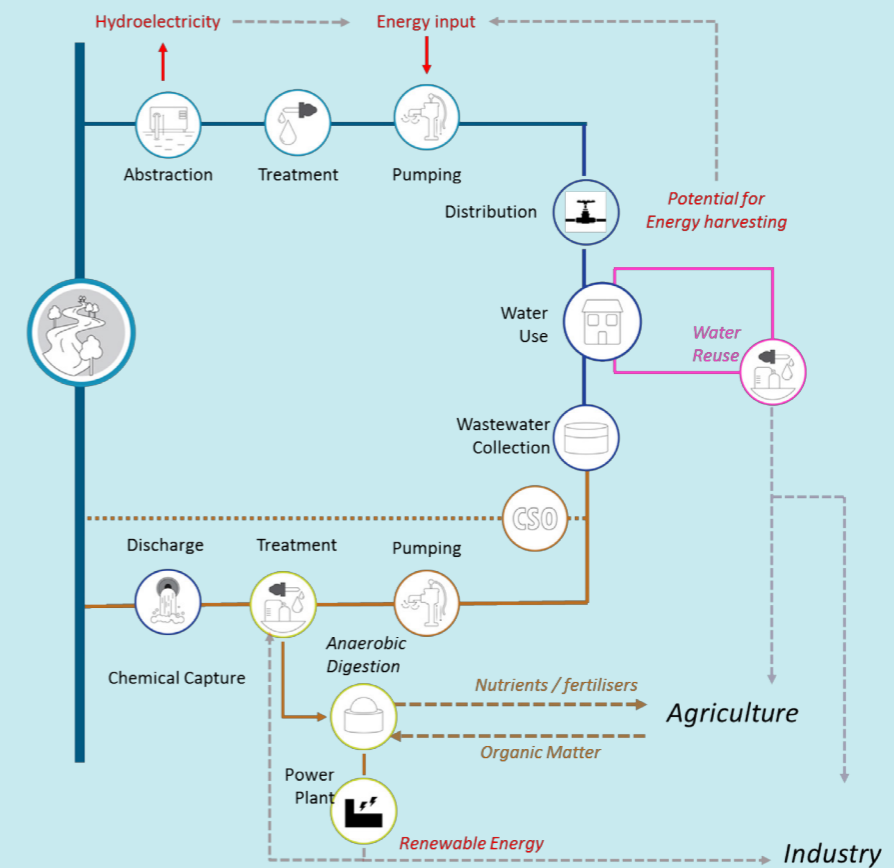
- Within a given basin, the natural water cycle acts to re-optimize, reuse, and replenish water. On the left side, water is depicted in its natural state, with no human-induced uses.
- The graph on the right shows the opportunity offered by the circular economy to better align the human water cycle with the natural water cycle by undertaking the following actions:
- Avoid use—through rethinking products and services and eliminating ineffective actions.
- Reduce use—driving continuous improvements through water use efficiency and better resource allocation and management.
- Reuse—pursuing any and all opportunities to reuse water within an operation (closed loop) and for external applications within the surrounding vicinity or community.
- Recycle—within internal operations and/or for external applications.
- Replenish—efficiently and effectively returning water to the basin.

Basin perspective

The document argues that it is important to understand a system and its context, and that depending on the type of basin and city characteristics (climate, scale, level of development, and so forth), the nature of the opportunities for generating additional value with the application of circular economy principles will be different. A suite of solutions that would be viable in one city-basin archetype could be less viable in another.

Urban water system perspective

The figure presents a simplified view of the components of a municipal water system and some examples of how a municipal water system interfaces with industry, energy systems, agriculture, food production, and the wider environment. The document further explains some of these potential circular economy examples.



Source: Adapted from Ellen MacArthur Foundation, ARUP, and Antea Group (2018).

The white paper also presents some case studies of the application of circular economy principles, including integrated water, waste, and resource recovery; wastewater heat recovery; waterless dyeing in textile industry; direct dry cooling in the power sector; energy positive wastewater treatment; nutrient recovery; and water reuse.

Finally, it concludes with saying that “Circular economy creates a shift that seeks value from the wider system rather than just from the fixed point at which consumption applies. Functional requirement will still be met; at the same time as creating value from resource efficiency and water use dimensions of service energy and carrier. Digital technology and innovative business practice help realize this. In this way the application of circular economy principles can help us meet the step changes to practice that will be necessary for it to meet future water demands, whilst facing key challenges access to resource, increased demand, and more stringent quality and pollution and environmental controls.”

[International Water Association. 2016. “Water Utility Pathways in a Circular Economy.” London.](#)

This report describes a framework that aims to support the identification of circular economy opportunities, and the means to make the most of them within three interrelated pathways: the Water Pathway; the Material Pathway, and the Energy Pathway.

The report identifies:

1. **Drivers and enablers of a circular economy:** consumers, industry, regulation, infrastructure and urban and basin economies
2. **Pathway boosters:** integrated urban resource management; connecting to stakeholders beyond traditional boundaries; leadership, innovation, and new business models
3. **Critical junctures where water, energy, or materials intersect and opportunities arise to transition to the circular economy:** water-wise communities, industry, wastewater treatment plans, drinking water treatment plants, agriculture, the natural environment, and energy generation

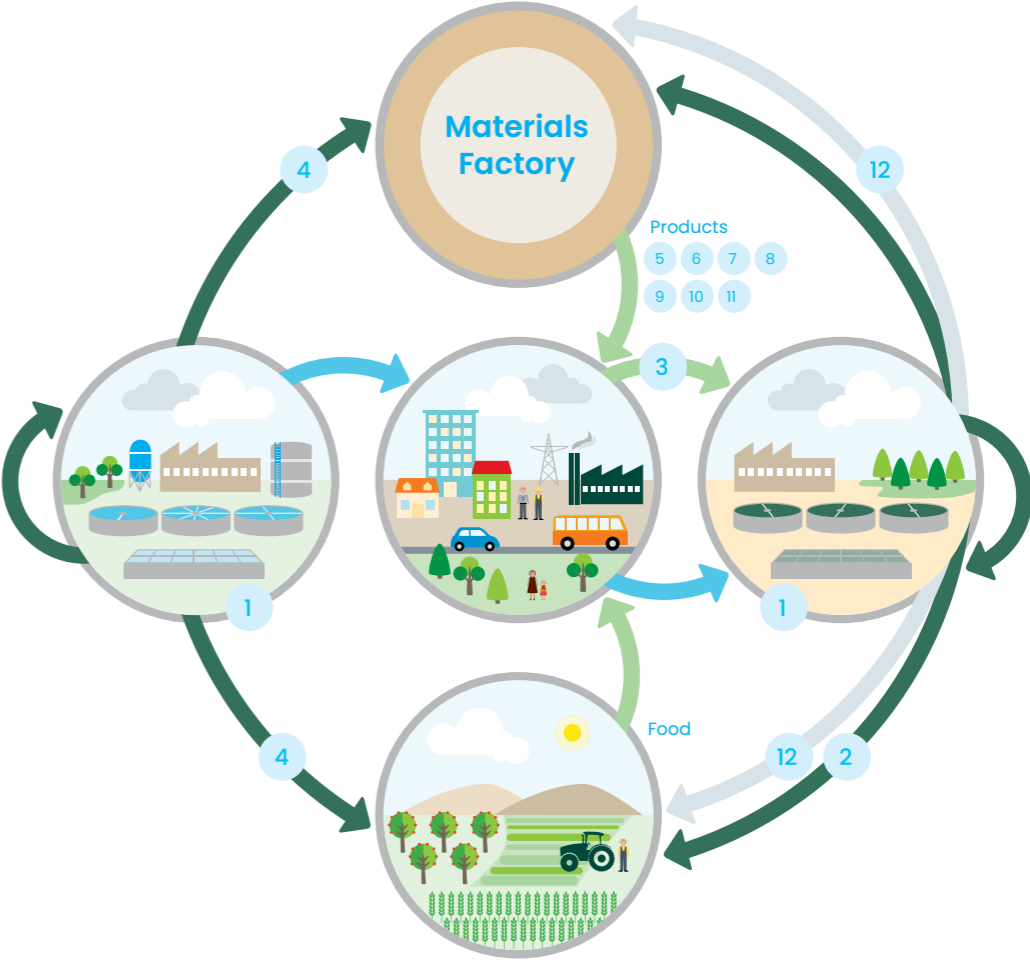
The report then uses diagrams (see [figure B.1](#)) to explain the different pathways, and provides examples of regulatory and market levers that could benefit each action (identified by number in the diagrams).

Figure B.1 Three pathways toward a circular economy



The Water Pathway

Potable water	1 Upstream investments	6 Reused water for industry
Non-potable water	2 Rainwater harvesting	7 Direct potable reuse
Wastewater	3 Greywater recycling for non-potable reuse	8 Leakage / Water loss
Reclaimed water	4 Greywater for agriculture and aquaculture	9 Reduction in water consumption
Greywater	5 Reused water for agriculture and aquaculture	X Onsite treatment
Rainwater		

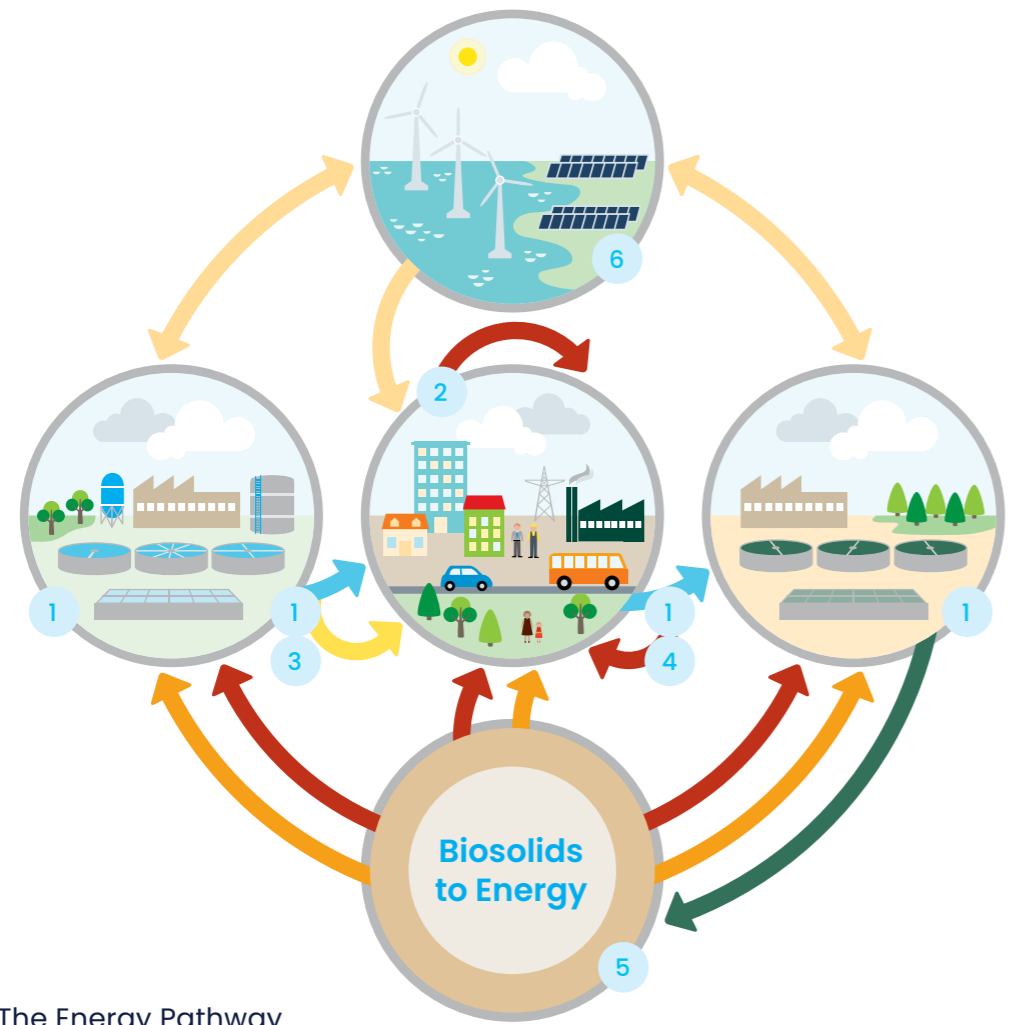


The Materials Pathway

Recovered materials	1 Resource efficiency
Organic matter	2 Wastewater sludge and products thereof for agriculture
Water	3 Organic waste added to wastewater sludge
Gas	4 Drinking water sludge to agriculture or industry
	12 Effluent gas reuse

Products

5 Bioplastics	9 Proteins & Feed
6 Fertiliser (non-agricultural)	10 Metals & Minerals
7 Paper & Cellulose	11 Human health products



The Energy Pathway

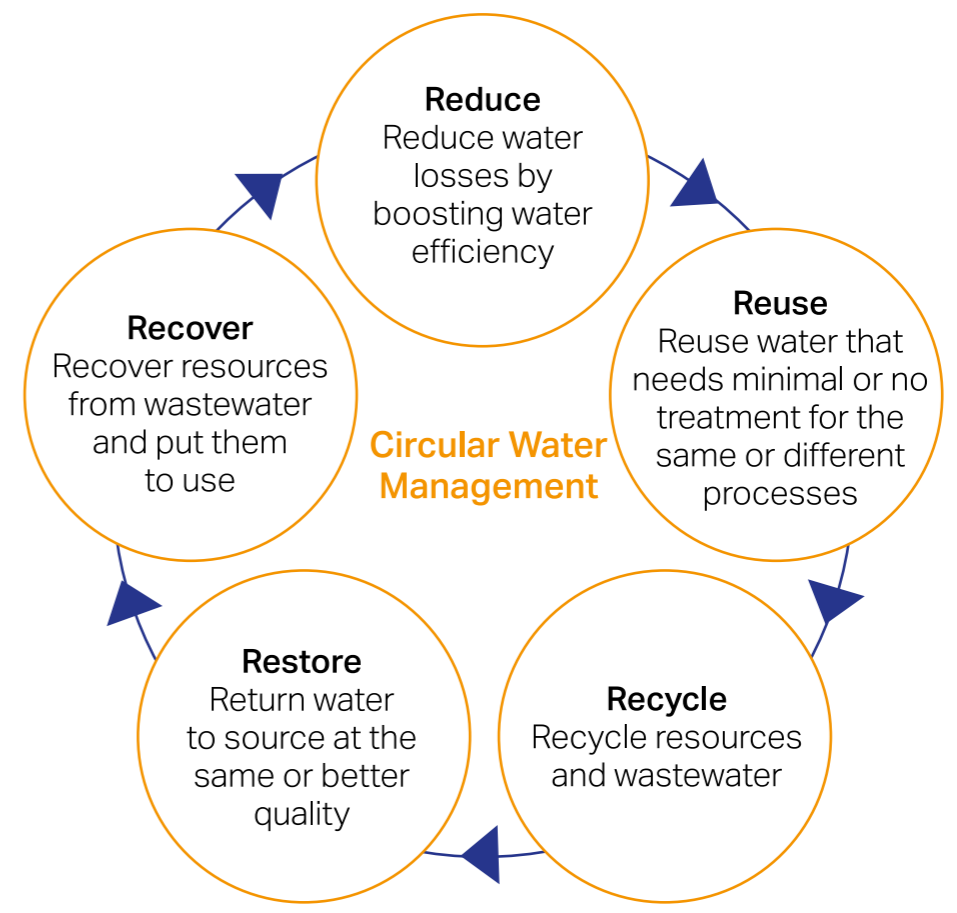
<ul style="list-style-type: none"> Organic energy Heat Topographic energy Other renewable energy Water Recovered materials 	<ul style="list-style-type: none"> 1 Energy saving at treatment plants & distribution systems 2 Energy reduction and recovery at home 3 Electricity produced from distribution systems 4 Heat produced from distribution systems 5 Wastewater biosolids to energy production (gas, electricity & heat) 6 Renewable energy
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Source: International Water Association 2016.

World Business Council for Sustainable Development. "Business Guide to Circular Water Management: Spotlight on Reduce, Reuse and Recycle." Geneva.

This report, more catered toward businesses, presents the 5Rs of circular water management: that is, to reduce, reuse, recycle, restore, and recover water resources (figure B.2).

Figure B.2 The five Rs of circular water management



Source: World Business Council for Sustainable Development.

ING Bank. 2017. “Less Is More: Circular Economy Solutions to Water Shortages.” Amsterdam.

This report analyzes the impact of measures to decrease pressure on water resources in six regions: northern India, California, Ghana, the United Arab Emirates, Bangladesh, and the Netherlands. The study concludes that, in those six regions, the application of circular economy principles has the potential to save 412 billion cubic meters of water a year, which is equivalent to 11 percent of annual global water demand, or almost the entire water consumption in the United States.

The circular water measures included in the analysis are classified under 3 Rs: reduce, reuse, and retain water:

Reduce water demand and water pollution

- Reduce water losses through leakages
- Switch to water-efficient processes in industry
- Use water-efficient irrigation techniques such as drip irrigation
- Improve the water efficiency of existing crops (crop refinement) and switch to more water-efficient crops
- Use saline water for irrigation when possible
- Apply sustainable water pumping
- Use more-water-efficient appliances
- Prompt behavioral changes toward using less water
- Use water in such a way that prevents water pollution (e.g., design industrial processes to separate dirty from clean water streams)

Reuse water

- Reuse graywater, which is nonpotable water that can still be used for many other purposes (e.g., in irrigation)
- Treat and reuse black water, which is heavily polluted water (e.g., toxic industrial wastewater) that can only be reused after heavy treatment
- Purify water through natural ecological processes, for example, through the use of wetlands (ecohydrology)

Retain water

- Invest in natural infrastructure upstream, such as wetlands and forestry projects able to hold water for long periods
- Set up water storage projects, such as aboveground water reservoirs or rainwater harvesting
- Set up underground aquifer storage and undertake recovery activities
- Increase water retention of the soil so that agriculture needs less water for irrigation

