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Wastewater

Turning Problem to Solution

A Rapid Response Assessment

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Glossary

Biosolids – Sewage sludge, adequately treated, processed and applied as fertilizer to improve and maintain productive soils and stimulate plant growth (World Water Assessment Programme [WWAP] 2017).

Blended finance – Blended finance is the strategic use of development finance for the mobilization of additional finance towards sustainable development in developing countries. Blended finance attracts commercial capital towards projects that contribute to sustainable development, while providing financial returns to investors (Organisation for Economic Co-operation and Development [OECD] n.d.).

Circular economy – A circular economy offers an alternative economic model, whereby natural resources, including water sources, are kept at their highest value, for as long as possible. Circularity thinking provides a framework to develop comprehensive strategies for water management within a circular economy (United Nations Environment Programme 2019).

De facto reuse – Where both treated and untreated wastewater can be used unintentionally where wastewater is incidentally present in a water supply (Jones *et al.* 2021).

Direct potable reuse (DPR) – The injection of high-quality reclaimed water directly into the potable water supply distribution system, either upstream or downstream of the water treatment plant (i.e. without the use of an environmental buffer) (International Organization for Standardization [ISO] 2018).

Domestic wastewater – Composed of black water, grey water and potentially other types of wastewater deriving from household activities in residential settlements (WWAP 2017).

Emerging pollutants – Also referred to as contaminants of emerging concern, emerging pollutants are defined as "any synthetic or naturally-occurring chemical or any microorganism that is not commonly monitored or regulated in the environment with potentially known or suspected adverse ecological and health effects" (United Nations Educational, Scientific and Cultural Organization [UNESCO] 2015).

Indirect potable reuse (IPR) – Augmentation of natural sources of drinking water (such as rivers, lakes, aquifers) with reclaimed water, followed by an environmental buffer that precedes drinking water treatment (ISO 2018).

Industrial reuse – The reuse of industrial wastewater or the reuse of municipal wastewater to satisfy industrial water requirements (ISO 2018).

Industrial wastewater – Water discharged after being used in or produced by industrial production processes (including, for example energy production, mining, textiles, steel works, etc.) (WWAP 2017).

Municipal wastewater – Wastewater that comes from urban domestic and commercial sources, and any parts of industry or urban agriculture that are connected to the municipal sewers networks.

Nature-based solutions – Actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services, resilience and biodiversity benefits (UNEP/EA.5/Res.5).

Non-potable reuse – Use of reclaimed water not meeting drinking water standards for non- potable purposes (ISO 2018).

Non-potable water – Water that has not been treated to drinking water standards, but that may be considered safe for other uses. Non-potable uses include toilet flushing, irrigation, industrial uses or other non-drinking water purposes. Implementing a non-potable water-use system would require separate water distribution and plumbing systems (Metropolitan Council n.d.).

Planned reuse – Where treated or untreated wastewater is intentionally used (Jones *et al.* 2021).

Potable reuse – Use of high-quality reclaimed water as a water source for drinking water treatment and supply (ISO 2018).

Potable water – Water that has been treated sufficiently to meet or exceed drinking water standards and is considered safe for human consumption. Potable water uses include drinking, bathing/showering, food preparation, dishwashing and clothes washing (Metropolitan Council n.d.).

Preliminary treatment – Removal of wastewater constituents such as rags, sticks, floatables, grit and grease that may cause maintenance or operational problems during the treatment operations and processes (WWAP 2017).

Primary treatment – Removal of a portion of the suspended solids and organic matter from the wastewater, which can or cannot include a chemical step or filtration (WWAP 2017).

Reclaimed water/recycled water/water reuse – Wastewater that has been treated to meet a specific water quality standard (fit for purpose) corresponding to its intended use (ISO 2018).

Secondary treatment – Removal of biodegradable organic matter (in solution or suspension), suspended solids, and nutrients (nitrogen, phosphorus or both) (WWAP 2017).

Sludge – Residual nutrient-rich organic material, whether treated or untreated, from urban wastewater treatment plants (WWAP 2017).

Sustainable agriculture – To be sustainable, agriculture must meet the needs of present and future generations while ensuring profitability, environmental health and social and economic equity. Sustainable food and agriculture contribute to all four pillars of food security – availability, access, utilization and stability – and the dimensions of sustainability (environmental, social and economic) (Food and Agriculture Organization of the United Nations [FAO] n.d.).

Tertiary treatment – Removal of residual suspended solids (after secondary treatment), further nutrient removal and disinfection (WWAP 2017).

Wastewater – A combination of one or more of: domestic effluent consisting of black water (excreta, urine and faecal sludge) and grey water (kitchen and bathing wastewater); water from commercial establishments and institutions, including hospitals; industrial effluent, stormwater and other urban run-off; agricultural, horticultural and aquaculture effluent or run-off (adapted from Raschid-Sally and Jayakody 2008).

Wastewater reuse – The practice of using untreated, partially treated or treated wastewater for resources including potable and non-potable water, irrigation water, nutrients, energy and heat value. Safe wastewater reuse is when the wastewater has been subjected to the appropriate level of treatment required to reach the quality standard for the intended purpose.

Wastewater treatment – A process, or sequence of processes, that removes contaminants from wastewater so that it can be either safely used again (fit-for-purpose treatment) or returned to the water cycle with minimal environmental impacts. There are several levels of water treatment, the choice of which is dependent on the type of contaminants, the pollution load and the anticipated end use of the effluent (WWAP 2017).

Acronyms and abbreviations

AMR	Antimicrobial resistance
ARB	Antibiotic resistant bacteria
ARG(s)	Antibiotic resistance gene(s)
CBD	Convention on Biological Diversity
COP	Conference of the Parties
DESA	United Nations, Department of Economic and Social Affairs
DEWATS	Decentralized wastewater treatment system
DPR	Direct potable reuse
EIB	European Investment Bank
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
g	Gram
GEF CReW+	The Global Environment Facility Caribbean Regional Fund for Wastewater Management (Phase 2)
GHG(s)	Greenhouse gas(es)
GWh	Gigawatt hour
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IPR	Indirect potable reuse
i-WSSM	International Centre for Water Security and Sustainable Management
IWA	International Water Association
IWMI	International Water Management Institute
IWWM	Integrated water and wastewater management
K	Potassium
kg	kilogram
kWh	Kilowatt hours
m^3	Cubic metres
MDG(s)	Millennium Development Goal(s)
Mg	Milligram
MJ	Million joules
N	Nitrogen
NBS	Nature-based solutions
OECD	The Organization for Economic Cooperation and Development
P	Phosphorus
SDG(s)	Sustainable Development Goal(s)
UN-Habitat	United Nations Human Settlements Programme
UN-Water	Coordination mechanism comprising United Nations entities (Members) and international organizations (Partners) working on water and sanitation issues
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
WBCSD	World Business Council for Sustainable Development
WHO	World Health Organization
WTO	World Trade Organization
WWAP	World Water Assessment Programme

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Foreword

In 2010, the United Nations Environment Programme (UNEP), the United Nations Human Settlements Programme (UN-Habitat) and GRID-Arendal published a report entitled Sick water? The central role of wastewater management in sustainable development – A rapid response assessment. The report called for a greater focus on the intelligent management of wastewater, which recognizes its potential in contributing to sustainable development.

This approach involves recovering and safely reusing the valuable ingredients that make up wastewater, such as nutrients, energy and water. Recovering these resources can deliver multiple co-benefits, such as reduced dependence on synthetic fertilizers, which constitute up to 25 per cent of the global nitrogen and phosphorus demand in agriculture; diversified energy production, which can provide electricity for around half a billion people per year; and increased water security, carrying the potential to irrigate around 40 million hectares.

More than a decade later, UNEP has recognized that we are facing a triple planetary crisis of climate change, biodiversity loss and rampant pollution. This crisis is undermining nature's ability to provide the ecosystems services that in turn support human and non-human well-being. Population growth and urbanization are also placing a huge strain on finite water sources, with a third of the global population already living in water scarce regions with demand set to intensify.

Therefore, it is an absolute priority to accelerate action to beat wastewater pollution while harnessing its underutilized potential. There has been some progress: We invite you to take a close look at the 20 case studies presented in this report. You will find amazing examples of solutions from every corner of our world, from the Caribbean to China, from Solomon Islands to Tunisia, from Singapore to Colombia, from India to Namibia, from London to Burkina Faso, from Black Sea to Sweden, from Denmark to Egypt, and so on. These case studies give real world examples of solutions that are already bringing about the changes we need.

But these changes are not happening at the speed or scale needed, creating serious risks for ecosystems and human health, as well as the resilience of societies. In many parts of the world, even the basic treatment and utilization of wastewater remains a significant challenge. In France, for example, only 0.1 per cent of treated wastewater produced is reused.

The "Wastewater – Turning Problem to Solution" report challenges the view that wastewater is an end-of-pipe problem to be disposed of and, instead, repositions it as a circular economy opportunity: a renewable and valuable resource to be conserved and sustainably managed with the potential to drive new jobs and revenue streams.

We are very pleased to publish this report, whose authors have defined three key areas for action and six necessary building blocks to help policy and decision makers lead transformational change in sustainable wastewater management. The three actions call for reducing how much wastewater we produce, being more careful about what goes into the water we use, and considering how to better collect and treat wastewater so that we can recover and safely use its valuable resources.

The building blocks focus on the social, cultural and behavioural changes that will need to happen in order for actions to succeed: ensuring an enabling, coherent governance and legislative framework; mobilizing investment in infrastructure and the human and institutional capacity that is needed; encouraging technical and social innovation; improving data feedback for iterative adaptation; and strengthening communication and awareness to build understanding and trust to help change our behaviours and attitudes to water usage.

It is our hope that this publication will help set in motion a shared global vision that recognizes the inherent value of wastewater as a resource. Action is needed in a whole-of-society approach recognising that the most appropriate solution, or combination of solutions for recovering resources from wastewater will depend upon economic, environmental, social and cultural contexts. We invite you to use this publication to elevate to the political agenda the urgent need for the safe recovery of resources from wastewater.

For us, it is clear that the transition will involve incremental actions, learning, adapting and innovating. We are confident that you will find this report very valuable in putting us on a pathway to success.

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The "Wastewater – Turning Problem to Solution" report challenges the view that wastewater is an end-of-pipe problem to be disposed of and, instead, repositions it as a circular economy opportunity.

Executive summary

More than 10 years have passed since the release of the report Sick Water? The Central Role of Wastewater Management in Sustainable Development – A Rapid Response Assessment report ("the Sick Water? report"), and despite some progress, significant amounts of wastewater are still being released untreated into the environment. Untreated wastewater is one of the key drivers of biodiversity loss and a major threat to human health, particularly affecting the most vulnerable people and ecosystems. But when adequately treated, wastewater can become a valuable resource.

This new report "Wastewater – Turning Problem to Solution" examines solutions to the challenges in realising sustainable wastewater management and capitalising on the opportunities for resource recovery and reuse. The report considers how to develop and extend these solutions to locations where improved wastewater management is desperately needed.

Key messages

1 Out of sight cannot be out of mind when it comes to wastewater. Wastewater is used water, something people produce every day, no matter who or where they are. It is produced in large quantities and then forgotten about. Ignoring this important resource would be a mistake that undermines our reliance on finite water supplies. It is time to transform how we see wastewater, from a smelly and dangerous source of pollution, improperly managed, having severe negative impacts on environmental and human health, to a well-managed and valued resource carrying huge potential as a source of clean water, energy, nutrients and other materials. This resource could help provide sustainable solutions to address the worsening environmental and societal crises, many rooted in water shortages, that contribute to food insecurity and undermine ecosystems. Only 11 per cent of the estimated total of domestic and industrial wastewater produced is currently being reused.

2 Given the world's worsening water and food and energy security crises, we cannot afford to waste a drop. The untapped potential for wastewater reuse is around 320 billion cubic metres (m^3) per year, with the potential to supply more than 10 times the current global desalination capacity. Unlocking the potential of wastewater requires rigorous collection and treatment processes so that we can safely recover the valuable embodied products. But negative public perceptions and concerns – about environmental and health risks – still surround wastewater resource recovery and reuse. There is a need for inspired critical thinking to transform the perception of wastewater from being an end-of-pipe pollution problem to a flourishing resource. To change how water is used, collected, treated and valued will require policies and actions that are inclusive and equitable. It will also need appropriate financing and capacity-building.

3 Elevating the reuse of resources from wastewater in the international policy agenda is critical to tackling the triple planetary crisis of climate, nature and pollution. Wastewater reuse needs to be a key component of the United Nations Water Action Agenda. Promoting wastewater as a resource requires raising awareness of the potential benefits of reuse. Leaving this issue behind will seriously undermine progress towards achieving the Sustainable Development Goals (SDGs), as the reuse of water and other resources from wastewater can make an important contribution to food and water security, with the potential to provide alternative water resources, valuable nutrients, create new jobs, develop new energy streams and ensure a clean, healthy and sustainable environment.

The issues

Water is central to life, biodiversity, ecosystem integrity, food and energy production, yet decades of mismanaging our water resources through overconsumption, pollution and insufficient recycling have led to a global water crisis. This is exacerbated by climate change impacts, population growth and urbanization. Sustainable water management is critical and must include how water is managed once it has been used. Wastewater volumes are continually increasing, and despite some progress in treatment and reuse over the past decade, untreated wastewater remains a significant global challenge – around half of the world's wastewater still enters the environment without adequate treatment. In 2013, it was estimated that the annual production of wastewater, primarily from municipal sources, to be 330 billion m^3. Subsequent estimates suggest this had risen to 360–380 billion m^3/year by 2015. This is five times the volume of water passing over Niagara Falls annually.

Population growth is a major driver in increasing wastewater volumes – with the world's population estimated to increase by another 2 billion to almost 10 billion by 2050. This growth is projected to occur mostly in urban agglomerations in developing countries – populations that are already underserved by adequate water supply and wastewater treatment systems. The volume of wastewater from domestic and municipal sources is estimated to rise to 470–497 billion m^3/year by 2030, representing a 24–38 per cent increase in the volume of wastewater produced by the time the SDGs expire.

Realizing human rights and global political ambitions with regards to water requires fundamental and systemic changes to see wastewater as a resource. Improper handling of wastewater disproportionately affects vulnerable groups, especially children and women. Due to gendered labour division, women are often most affected by the lack of wastewater treatment and consequent poor water quality. They are the most likely to be in contact with faeces and food as primary carers, increasing health risks to themselves and their families.

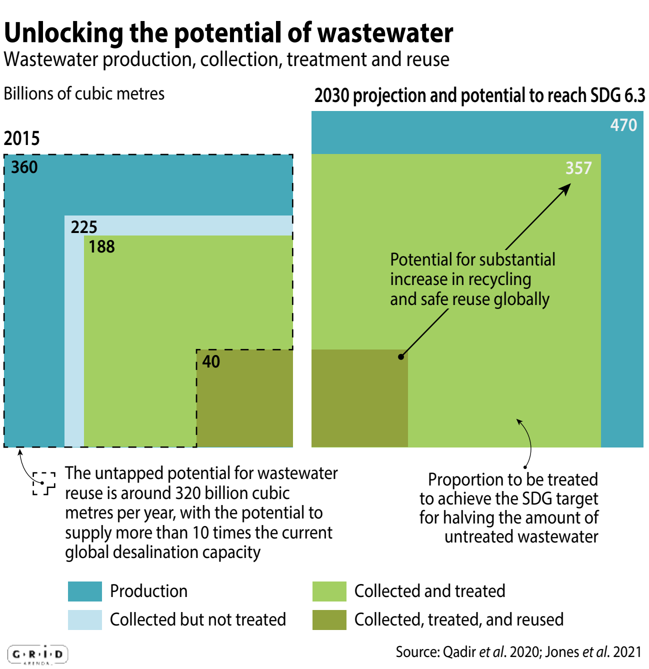

Figure 0.1: *The potential of wastewater as a resource.*

Safe and appropriate wastewater management for resource recovery and reuse goes beyond achieving water security, with potential co-benefits including improved environmental health, human health and well-being, protecting biodiversity, reducing dependence on synthetic fertilizers, and diversifying energy production and economic opportunity. Additionally, an inclusive approach to water and wastewater management results in societal benefits, especially among women, ensuring they can easily access safe water and have more time to earn income. Despite several successful wastewater reuse applications in many countries, persistent barriers and concerns linger, continuing to limit the widespread implementation of water reuse at scale. These barriers and concerns include:

- Inadequate political support or lack of priority setting in the political arena – wastewater resource recovery and reuse is not sufficiently prioritized in the political discourse.
- Governance, institutional and regulatory barriers – where there are policies for resource recovery and reuse from wastewater streams, there are often inconsistent or competing policy objectives and low levels of implementation, with weak compliance and enforcement.
- Insufficient data and information – current deficits in data availability and accessibility relating to wastewater resource recovery and reuse, and lack of gender-disaggregated data make it difficult to assess impacts, target actions and track progress in implementation.
- Inadequate financing – there is a practical need to close the water loop, but sustainable investment will only occur if it is economically viable to treat and reuse wastewater. Innovative approaches to financing such as blended finance approaches, cost recovery and other incentives need to be implemented to fund improved collection and treatment, immediately and at scale.
- Low social and cultural acceptance, including for religious reasons – familiarity, awareness and trust are required to tackle the negative perceptions of wastewater and bring about the required behaviour changes, recognizing there are different implications for different stakeholder groups.
- Limited human and institutional capacity – in many cases, lack of capacity is hindering wastewater management, resource recovery and reuse, including for monitoring and data management.

- Environmental and human health concerns, and potential risks from pollutants, pathogens, antimicrobial resistance (AMR) and contaminants of concern – including emerging and persistent pollutants and microplastics that may still be present in reclaimed resources and recycled water.

The solution

As an integral part of sustainable water management, wastewater resource recovery and safe reuse can be a consistent and effective way to address a range of sustainable development issues: from water scarcity to pollution, climate change adaptation and resilience, energy security, sustaining food systems, and human and ecosystem health. This central role of wastewater in securing our common future was recognized in target 6.3 of the SDGs, calling for improved water quality, including reducing the proportion of untreated wastewater, and increasing recycling and safe reuse.

The transformation needed to move away from seeing wastewater as a waste management issue to a valued resource is increasingly urgent. This can only be delivered by combining technical solutions with capacity development, mobilizing adequate resources, and a clear, shared strategy to create the social, cultural, regulatory and institutional shifts that can develop new values and norms in society.

It is possible to recover valuable resources, such as nutrients, energy and water, when appropriate wastewater collection, treatment and management are in place. A key requirement for any sustainable resource recovery and reuse from waste streams is to ensure that it is safe for people and the environment. When fit for purpose, these resources can deliver multiple co-benefits, such as: reduced dependence on synthetic fertilizers (i.e. up to 25 per cent of the global nitrogen and phosphorus demand in agriculture could be met by recycling human urine-derived nutrients); diversification of energy production (i.e. providing electricity for around half a billion people per year, based on potential methane production); and increased water security (i.e. the untapped potential for wastewater reuse is around 320 billion m^3/year, with the potential to irrigate around 40 million hectares.

Noting the continued relevance of the recommendations made in the 2010 Sick Water? report, this new report examines the challenges to realizing the benefits and opportunities of wastewater resource recovery and reuse. It draws on case studies to explore potential interventions and approaches to overcome these challenges. It defines **three key action areas** and identifies **six building blocks** to maximize the opportunities of wastewater resource recovery and safe reuse. The aim is to inspire policymakers and decision makers to be proactive in leading transformational change in sustainable wastewater management, providing options for solutions. The right solution, or combination of solutions, will depend on the local or regional circumstance, and must fit the economic, environmental, social and cultural contexts. There are many excellent experiences to learn from, to realize the opportunities of wastewater reuse, some of which are provided as case studies in this report.

The three key action areas:

1. **Reduce the volume of wastewater produced**
   Freshwater resources must be used more responsibly. Reducing water consumption will lower the wastewater volumes produced, making the task of recovering and reusing wastewater more achievable, by reducing energy requirements and the cost of collection and treatment. It will also reduce pollution risks to people and nature.

2. **Prevent and reduce contamination**
   What goes in = what comes out. More attention must be paid to what is put into water when it is used, and where feasible, separating and eliminating compounds at source before they enter the wastewater flow. By reducing and restricting the contaminants of concern in our water (e.g. pharmaceutical compounds, chemical and synthetic compounds, microplastics or nanoparticles), it is easier and cheaper to treat, and safer to reuse the resources in wastewater or to release treated water back to the environment.

3. **Sustainably manage wastewater for resource recovery and reuse**
   Collection is a prerequisite to treatment. There are many solutions for the collection and treatment of wastewater to recover resources of appropriate quality standards, depending on its application. Investments are needed to expand the capacity for wastewater collection and treatment that includes the recovery of resources for reuse. Investment is also needed to address the neglect or insufficiency of existing wastewater management facilities to ensure they are fit for purpose.

These action areas must be addressed in conjunction with each other and at multiple levels. As with the three action areas, successfully expanding the reuse of wastewater will require urgent progress on the following

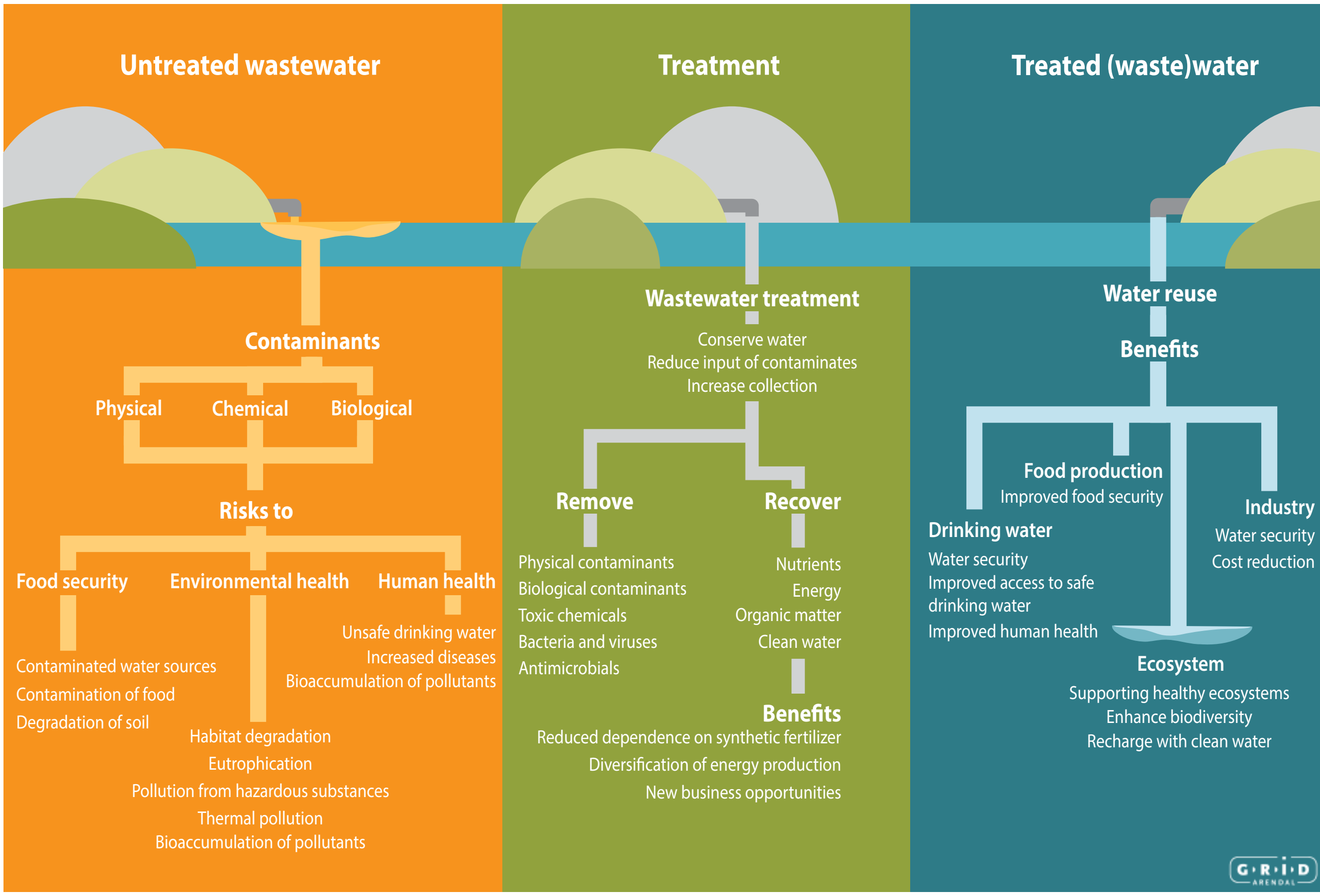

Figure 0.2: *Environmental implications of wastewater and intervention points*

building blocks to create an enabling environment, giving a clear, shared vision and a framework to help realize that vision:

1. Ensuring effective and coherent governance and legislation to create an enabling political and regulatory environment
2. Mobilizing adequate and sustained investment and access to financing to optimize the wastewater value chain; to create markets for resource recovery; and to facilitate business opportunities and investment by the private sector
3. Enhancing human, technical and institutional capacity at all levels (from local to global) to empower others to act on a shared vision
4. Enabling technical and social innovation to establish new approaches and equitable solutions that are appropriate to different socioeconomic-environmental situations
5. Delivering robust data collection and information management to support implementation, learning and ensure accountability
6. Increasing communication, awareness and transparency to build trust to support behaviour change and social acceptance

Realizing the economic value of wastewater is essential for transitioning to sustainable wastewater management. It is not an easy task, and there is no one-size-fits-all solution. However, there is existing experience to build on, and the challenge is not an excuse for inaction. There is too much to lose. Everyone, as individuals and collectively, are part of both the problem and the solution. Coherent and sustained action is needed by all sectors of society, which means us as individuals, businesses, industry, farmers and governments – locally, nationally and regionally. The elements to make this transition successful lie in creating a shared vision for the future, and collectively realizing the urgency to get there. They also lie in creating an enabling and empowering environment to support the necessary system-level change at scale.

PART 1

Background and purpose

A decade on from Sick Water?

In 2010, the United Nations Environment Programme (UNEP) and the United Nations Human Settlements Programme (UN-Habitat) published Sick Water? The Central Role of Wastewater Management in Sustainable Development – A Rapid Response Assessment ("the Sick Water? report") (UNEP, UN-Habitat and GRID-Arendal 2010). Set against the background of the Millennium Development Goals (MDGs) and the International Year of Sanitation 2008, this report aimed to change the narrative of wastewater management. It called for a greater focus on the intelligent management of wastewater, recognizing its critical contribution to sustainable development. This included addressing increasing water stress and inequity, but also capitalizing on the multiple potential benefits to be gained from wastewater. The report examined key challenges in wastewater management, looked at possible solutions for reducing both water usage and contamination levels in wastewater and detailed how wastewater could be reused in an affordable and sustainable way.

The four key messages and six policy recommendations set out in the Sick Water? report highlighted the need to shift perspective and trigger a move away from seeing wastewater management as a linear process, with disposal as the end point, to a circular approach, which realizes the value of wastewater as a resource.

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More than 10 years have passed since the release of the Sick Water? report. Despite some progress against the key messages and recommendations made in 2010 (see figures 1.1 and 1.2), untreated wastewater remains a significant global challenge, with an estimated 48 per cent still being released untreated into the environment (Jones *et al.* 2021), and pollution, including from wastewater, being identified as a key driver of biodiversity loss (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services [IPBES] 2019). Climate change impacts, population growth and urbanization continue to put a strain on water resources globally, with a third of the global population already living in water scarce regions (Ruiz 2020). The global demand for water, food and energy is expected to intensify, resulting in scarcity, energy shortfalls and declining reserves of non-renewable nutrients such as, phosphorus, zinc and copper. There is therefore a growing urgency to develop solutions to ensure circularity of our water use to meet these future needs. This will require a greater commitment and investment by governments.

Safe and appropriate wastewater management for resource recovery and reuse goes beyond achieving water security to include potential co-benefits. This includes improved environmental and human health and well-being; reduced dependence on synthetic fertilizers; diversification of energy production and economic opportunity, increasing opportunities, especially for women. As an important component of a circular economy, resource recovery from wastewater can generate new business opportunities, while helping to improve water supply and sanitation services.

This new report builds on the previous Sick Water? report, starting with the premise that wastewater is an important and valuable resource that can also help avoid costs of pollution and biodiversity loss. It aims to inspire policy and decision makers to be proactive in leading transformational change in sustainable wastewater management by closing the loop in the water cycle and realizing the opportunities to reuse the resources that can be recovered from wastewater. Despite the potential for resource recovery, wastewater is at times difficult to collect, in many instances expensive to treat, and there are some significant challenges to the recovery of products that are for safe reuse. While implementing wastewater resource recovery and reuse will not be easy, this is not an excuse for inaction. The report examines the barriers to wastewater resource recovery and reuse. It describes areas of action vital for creating the necessary systemic change. Finally, the report draws on the latest research and case studies from different geographic regions and sociocultural contexts to showcase opportunities in key areas.

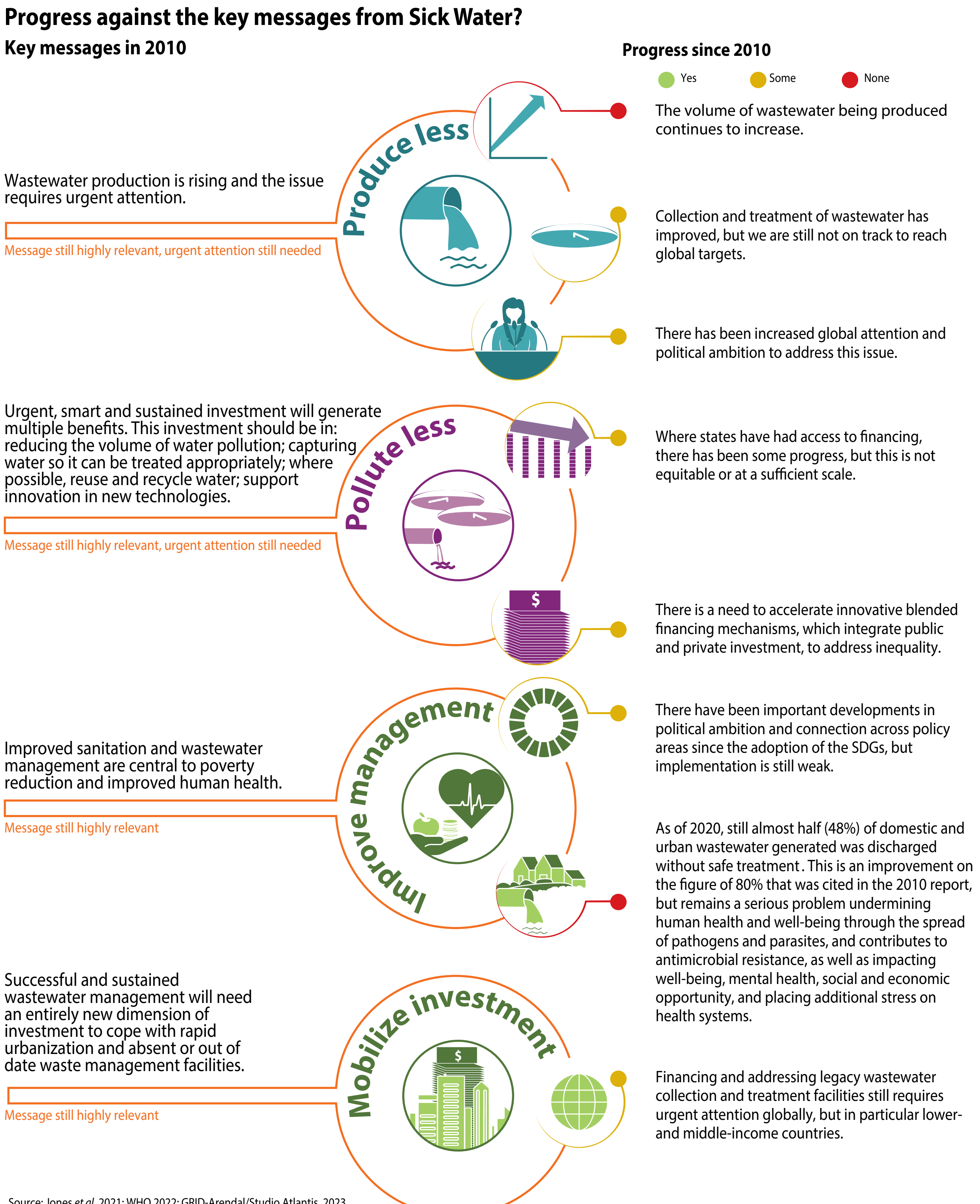
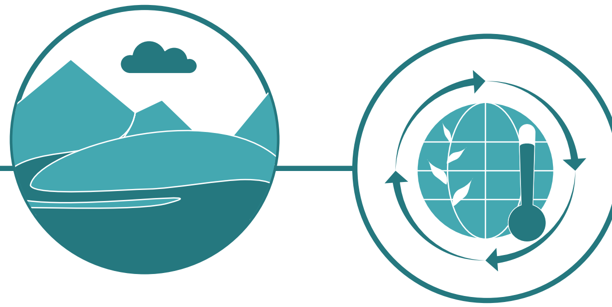


Figure 1.1: *Progress since 2010 against the key messages from Sick Water?*

2010 Recommendations
for short-term, immediate actions

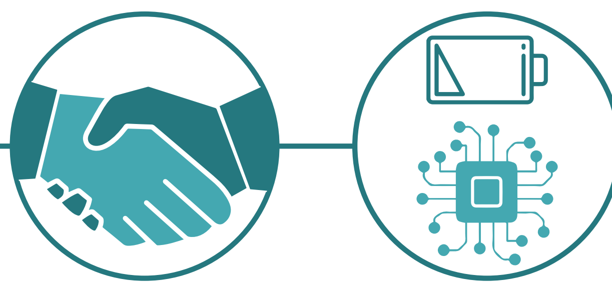
Examples of
Progress since 2010

Take a multi-sectoral and ecosystem approach to wastewater management from watershed to sea.



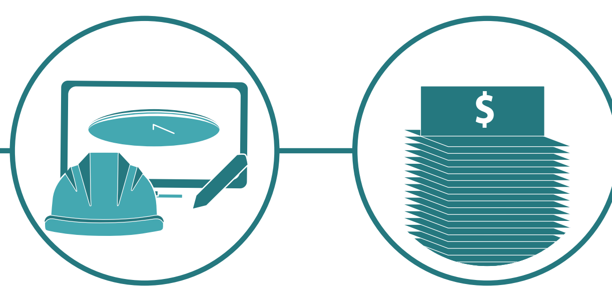
Wastewater sits at the crossroads of multiple policy areas: water management, circular economy, climate and environmental protection, and urban development.

The need for a suite of innovative solutions would be required to engage private and public sectors to address the different geographic, climatic, social, political and economic contexts.



It is acknowledged that there will not be a one-size-fits-all solution. There has been considerable innovation in the development of solutions since 2010, from decentralized low-tech-nature-based solutions to high-tech approaches for treating emerging pollutants and recovering resources safe for reuse.

Innovative financing of appropriate wastewater infrastructure from design, implementation and decommissioning, and recognizing livelihood opportunities.



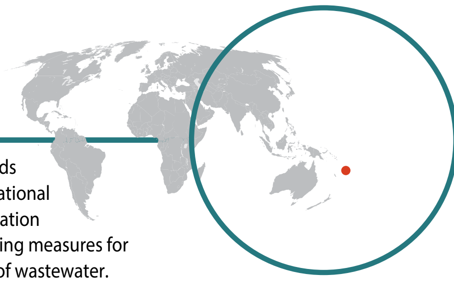
There are examples where states with access to finance and technology have made significant advances in the last decade.

Figure 1.2-a: *Key areas of progress against the short-term actions recommended in the 2010 report 'Sick Water?'*

Case studies

Persistent challenges

Cook Islands

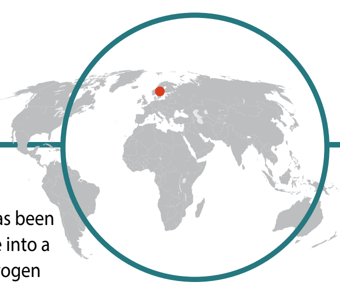


The Cook Islands developed a national policy for sanitation in 2014, including measures for management of wastewater.
A multi-sectoral and ecosystem approach were central to this policy: 'The Government will work in an integrated manner across all relevant Ministries and Agencies, and with communities, businesses and other stakeholders, to achieve the aims and implement the principles of this Sanitation Policy' (Ministry of Infrastructure and Planning, Cook Islands 2014). The policy identifies the importance of appropriate wastewater management for the health of the economy, people, visitors and the environment. It does not, however, expand into reuse.
Adoption of indicators under the SDGs to measure the proportion of safely treated domestic/industrial wastewater and ambient water quality are important tools for measuring progress and ensuring accountability in implementation.

INCREASINGLY URGENT

The practicalities of implementing coherent multi-sector policies remain difficult, in particular due to the coordination required. Across sectoral policies, there are often differing contradictory objectives, making it difficult to develop a coherent system-wide strategy, resulting in important gaps in decision making systems. Better monitoring and reporting is increasingly urgent to support planning and implementation. This recommendation is increasingly urgent, including when focusing in on the issue of reuse.

Sweden



In Sweden, a urine-separating toilet integrated with a urine dryer has been developed to turn human urine into a solid fertilizer, reducing the nitrogen load in the influent to the wastewater treatment plant (Simha 2021).

STILL RELEVANT

A key challenge is scaling the innovations appropriately to specific socioeconomic and geographic contexts.

China

There are examples where states with access to finance and technology have made significant advances in the last decade.
Municipal wastewater treatment coverage in China increased from 32% in 1999 to 96% in 2019. In 2021, China set a target by 2025 to: further increase wastewater treatment capacity an additional 20 million cubic metres per day; add an additional 80 000 kilometres of wastewater collection pipes; and require 25% of sewage to be treated to reuse standards (Global Water Intelligence 2021).
Globally, however, there is still a long way to go befre there is sufficient wastewater treatment capacity to meet SDG target 6.3 (Jones *et al.* 2022).

STILL RELEVANT

The infrastructure required for wastewater treatment can be very expensive and technologically challenging, requiring large investment of public funds. Although there are successfully applied and lower-cost nature-based solutions that exist, and these could be appropriate in some circumstances.

Source: GRID-Arendal/Studio Atlantis, 2022

2010 Recommendations

Long-term strategy

Examples of Progress since 2010

Planning should account for future global change scenarios (including climate change and population growth).

Climate change, urbanisation, population growth and economic development are all processes that impact the demands on water with consequences for wastewater production and treatment. Whilst some progress has been made in understanding the implications of climate change in water suppl and management, as well as the contribution of the high energy demands for wastewater treatment to carbon emissions, there is much that needs to be done.

Solutions must be sustainable, i.e. socially and culturally suitable, economically viable and ecologically appropriate.

There are a wide range of solutions available for wastewater reduction, collection, treatment and reuse, suitable for different social, environmental and ecologycal contexts. transparency and trust are recognised as critical to the success of such solutions.

Education and awareness are important to reduce overall volume and harmful content of wastewater.

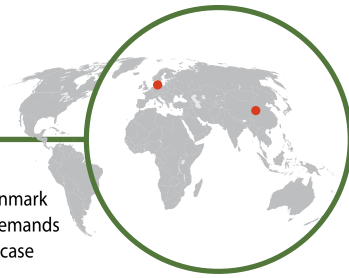
There are examples emerging to show that increasing awareness through education and information sharing can help change behaviour in water use at the individual and business level.

Figure 1.2-b: *Key areas of progress against the long-term actions recommended in the 2010 report 'Sick Water?'*

Case studies

Persistent challenges

Denmark and China

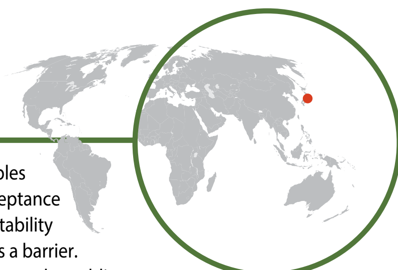


Resources recovery from wastewater treatment in Denmark is helping to lower energy demands from this sector (see Billund case study).
Despite an increasing population, water use in China has declined since 2013, largely due to government policies. There has been an associated decrease in wastewater generation (Xu *et al.* 2020).

INCREASINGLY URGENT

There is a need for systemic change across the whole water supply, management and reuse system. It needs to be sufficiently flexible to meet future challenges, such as climate change and population growth. There is also a recognition that success in implementing such change could have multiple co-benefits.
Improved monitoring and reporting is critical to inform planning.

Japan



While there are examples of growing public acceptance for reuse, social acceptability of wastewater remains a barrier.
In an example from Japan, the public acceptance of vegetables cultivated using reclaimed water was shown to increase from 40% to 60%, when accompanied by an awareness campaign to inform consumers about the water reuse project and provide reassurance as to the quality and safety of reclaimed water. This awareness-raising was important for developing trust (Takeuchi and Tanaka 2020).

STILL RELEVANT

Social acceptability still remains a barrier to wastewater reuse. Consideration of sustainability must include financial sustainability.

Singapore

As part of its water security strategy, Singapore has set a target to reduce per-capita consumption of water to 130 litres per day by 2030.
This has been done through a combinaton of awareness campaigns and community participation to encourage sustainable water use behaviour across sectors. Measures include a toilet replacement programme, awards for water efficiency and water efficiency labelling schemes (Singapore's National Water Agency, Public Utilities Board 2021).

STILL RELEVANT

Changes in behaviour and social acceptability are important challenges to be taken into account in order to identify socially/culturally appropriate and gender sensitive opportunities for wastewater resource recovery and reuse.

Source: GRID-Arendal/Studio Atlantis, 2023

Why addressing wastewater is still urgent

Addressing wastewater is vital to securing human rights

The human right to water and sanitation

The human right to water and sanitation was formally recognized by the United Nations in 2010 through United Nations resolution 64/292 (United Nations, General Assembly 2010). The resolution affirmed that the right to water and sanitation is part of existing international law and should be treated as legally binding by all Member States. In other words, this milestone recognizes water and sanitation as legally binding rights. In 2015, another resolution from the United Nations General Assembly further clarified that water and sanitation are interlinked but separate, providing Member States with the opportunity and policy instruments to focus on sanitation independently from water (Giné-Garriga *et al.* 2017). The resolution further calls for the full, effective and equal participation of women in decision-making, and for the development of specific measures to reduce the gender-specific burdens and threats faced by women and girls, including additional health threats due to gendered division of labour. This provides a new additional legal basis for the need to mainstream gender in wastewater management.

The realization of these rights implies that everyone is entitled to access sufficient, safe and contamination-free water to sustain their basic needs, and to have affordable access to safe, hygienic and secure sanitation (United

Box 1: What is wastewater?

Wastewater can mean different things to different people, with many definitions in use, including and excluding different fractions. This report carries across the broad perspective used for the Sick Water? report, and has defined wastewater as "a combination of one or more of: domestic effluent consisting of black water (excreta, urine and faecal sludge) and grey water (kitchen and bathing wastewater); water from commercial establishments and institutions, including hospitals; industrial effluent, stormwater and other urban run-off; agricultural, horticultural and aquaculture effluent or run-off" (adapted from Raschid-Sally and Jayakody 2008).

An alternative definition is used by the United Nations Statistics Division, although this definition does not include industrial sites: wastewater refers to water which is of no further value to the purpose for which it was used because of its quality, quantity or time of occurrence. However, wastewater from one user can be a potential supply to a user elsewhere (United Nations Statistics Division 2011).

Wastewater can contain a wide range of biological, chemical and physical contaminants including biodegradable organics, inorganic solids, heavy metals, microplastics, macrosolids, emulsions, pharmaceuticals, pathogens, nanoparticles, endocrine disruptors, refractory organics and nutrients. Discharge of partially treated and/or untreated wastewater into the environment is a common practice, particularly in low-income countries. This practice results in significant negative environmental, human health, and economic impacts, as well as a range of socioeconomic costs (United Nations Environment Programme 2020). Examples of negative environmental impacts include:

- algal blooms resulting from excess nutrients in the wastewater causing eutrophication, which can lead to reduced light levels and decreased oxygen levels killing aquatic and marine life
- contamination of habitats and water, disrupting ecosystems and undermining the benefits they provide to people
- some chemicals (endocrine disruptors) causing abnormalities in aquatic species, reducing reproductive success and changing immunity
- changes in temperature, affecting species composition
- pathogens in wastewater, which can cause disease not only in humans but also in animal populations
- use of untreated wastewater for agricultural irrigation, which contains contaminants that can degrade soil and impact food safety

Nations 2019). The human right to water and sanitation is inextricably linked to human dignity; access to water and sanitation has an impact on everyone's daily life. Unfortunately, equitable and safe access to water and sanitation remains a challenge for many communities around the world.

The lack of adequate sanitation and appropriate wastewater management directly affects people and the environment alike. Consequently, it also hinders other human rights that depend on water, such as the rights to development, to life, to health and food.

There is a universal understanding that access to water is necessary to sustain human life and ecosystems, but its true value is still not fully appreciated. The value of water is often equated to what is paid, rather than the catastrophic cost of not having enough of it to fulfil basic needs. Despite the progress made in the past decade to tackle core issues, such as open defecation and the lack of sanitation systems, far too many people – an estimated 46 per cent of the world's population – still do not have access to these basic facilities (United Nations 2023a). This has enormous repercussions on people's dignity and health, as well as contributing to exacerbating environmental pollution, a situation that will become more serious with changing climatic conditions and increasing populations (Intergovernmental Panel on Climate Change [IPCC] 2022). The provision of sanitation and the management of wastewater is therefore as much a human rights issue as it is a governance, technical and financial challenge. Effectively managing wastewater in a way that recognizes these rights must be a priority if there is to be any chance of achieving the SDGs.

The human right to a clean, healthy and sustainable environment

On 28 July 2022, the United Nations General Assembly passed a resolution A/RES/76/300 (United Nations, General Assembly 2022) on the human right to a clean

Discharge of untreated wastewater also reduces the opportunity to reuse this potentially valuable resource (Peters 2015). There are several reasons why partially or untreated wastewater is being discharged into receiving waterbodies, including the ocean: poor wastewater collection, insufficient or inadequate treatment infrastructure, expanding populations and urban areas (Corbin 2020), and the increased spatial and temporal variability in precipitation events resulting from changing climatic conditions (Voulvoulis 2018).

Description of the different fractions of wastewater

Domestic/urban water – *Grey water* is water that has been used for bathing, laundry, cleaning and cooking. It can contain a range of contaminants, including cleaning products, disinfectants and organic kitchen waste including oil and microplastics. Depending on a household's behaviour, grey water can also contain improperly disposed toxic household chemicals, such as paints or pharmaceuticals. *Black water* is water from toilets. It contains urine and faeces with any associated pathogens and can also contain excreted pharmaceuticals.

Industrial wastewater – Water from any industry (including, for example extractive, transformational and manufacturing industries) that may contain pollutants. The pollutants depend on the type of industrial process e.g., textile production, paper production, mining, energy production, food processing, etc. and can include suspended solids, nutrients, heavy metals, oils and greases, and other toxic organic and inorganic chemicals

Agricultural wastewater – Can contain high concentrations of nitrogen and phosphorus from fertilizer, animal waste, farm chemicals such as pesticides, plastic including microplastic and other contaminants.

Stormwater – Depending on the location, this may contain solid waste, such as plastic, sediment, suspended solids, fertilizer, heavy metals and many other pollutants, especially in urban areas.

and healthy and sustainable environment, ensuring this right is recognized by the United Nations and its 193 Member States. While not binding, the resolution sets an expectation on Member States to enshrine the right to a healthy environment within national and multilateral treaties. This resolution is an opportunity to step up efforts against pollution at all levels. It calls on Member States to ensure that people have access to a "clean, healthy and sustainable environment", and provides safeguards for people to stand up for their rights, including the right to live in a non-toxic environment with safe and sufficient water.

Ensuring this human right will require countries and relevant stakeholders to progress wastewater management and sanitation provision. Addressing wastewater pollution and lack of sanitation has direct, positive repercussions on our daily lives and the environment, and is essential to the realization of this and other human rights.

Addressing wastewater is key to achieving success in key policy areas

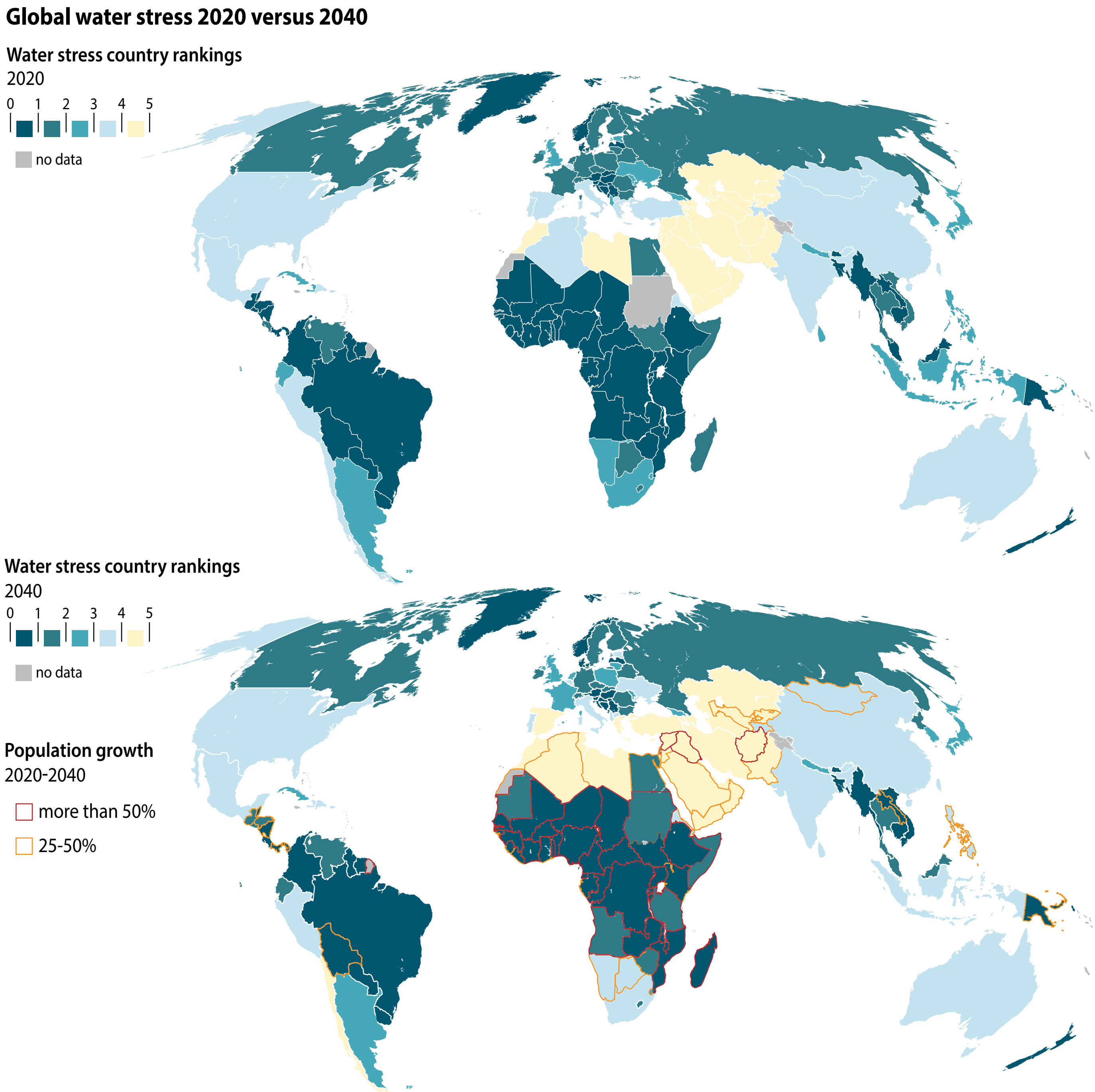
Water is a key enabler, providing multiple co-benefits. It cuts across policy sectors, from the New Urban Agenda to the Paris Agreement on climate change, the Sendai Framework for Disaster Risk Reduction, the Kunming-Montreal Global Biodiversity Framework and the United Nations Convention to Combat Desertification. Water cooperation has been identified as an imperative for global peace and security (High-Level Panel on Water and Peace 2017; Council of the European Union 2018), as well as for dismantling stereotypes to accelerate gender equity, for example through the United Nations Educational, Scientific and Cultural Organization (UNESCO) World Water Assessment Programme (WWAP) Water and Gender Working Group's Call to Action that was launched in 2021 (WWAP 2021). A third of the global population live in water scarce regions (Ruiz 2020), and expectations are that water scarcity could displace up to 700 million people by 2030 (Hameeteman 2013) and act as a multiplier to shortages of other key resources (World Economic Forum 2023).

In 2010, at the time of the publication of the Sick Water? report, the MDGs had the ambition to reduce by half the number of people lacking access to safe drinking water and sanitation by 2015. Wastewater quality and the management of wastewater was not, however, explicitly addressed in the MDGs, and according to Tortajada (2020), this represented an important limitation in realizing this goal. The adoption of SDG 6 under the 2030 Agenda for Sustainable Development ("the 2030 Agenda") in 2015 (see box 2) addressed this shortcoming (United Nations, Department of Economic and Social Affairs [DESA] 2015; Tortajada 2020).

In 2016, following the adoption of the SDGs, the United Nations General Assembly declared an International Decade for Action on Water for Sustainable Development from 2018–2028 ("the Water Action Decade" (A/RES/71/222) (United Nations, General Assembly 2016), aiming to bring visibility to the issue and accelerate global efforts to address water-related challenges. SDG 6, with wastewater management and resource recovery for reuse, is an integral part of the Decade for Action.

Despite increased visibility within the 2030 Agenda, and in particular SDG 6, cooperation on wastewater issues still suffers from lack of visibility in international processes. The review of SDG 6 by the high-level political forum on sustainable development in 2018 concluded that "the world is not on track to achieve SDG 6 by 2030" (United Nations 2018). In many regions, achieving ambitions for SDG 6 and effective water management will require institutional reform to create regulatory frameworks that can channel resources, encourage innovation and provide the necessary guidance incentives to support unconventional approaches.

Marking the midpoint of the Water Action Decade, the United Nations 2023 Water Conference in New York, co-hosted by the Kingdom of the Netherlands and Tajikistan, has provided an opportunity for an in-depth review of progress towards SDG 6, with only seven years remaining before the goals expire. The need to address the whole of the water cycle and progress to achieving a net-zero water industry was highlighted as an important issue that would require cooperation across sectors and governance scales (DESA 2022). Several leaders during the conference highlighted the need to accelerate



Sources: World Resources Institute, 2015; Aqueduct projected water stress rankings; United Nations Population, Division Data Portal; GRID-Arendal/Studio Atlantis, 2023

Figure 1.3: *Global water stress by country in 2020 and 2040.*

investments in addressing ageing infrastructure, watershed management and associated technologies, which included recycling of water and wastewater treatment (United Nations, General Assembly 2023). In addition, the need for water-use efficiency and reuse to become the new norm for all economic sectors emerged as a key message from the conference dialogues (United Nations, General Assembly 2023).

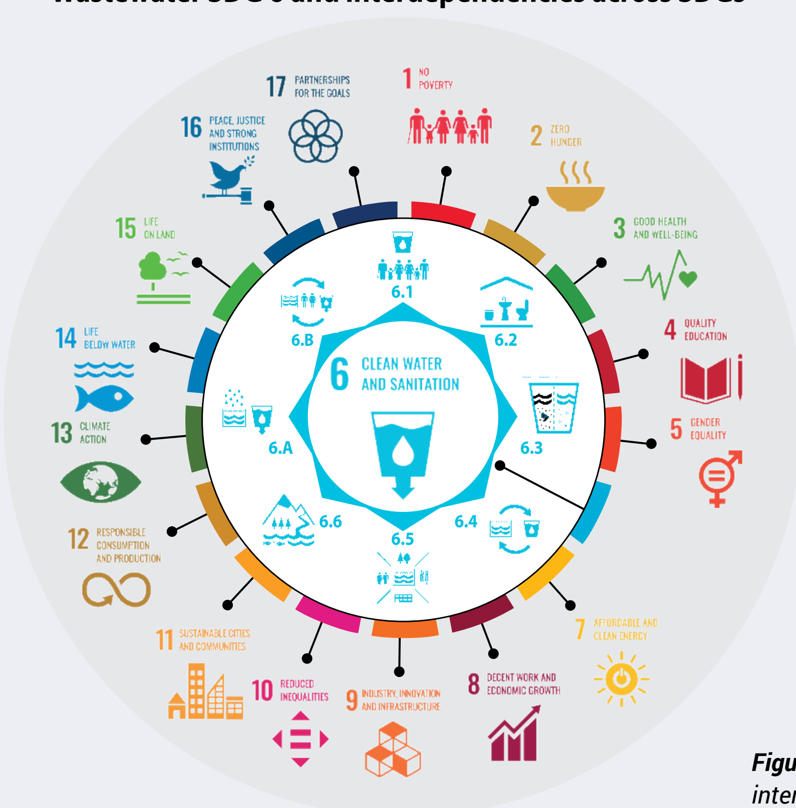
Box 2: The Sustainable Development Goals and wastewater

Water is integral to the Sustainable Development Goals (SDGs) adopted in 2015, an agenda guided by three universal principles: application of a human rights-based approach; leave no one behind; and gender equality and women's empowerment (United Nations DSDG 2022). SDG 6 has an ambitious target to improve wastewater management and safe reuse, explicitly recognizing its importance both in its own right, as well as a contributor to achieving many other SDGs, including food security (SDG 2), health and well-being (SDG 3), achieving gender equality, and empowering all women and girls (SDG 5), clean affordable energy (SDG 7), responsible production and consumption (SDG 12), climate action (SDG 13), life below water (SDG 14) and life on land (SDG 15), among others.

SDG 6 sets the ambition to ensure access to water and sanitation for all by 2030. Specifically, target 6.3 aims, by 2030, to improve water quality by reducing pollution, eliminating dumping, minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater, and substantially increasing recycling and safe reuse globally (DESA 2015).

Two indicators have been adopted to track progress in implementation: the proportion of total domestic and industrial wastewater flows safely treated (6.3.1), and the proportion of waterbodies with good ambient water quality (6.3.2). There is currently no indicator adopted to measure the reuse component of the target, although this is in development as part of indicator 6.3.1. Water quality has tremendously degraded due to effluent discharge and countries are still lagging on achieving both indicators 6.3.1 and 6.3.2 (UN-Habitat and World Health Organization [WHO] 2021). Progress to deliver SDG 6 target 6.3 is considered in chapter 3.2 of this report.

Wastewater SDG 6 and interdependencies across SDGs



GRID-Arendal/Studio Atlantis, 2023

Figure 1.4: *Wastewater SDG 6 and interdependencies across SDGs.*

Why focus on wastewater resource recovery and reuse?

As we use water in our lives, our businesses and industries, its physical, chemical or microbiological qualities are inevitably altered. It becomes "wastewater" and is flushed down the drain or down our toilets. Some wastewater is cleaned before it re-enters the water cycle, but this is not always the case with an estimated 48 per cent being released back into the environment untreated (Jones *et al.* 2021).

If human rights and global policy ambitions with regards to water are to be realized, there must be fundamental and systemic changes to our behaviour and attitudes around water use and wastewater. "In a world where demands for fresh water are evergrowing, and where limited water resources are increasingly stressed by overextraction, pollution and climate change, neglecting the opportunities arising from improved wastewater management is nothing less than unthinkable" (WWAP 2017). Water, once used, needs to be collected, treated, any by-products recovered and utilized, and clean water either returned to the environment or reused.

What is meant by "wastewater reuse"?

For the purpose of this report, reuse of wastewater is the practice of using untreated, partially treated or treated wastewater for resources, including potable and non-potable water, irrigation water, nutrients, energy and heat value. Safe wastewater reuse is when the wastewater has been subjected to the appropriate level of treatment required to reach the quality standard for the intended purpose.

The reuse of wastewater presents a solution for mitigating the environmental, health and climate impacts of wastewater disposal. Wastewater is a renewable resource within the hydrological cycle but can contain harmful contaminants that need to be removed or neutralized. If properly managed, wastewater can be a valuable resource for multiple purposes, including potable water, water for industry, agricultural or aquaculture uses, nutrient recovery for fertilizer and green energy production.

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Table 1.1: *The connection between sustainable wastewater management, resource recovery and reuse, with key societal concerns.*

Societal concerns	Potential contribution to be gained from improved wastewater treatment, resource recovery and reuse
Water security	Withdrawal of water resources continues to increase, with escalating costs and increasing pollution. A gap between water supply and demand of approximately 40 per cent is expected by 2030 if current practices continue (2030 Water Resources Group 2009). Closing this gap needs diversification of water supply sources, for both potable and non-potable applications, by integrating the use of unconventional water resources, including recovery from wastewater (Tzanakakis, Paranychianakis and Angelakis 2020) (see figure 1.3).
Energy security	The good news is that there is about five times more energy in wastewater than is required for its treatment (Hao *et al.* 2019). As the volumes of wastewater are expected to increase over time, by 2030, the energy embedded in wastewater could be enough to fulfil the energy needs of 196 million households, increasing to 239 million households by 2050 (Qadir *et al.* 2020).
Food security	Another promising feature of wastewater is the nutrients it contains. Recovering these nutrients reduces dependence on high cost- and energy-intensive conventional fertilizers. Qadir *et al.* (2020) reported that the annual global volume of wastewater contains an estimated 16.6 million tonnes of nitrogen, 3 million tonnes of phosphorus and 6.3 million tonnes of potassium. Recovering these nutrients could offset 13.4 per cent of the global agricultural nutrient demand.
Environmental security	Water is vital to peace and security (High-Level Panel on Water and Peace 2017). Sustainable management of wastewater can help contribute to achieving environmental security through not only optimizing how we use this resource, but also avoiding the environmental damage from pollution.
Biodiversity loss	Pollution, including from unmanaged or inadequately managed wastewater is recognized as one of the five direct drivers of biodiversity loss (IPBES 2019). In December 2022, a new global target was adopted under the Kunming-Montreal Global Biodiversity Framework, agreed at the 15th meeting of the Conference of Parties to the United Nations Convention on Biological Diversity, to “reduce pollution risks and the negative impact of pollution from all sources, by 2030, to levels that are not harmful to biodiversity and ecosystem functions and services, considering cumulative effects, including: reducing excess nutrients lost to the environment by at least half including through more efficient nutrient cycling and use…” (target 7) (Convention on Biological Diversity [CBD] 2022). The negative impact of excess nutrients in wastewater on aquatic biodiversity and ecosystem services is well documented (CBD 2022). Improving wastewater management will reduce pollutants entering receiving waters (including nutrients, harmful substances and plastics). Technologies exist to recover 75 per cent of nitrogen and 20–50 per cent of phosphorus for reuse in agriculture, while wastewater treatment technologies can reduce the concentration of nitrogen and phosphorus in wastewater by up to 80 per cent and 96 per cent, respectively (Kanter and Brownlie 2019). This would increase access to valued resources, reduce a key pressure on ecosystem integrity and contribute to alleviating one of the key drivers of biodiversity loss (CBD 2022).

Table 1.1 *(continued)*

Societal concerns	Potential contribution to be gained from improved wastewater treatment, resource recovery and reuse
Gender equity	The exposure of vulnerable groups, especially women, farmers and children, to partially treated or untreated wastewater requires specific attention. Women play an important informal role in the management and use of wastewater (International Labour Organization 2017), in addition to which Ungureanu, Vlădu and Voicu (2020) identify women and children as being at particular risk of disease from eating food produced with wastewater. The development of policies and interventions needed to realize benefits from wastewater resource recovery and reuse will require a gendered perspective to ensure solutions are both safe and appropriate (Taron, Drechsel and Gebrezgabher 2021; see also case study 16 – Georgia). The WWAP Water and Gender Working Group's Call to Action for accelerating gender equity across the water domain was adopted in 2021 and included a road map to ensure successful delivery of the 2030 Agenda.
Sanitation and health	According to WHO, over 1.7 billion people still lack sanitation services, and as of 2020, almost half of household wastewater generated was discharged without safe treatment (Jones *et al.* 2021; WHO 2022). Increased collection and treatment of wastewater will reduce exposure of people to wastewater and reduce contamination of water supplies. Increased recovery of used water increases access to water for sanitation and consequently lowers health costs and reduces premature deaths.
Climate change mitigation and adaptation	Climate change is expected to increase water insecurity in many already vulnerable communities. Harnessing wastewater is one adaptation strategy that can help address the problem (see box 3).

Box 3: Wastewater reuse and climate change

Water security is critical to achieve the SDGs and will require climate-resilient, circular solutions (IPCC 2022), including in the wastewater sector. Climate change is projected to increase variability in weather patterns and rainfall, with around half of the world's population facing severe water scarcity for at least one month per year (IPCC 2022). This affects people's access to safe water, in particular vulnerable groups, including women, children and older persons. For example, as water scarcity increases the amount of water available for farming decreases, particularly the informal sector on which women are particularly dependent. This results in greater vulnerability to income and food security (Food and Agriculture Organization of the United Nations [FAO] 2017). Extreme conditions also disrupt wastewater collection and treatment services.

The wastewater sector produces emissions from the organic breakdown of matter, which are important sources of methane and nitrous oxide, both powerful greenhouse gases (GHGs), particularly over the short term (Bartram *et al.* 2019). Globally, wastewater and sludge management are responsible for 257 million tonnes of carbon dioxide equivalents, almost half being energy-related emissions. In addition, 267 million tonnes of carbon dioxide equivalents from on-site sanitation. It also estimates that nitrous oxide is responsible for 32 per cent of emissions from sewered wastewater treatment (Lutkin *et al.* 2022). It is estimated that the degradation of organic matter during wastewater treatment contributes ~1.57 per cent of global GHG emissions and 5 per cent of global non-carbon dioxide GHG emissions (Dickin *et al.* 2020). In addition, the conventional treatment processes to deal with wastewater are energy intensive and are estimated to account for 3 per cent of global electricity consumption (Dickin *et al.* 2020). As countries implement measures to increase wastewater treatment, towards the ambitions of SDG 6.3, these figures are likely to increase. For example, increased urbanization and consequently an increase in wastewater treatment plants has meant emissions from domestic wastewater increased 400 per cent between 2000 and 2014 (Du *et al.* 2018) and still requires significant increase in treatment capacity by 2030 to meet the target (Jones *et al.* 2022).

Water was identified as an imperative for climate action at the Conference of the Parties to the United Nations Framework Convention on Climate Change in November 2022 (COP 27), with calls for a more integrated, circular approach to water management, and the potential

contribution that management and reuse of wastewater can make to adaptation and mitigation (Water and Climate Coalition 2022). This provides an entry point to strengthen collaboration between climate and water stakeholders (United Nations 2023a).

Mitigation: The design of wastewater treatment can improve efficiency in energy requirements (Dickin *et al.* 2020), including use of nature-based solutions (NBS), where this is appropriate. In addition, wastewater can be treated to produce biogas, heat and electricity (United Nations 2023a), which can be used to supply on-site energy requirements, reducing the requirements for using fossil fuels and significantly contributing to the reduction of carbon dioxide and methane emissions for the sector. Net-zero carbon wastewater treatment plants are possible through the use of energy from biogas to meet energy requirements for wastewater treatment, as technologies for energy recovery from wastewater are well developed. Global Water Intelligence (2022) maps water utilities and wastewater treatment plants with commitments towards the net-zero or climate neutrality targets, some of which have joined the United Nations Framework Convention on Climate Change's Race to Zero global campaign.

Adaptation and resilience: Water reuse enhances adaptation and resilience to climate change, especially in regions with already high water stress, including due to climate change impacts and growing water demand. Treated wastewater offers an alternative and reliable source of water that, depending on treatment level, can be safely and appropriately reused to reduce vulnerability to water scarcity. In addition, according to climate change scenarios, many freshwater systems will become increasingly stressed, and appropriately treated wastewater can help to maintain environmental flows of receiving systems. The Synthesis Report of the IPCC Sixth Assessment Report highlights the risks to water-intensive industries, and the need to recycle and reuse water to reduce impacts of water stress (IPCC 2023).

The Action on Water Adaptation and Resilience initiative was launched in November 2022 by Egypt, as host of COP 27, in partnership with the World Meteorological Organization, to address water in the context of climate change adaptation, and will be delivered by the Pan-African Centre for Water Climate Adaptation. Sustainable wastewater management and its safe reuse is an explicit component of this initiative (COP 27 Presidency and World Meteorological Organization 2022).

PART 2

The potential for wastewater resource recovery and reuse

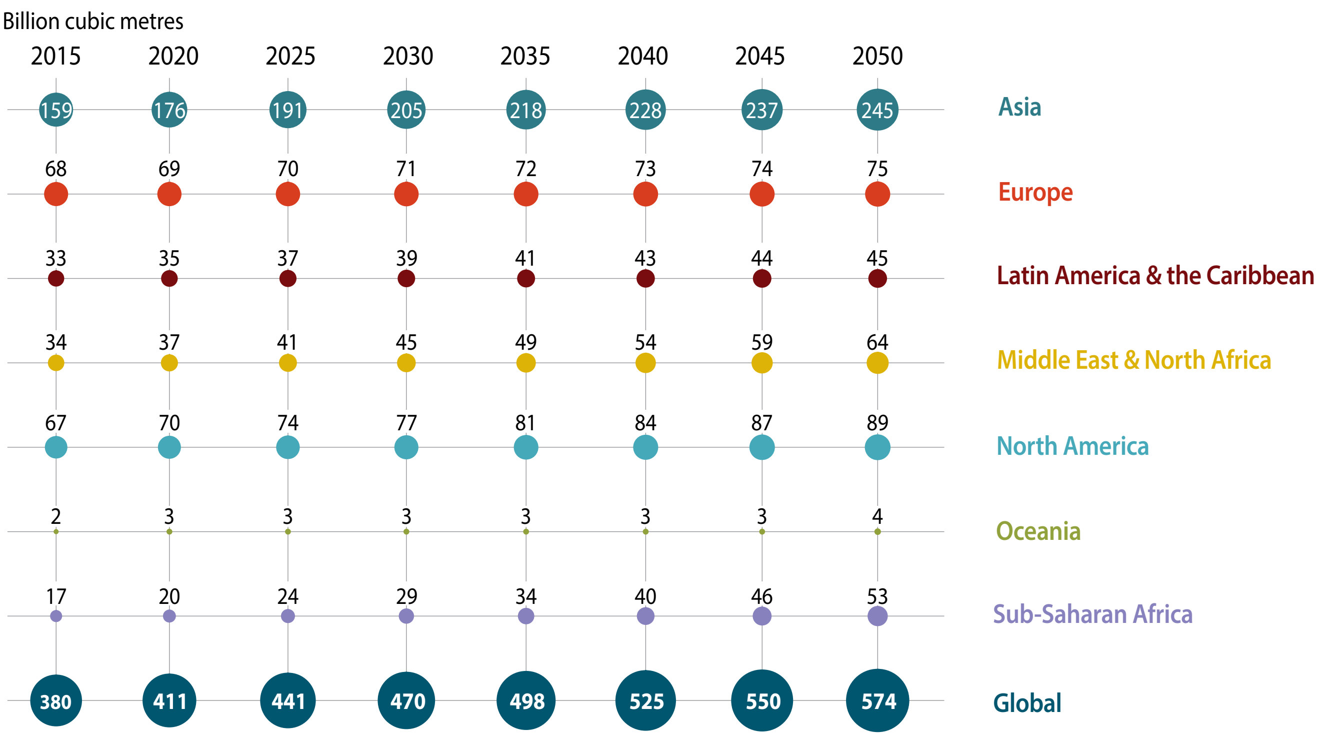
Wastewater in numbers

How much wastewater is being produced?

In 2013, Sato *et al.* estimated the annual production of wastewater to be 330 billion m³ (m³ = 1 000 litres) (Sato *et al.* 2013). This volume has been estimated to increase to 497 billion m³/year by 2030 (Jones *et al.* 2022) representing an increase of just over 50 per cent in the volume of wastewater produced between 2013 and 2030, when the SDGs expire. Box 4 presents an explanation of the different fractions of wastewater included in these estimates.

The global average per capita production of wastewater is 49 m³ per year. The United States of America population average is four times this amount per capita (211 m³/year), the Canadian average is 198 m³/year per capita, with small prosperous European States such as Andorra at 257 m³/year per capita, Austria at 220 m³/year per capita and Monaco at 203 m³/year per capita (Jones *et al.* 2021). Comparatively, the larger Western European countries have lower wastewater production per capita, with Germany, the United Kingdom of Great Britain and

Municipal wastewater production across regions in 2015 and predicted until 2050



Source: Qadir *et al.* 2020; GRID-Arendal/Studio Atlantis, 2023.

Figure 2.1: *Municipal wastewater production across regions in 2015 and predicted until 2050, calculated using wastewater data from different sources.*

Northern Ireland and France at 92 m^3/year, 92 m^3/year and 66 m^3/year per capita, respectively. Conversely, most sub-Saharan African countries produce less than 10 m^3/year per capita (Jones *et al.* 2021).

How much is being treated?

There is an often quoted statistic that "over 80 per cent of wastewater is released to the environment without being treated or reused". However, this figure has been difficult to substantiate. The SDG indicator 6.3.1 measures the proportion of domestic and industrial wastewater flows that are safely treated. However, the data reported in the 2021 progress report are predominantly for domestic urban wastewater flows, with industrial wastewater flows reported for only 14 countries. Where industrial wastewater has been reported, about one third undergoes treatment (UN-Habitat and WHO 2021). However, current reporting leaves important data gaps in understanding how much of the world's industrial wastewater is treated.

For domestic wastewater (considering rural and urban domestic wastewater) SDG indicator 6.3.1 data suggest that around half enters the environment without adequate treatment (UN-Habitat and WHO 2021). This is supported by an analysis by Jones *et al.* (2021), who calculated that for domestic and urban wastewater in 2015, globally, 63 per cent of wastewater was collected, 52 per cent was treated and 11 per cent was intentionally reused (see figure 2.2). These statistics were produced based on reported and modelled data, and again, the authors have acknowledged uncertainty in the underlying data, as well as discrepancies in these numbers across geographic regions and by level of economic development. Different approaches to calculate outcomes produce different results, and the information provided for decision-making should be used recognizing these limitations. Improving the quantity and quality of data relating to wastewater and its recovery and reuse, including gender-disaggregated data, will be important for improving management. The issue of monitoring for wastewater management and reuse is picked up again later in this report as a persistent barrier.

Are we on track to achieve SDG 6.3?

There is still a need to drastically increase the expansion of wastewater collection and treatment capacity to meet SDG 6.3. Jones *et al.* (2022) estimated that China would need to increase treatment capacity by 40 billion m^3/year by 2030; the United States by 15.9 billion m^3/year, India by 14.9 billion m^3/year and Indonesia by 11.6 billion m^3/year. The question is what this increased treatment capacity will look like.

Currently only 11 per cent of the estimated total volume of domestic and manufacturing wastewater being produced

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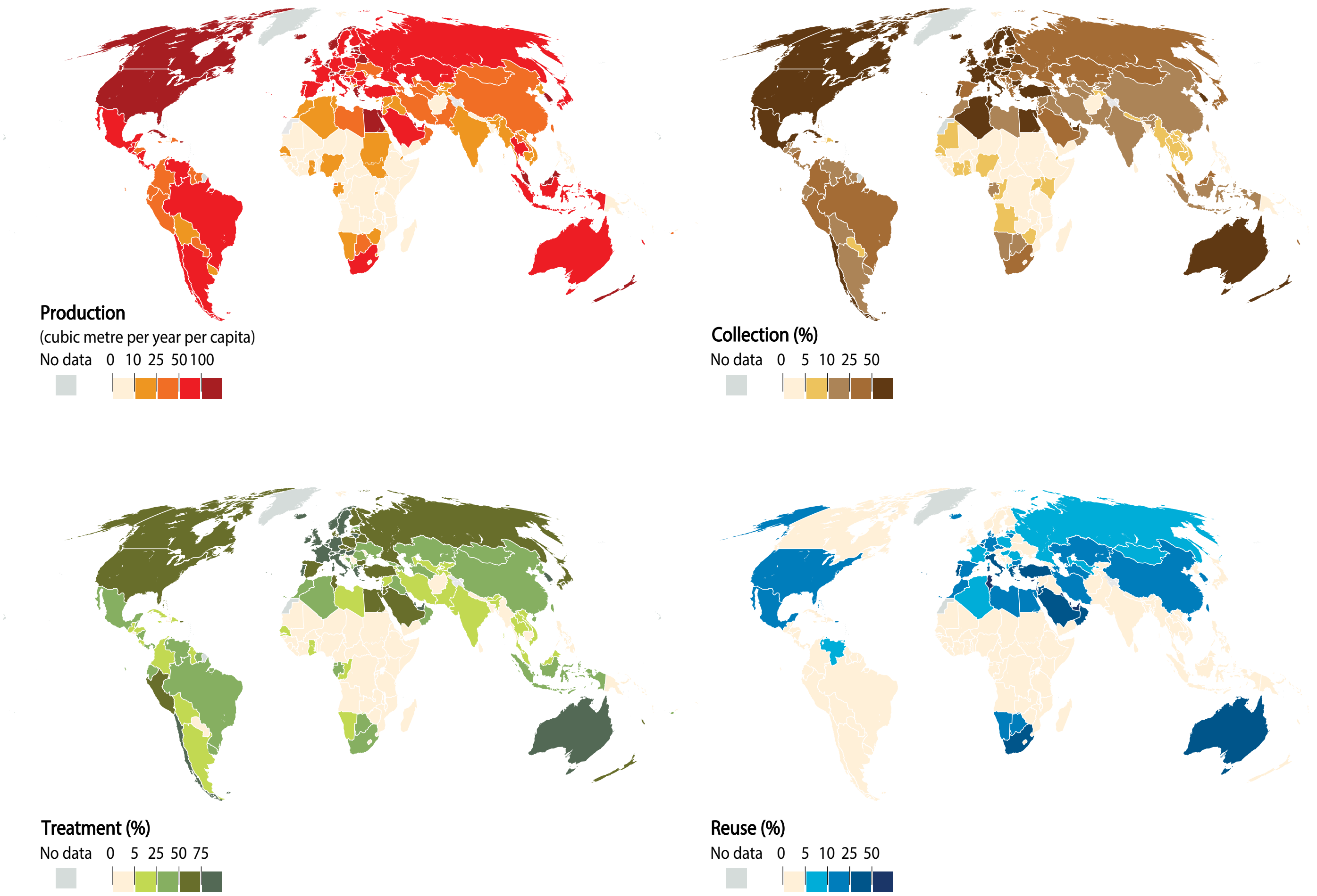
Country level estimates of wastewater production, collection, treatment and reuse



Source: Jones *et al.* 2021; GRID-Arendal/Studio Atlantis, 2023.

Figure 2.2: *Estimates of country level (a) domestic and manufacturing wastewater production (m³/year per capita), (b) collection (%), (c) treatment (%), and (d) reuse (%) at the country scale, based on 2015 data and reproduced from Jones et al. (2021).*

is being intentionally reused (Jones *et al.* 2021). The planned reuse of treated municipal wastewater has been predicted to increase 271 per cent, from approximately 7 billion m^3/year in 2011 to 26 billion m^3/year in 2030 (Global Water Intelligence 2014). The untapped potential for wastewater reuse is around 320 billion m^3/year, with the potential to supply more than 10 times the current global desalination capacity (Jones *et al.* 2021). This is likely to be a gross underestimate of the potential for wastewater reuse, due to data gaps. The best data available are for municipal wastewater, which comes from urban domestic and commercial sources, and any parts of industry or urban agriculture that are connected to the municipal sewer networks. Increasing the percentage of treated water being intentionally reused could help to relieve the increasing pressure on freshwater supplies.

Jones *et al.* (2021) found that reuse is highest in the Middle East and North Africa Region and in Western Europe, with high rates also in water scarce small island developing States. Approximately half (52 per cent) of intentional reuse of treated wastewater occurs in high-income countries. Reuse is lowest in areas where collection and treatment are also low (e.g. sub-Saharan Africa or South Asia), or in areas where there are abundant conventional water supplies (e.g. Scandinavia, where reuse is less than 5 per cent). Israel and Singapore have national reuse policies in place. In Israel, almost 25 per cent of the country's water demand is met by reused water, and in Singapore, it can be 40 per cent (Kehrein *et al.* 2020). In 2015, China reclaimed 10–15 per cent of its wastewater in 2019, with ambitions to exceed and reach 15–30 per cent in 2020 (Xu *et al.* 2020).

Box 4: Wastewater data and statistics

While this report considers wastewater in its broadest sense, there are considerable difficulties in assessing wastewater production, treatment, collection and reuse due to data gaps, and inconsistencies in reporting of the source of wastewater data, its scale and frequency, although there are several attempts (Qadir *et al.* 2020; Jones *et al.* 2021; UN-Habitat and WHO 2021). Another challenge is that different studies include multiple data sets and different terminology.

- Qadir *et al.* 2020 – assessed municipal wastewater, considering it as a possible combination of (a) domestic effluent consisting of black water from toilets, grey water from kitchen, bathing and other household uses; (b) waste streams from commercial establishments and institutions; (c) industrial effluent where it is discharged into the municipal sewerage systems; and (d) stormwater and other urban run-off ending up in municipal sewerage systems.
- Jones *et al.* 2021– used data on domestic and manufacturing wastewater, and thus excluded agricultural run-off.
- UN-Habitat and WHO 2021 – the report refers explicitly to household wastewater, although in principle, domestic wastewater includes wastewater from services and households, but flows from services are not sufficiently reported to be included at this time.

Agricultural wastewater data
Agricultural run-off is rarely collected and treated. Despite being a major source of pollution, country level data for agricultural run-off is not readily available, and so no estimates can be included in this report.

Industrial wastewater data
Only 14 countries reported on the generation and treatment of industrial wastewater in the latest assessment of SDG indicator 6.3.1, with a third of the reported wastewater volume being treated (UN-Habitat and WHO 2021). The 2021 assessment of this indicator concluded that it was not yet possible to assess regional and global estimates of the proportion of total industrial wastewater flows safely treated.

Wastewater from rural areas
This is another data gap due to the challenges of monitoring wastewater flows in rural areas that are not connected to sewer systems.

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Wastewater in the circular economy

The fresh water that sustains us makes up only 3 per cent of the water on the planet. It is detrimental to keep degrading this finite resource, and improvements are needed in both the environmental and financial performance of the water sector. Circularity thinking provides a framework to develop comprehensive strategies for water management within a circular economy (figure 2.3). It offers an alternative economic model, whereby natural resources, including water sources, are kept at their highest value for as long as possible (UNEP 2019).

The transition to a more circular approach to wastewater treatment is gaining traction to improve resilience, design out waste and restore ecosystems. Efforts to reduce the volumes of wastewater produced, improve collection and treat with a view to increase reuse are central to transforming wastewater from a waste into a resource (International Water Association [IWA] 2016; Voulvoulis 2018).

The motivation for circularity in water and wastewater management is being driven by increasing water stress and cost of water and environmental protection (van Rossum 2020; Breitenmoser *et al.* 2022), with long-standing examples of reuse not only in arid and semi-arid countries such as Namibia, Israel and Jordan, but even in countries considered to have plentiful water resources. In Japan, for example, water reuse started in the 1980s in response to severe drought and increased demand from urbanization and economic growth (Takeuchi and Tanaka 2020). Embracing circularity encourages a holistic approach to water management to prevent and/or reduce the generation of wastewater by decreasing consumption to sustainable levels, optimizing reuse, recycling and cascading water, recovering contaminants, thereby minimizing waste and pollution, storing and recovering water for protecting and regenerating waterbodies (Morseletto, Mooren and Munaretto 2022). Recovering nutrients (such as nitrogen and phosphorus) and reducing the volume of released wastewater can reduce eutrophication and avoid development of dead zones (UN-Water 2020).

In some cases where wastewater treatment is well developed, treatment plants are no longer just removing contaminants during treatment, but are also recovering resources including energy and nutrients (Guest *et al.* 2009). Recovery and reuse of water can reduce the pressure on the resource, which may be stressed seasonally or by intermittent droughts. It is a way of providing long-term resource stability and generating income while also improving environmental outcomes (Byrne *et al.* 2019). In Dakar, Senegal, circularity is being developed because of the co-location of wastewater treatment plants and faecal sludge treatment plants. This has enabled the recovery of resources for: the sale and reuse of treated wastewater for irrigation purposes (horticulture) around Dakar; the production of energy from biogas, saving 25 per cent of energy costs; and 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 (World Bank Group and Global Water Security & Sanitation Partnership 2021).

Increased freshwater withdrawal can result in reduced water being available to sustain natural waterbodies and wetlands, with detrimental effects for biodiversity and associated ecosystem services. Once treated to remove contaminants of concern, such as elevated nutrients, pharmaceutical compounds, microplastics and hazardous compounds, wastewater can be safely fed back into streams, wetlands and waterbodies to maintain water flow and support environmental and recreational (European Union [EU] 2016; Hamdhani, Eppehimer and Bogan 2020).

The estimates and projections on the potential of wastewater for resource recovery are based on the maximum theoretical amounts of water, nutrients and energy that exist in wastewater produced worldwide annually (Qadir *et al.* 2020). However, achieving full-scale resource recovery from wastewater will need a systematic change in policy, legislation, practices and behaviour. Resource recovery from municipal wastewater can generate new business opportunities while helping improve water supply and sanitation services (Otoo and Drechsel 2018). The European Investment Bank (EIB) has estimated that the world water market was 1 trillion euros in 2020, with between 60–70 per cent of the potential of wastewater still unexploited in Europe, creating significant potential for new jobs in this sector (EIB 2022). This is particularly relevant for women, who remain underrepresented in the formal wastewater treatment and reuse sector. One study that looked at wastewater workers in 15 countries found that only 17 per cent of the workforce were women (IWA 2014).

Prevailing water scarcity, energy shortfalls and declining reserves of non-renewable nutrients, such as phosphorus, zinc and copper, underpin the need for greater commitments and investments in the recovery of these resources from wastewater. The good news is that there are an increasing number of real-world examples demonstrating business thinking in a sector that traditionally relies on public funding (Otoo and Drechsel 2018). This is illustrated, for example, in the public-private partnership to convert a traditional wastewater treatment plant into a biorefinery at Billund in Denmark. With continued applied research and technological advances, effective policymaking, private sector involvement and successful business development, the prospects of extracting resources and energy from wastewater will accelerate.

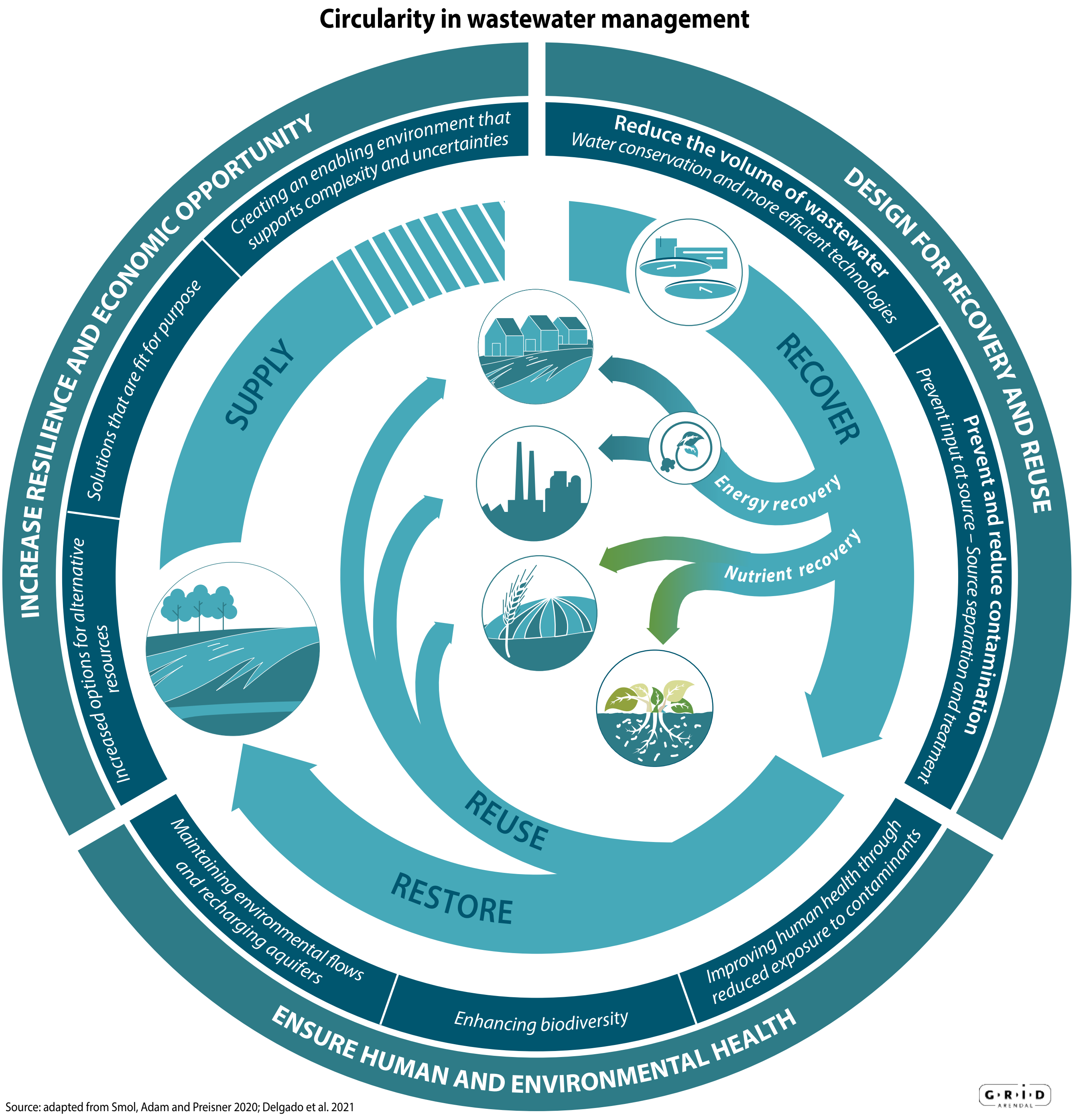


Figure 2.3: *Circularity in wastewater management. Source: adapted from Smol, Adam and Preisner 2020; Delgado et al. 2021.*

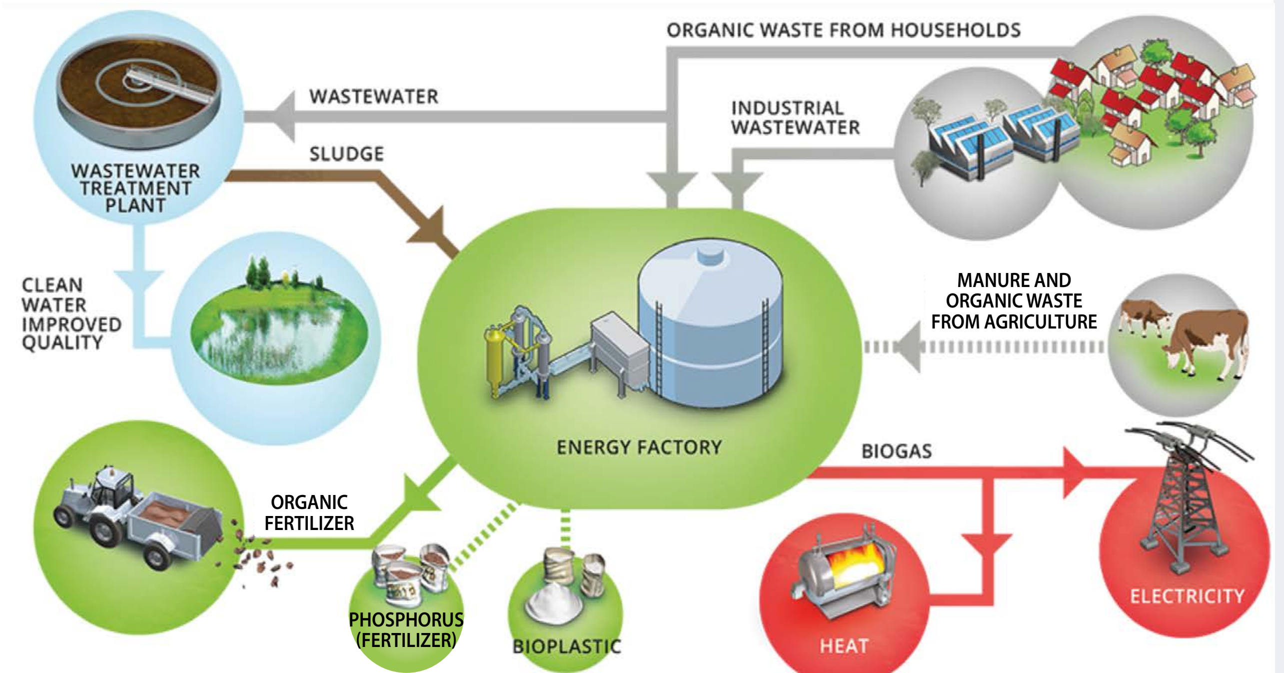
CASE STUDY 1 EXTENDED VERSION

An innovative circular wastewater treatment plant conversion – Billund Biorefinery, Billund, Denmark

Daniel Ddiba

Billund, Denmark, is the home of the LEGO toy company. It is also home to an innovative circular economy wastewater treatment plant. A conventional wastewater treatment plant had been operational since 1996, but because of pressures to reduce costs, increase energy production and generate cleaner water, in 2017, a US$ 12 million public-private initiative converted the facility into the Billund Biorefinery. The facility receives wastewater and solid waste from domestic and industrial sources, treating wastewater for a population of 70 000, as well as 70 000 tonnes per year of sewage sludge and organic waste. Compared with the previous configuration of the plant, the biorefinery has significantly improved the recirculation of nutrients and energy in the town. Up to 98 per cent of all household wastewater and organic solid waste is now recycled, and the plant has doubled its intake capacity for household and industrial organic waste. Energy production has increased by over 60 per cent, and the plant is a net energy exporter with US$ 1.8 million of revenue from annual energy sales – enough for the annual consumption of 1 600 households. Recovery of nitrogen and phosphorus for the organic fertilizer produced at the facility has increased by about 18 per cent, generating US$ 200 000 in revenue per year.

Schematic of the Billund Biorefinery



Source: www.billundbiorefinery.com

Figure 2.4: *Schematic of the Billund Biorefinery. Source: (Billund BioRefinery n.d.).*

What are the resources that can be recovered from wastewater?

There are a range of resources that can be recovered from wastewater streams, including water, nutrients, energy and heavy metals, with a wide range of applications for domestic, agricultural and industrial uses of non-conventional water resources, fertilizers and energy, and for sustaining environmental flows (box 5; figure 2.5). The cost and effort of recovery and benefits vary depending on the targeted resource(s) (figure 2.6). This section describes selected resource recovery with case study examples.

Box 5: Overview of the potential for resource recovery from wastewater

Water recycling

Benefits include:

- reducing the demand on fresh water, especially for non-potable uses
- providing a consistent supply of water in water stressed regions

It is estimated that 160 per cent of the globally available water will be needed to meet the demands by 2030 (Vo *et al.* 2014). At the same time, wastewater volumes are increasing. To put wastewater as a potential alternative resource into perspective, Jones *et al.* (2021) estimated that the over 360 billion m^3 per year of wastewater produced is more than 10 times greater than the global desalination capacity (34.6 billion m^3 estimated in 2019 according to Jones *et al.* 2019). It is obvious that the potential of wastewater is drastically under realized, although it is predicted that the planned reuse of treated municipal water will increase 271 per cent from approximately 7 billion m^3/year in 2011 to 26 billion m^3/year in 2030 (Global Water Intelligence 2014).

Nutrient recovery

Benefits include:

- reducing nutrient run-off into freshwater and coastal environments, reducing eutrophication and the development of dead zones in coastal waters and the ocean, leading to the recovery of freshwater and marine biodiversity, and supporting human activities such as fisheries
- provide an alternative to chemical nitrogen (N), phosphorus (P) and potassium (K) fertilizers

The full nutrient recovery potential from wastewater has been estimated to offset around 13.4 per cent (Qadir *et al.* 2020) of global fertilizer demand in agriculture and generate a revenue of approximately US$ 13.5 billion (as of 2015), (Qadir *et al.* 2020) noting that fertilizer prices in some cases doubled or trebled between 2020 and 2022 (FAO and World Trade Organization [WTO] 2022). In another study focusing on the use of human urine as a nutrient source, Simha (2021) projected that up to 25 per cent of the global demand for nitrogen and phosphorus from agriculture could be met by collecting and processing our urine.

Energy recovery

Benefits include:

- increasing the self-sufficiency of energy-intensive water treatment plants
- providing an alternative to fossil fuels

Based on estimations of methane production, with an estimated global calorific value of 1908 × 109 million joules (MJ) (531 × 109 kilowatt hours [kWh]), and anticipating the average household electricity needs of 3 350 kWh (World Energy Council 2016), enough energy can be recovered to provide electricity for half a billion people (Qadir *et al.* 2020). Another alternative fuel source is the production of solid fuel briquettes from faecal sludge, which can provide a heating value of 25 MJ/kilogram, comparable to that of commercial charcoal briquettes (Ward, Yacob and Montoya 2014).

Figure 2.5: *Potential resources that can be recovered from wastewater.*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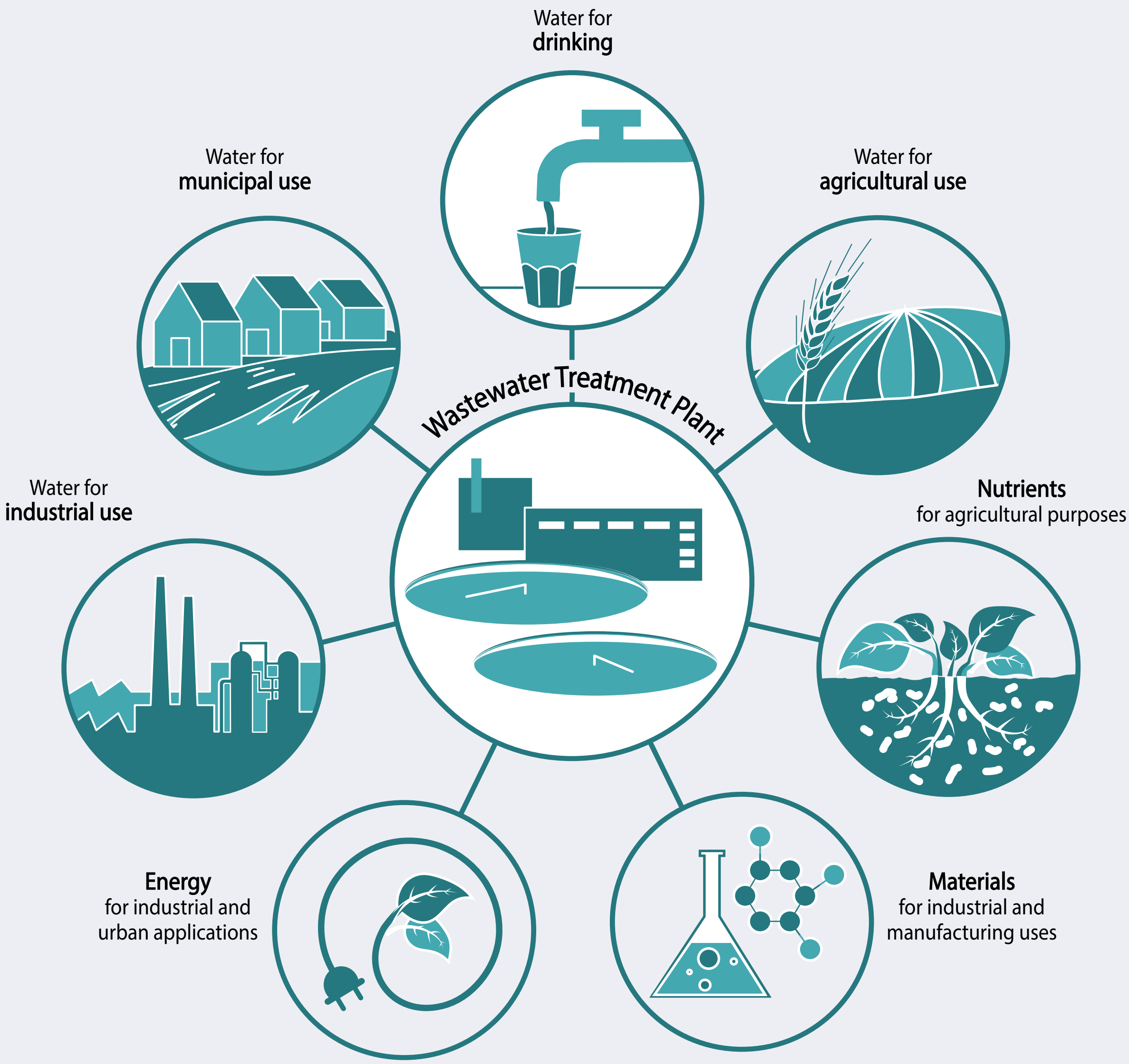
Potential resources that can be recovered from wastewater



Source: GRID-Arendal/Studio Atlantis, 2023

Figure 2.6: *Increasing value propositions related to wastewater treatment based on increasing investments and cost recovery potential. Note: There is a need to reflect on balancing the value of resource recovered with the cost of treatment to produce it and the concept of fit for purpose.*

Safe reusable water

Around 60 per cent of the global population live in areas of water stress where available supplies cannot sustainably meet demand for at least part of the year (Damania *et al.* 2017). The provision of conventional water sources through snowfall, rainfall and groundwater extraction are insufficient to meet growing demand, with a need to find sustainable alternatives (UN-Water 2020). It is estimated that 160 per cent of the globally available water will be needed to meet the demands by 2030 (Vo *et al.* 2014). Increasing rates of freshwater withdrawal, escalating costs and increased pollution are undermining the available water resources, further exacerbated by climate change (Voulvoulis 2018). With wastewater volumes increasing (UN-Water 2020), there is huge potential for fit-for-purpose treatment and use as an unconventional water source for both potable and non-potable applications (Tortajada 2020; UN-Water 2020) (see figure 2.7).

Depending on the treatment and quality standards required by regulation, wastewater can be recovered and safely used for:

- drinking water
- industrial applications, such as cooling power plants
- manufacturing, such as textile production
- irrigation of agriculture and/or municipal parks
- recreational use
- replenishing aquifers
- returning in a good state to waterbodies to maintain environmental flows

The extent of wastewater reuse varies greatly across the world, influenced by water scarcity, availability of technology, as well as regulations, standards and public perception. Some communities have embraced water reuse.

Wastewater treatment offers economic opportunities for water swapping. These schemes include water swaps where, for example, farmers use treated water for agriculture in exchange for fresh water for domestic purposes (Rao *et al.* 2015). In this way, donors (in this example, the farmers) can be compensated for using reclaimed water while releasing freshwater for higher value use, and thereby increasing overall economic water productivity.

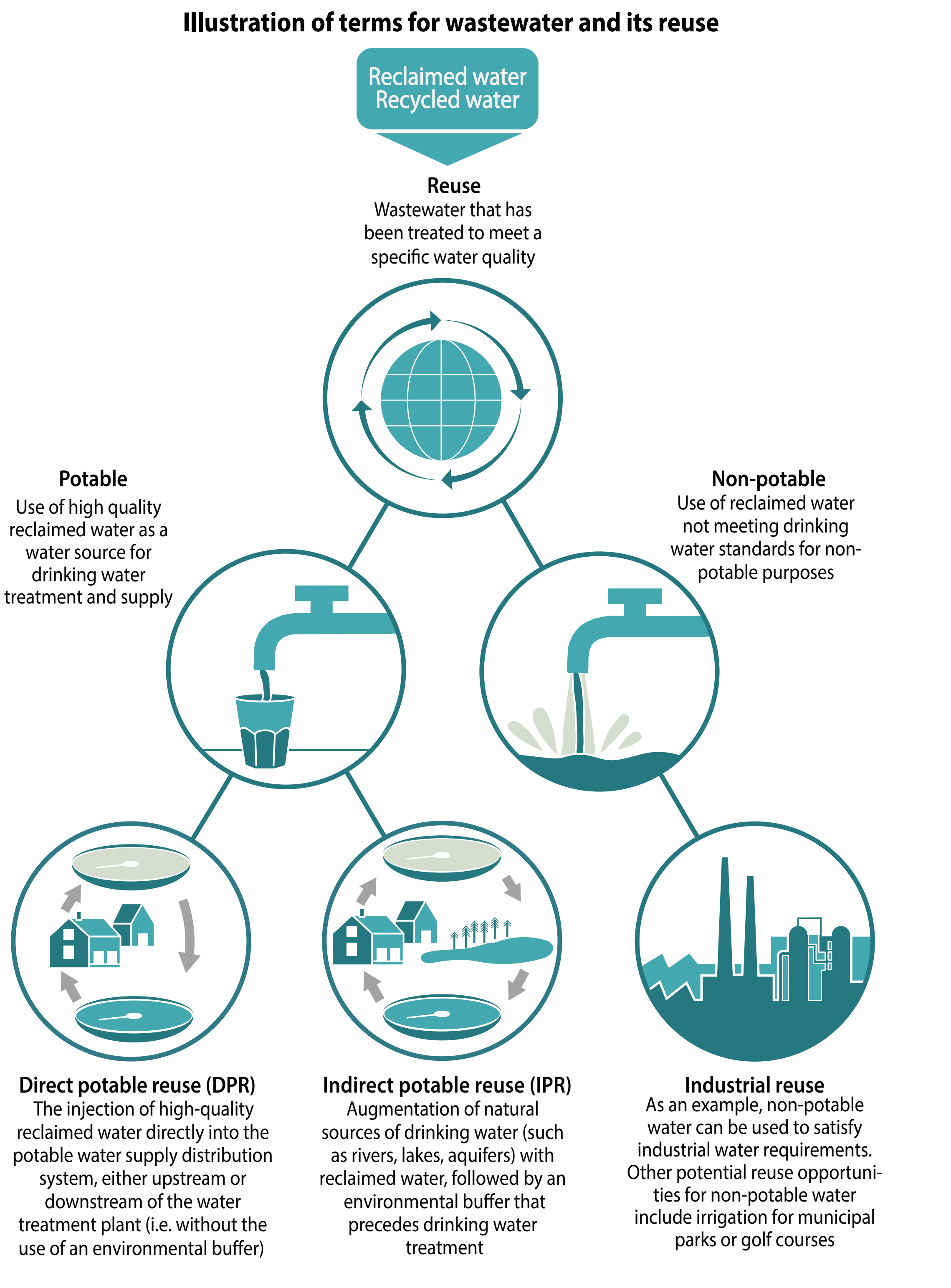


Figure 2.7: *Illustration of terms for wastewater reuse.*

Potable water

There are relatively few examples of direct potable reuse (DPR) (treatment and reuse of water without an environmental buffer [United States, Environmental Protection Agency 2023]), although the practice is not new. Direct reclamation of water for drinking water has been practised in Namibia's capital city of Windhoek for over 50 years, supplying around 400 000 people. Established in 1968, this is the oldest potable reuse project, with the aim to address water scarcity and recurrent drought (Tortajada 2020). Singapore, recognized as the most water scarce city in South-East Asia, provides another example. Driven by a need to increase water security and reduce dependence on importing water, Singapore has made major progress in recycling water (figure 2.7). Since its introduction in 2002, the country can meet approximately 40 per cent of total potable water demand through recycled water, with the objective of reaching 50 per cent by 2060 (High-Level Panel on Water and Peace 2017; Ghernaout, Elboughdiri and Alghamdi 2019).

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In contrast to DPR, there are many locations where treated water is released back into a water supply source, such as a reservoir or river, and then extracted for treatment and distribution. An example is the Torreele facility in Flanders, Belgium. This produces water for indirect potable reuse (IPR) through aquifer recharge and has supplied 60 000 people a day since 2003 (EIB 2022).

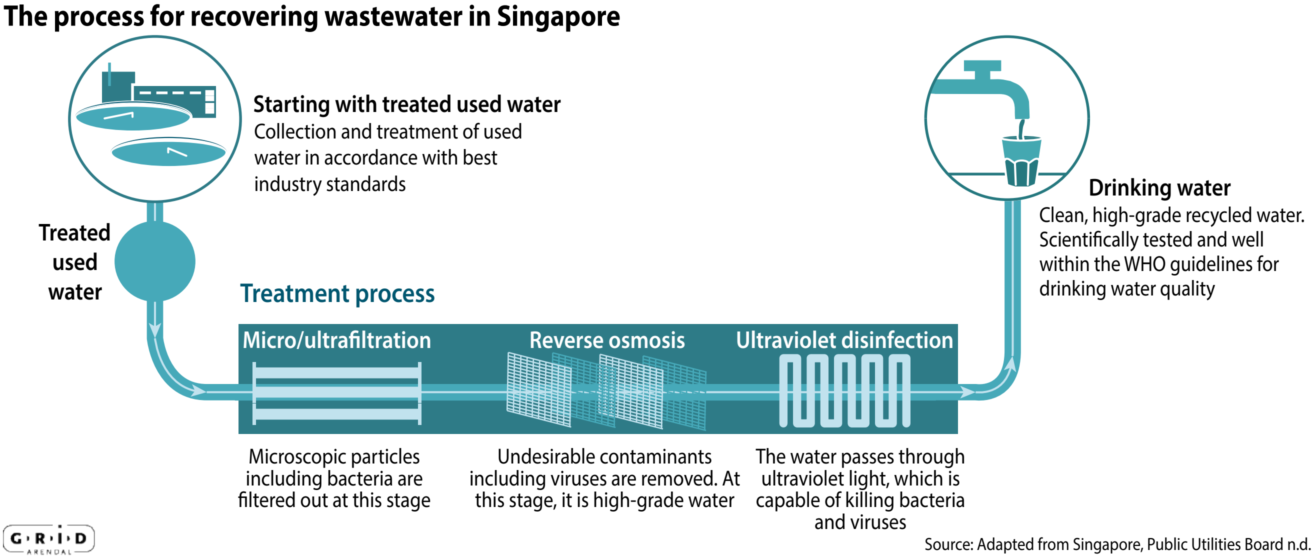


Figure 2.8: *The process for recovering wastewater, branded as NEWater in Singapore.*

CASE STUDY 2 EXTENDED VERSION

Direct potable reclamation in Windhoek, Namibia

Pierre van Rensburg

Extreme water scarcity has been part of the historical water supply scenario for Windhoek, the capital city of Namibia, with a population of approximately 350 000 inhabitants. The semi-arid environment receives on average 360 millimetres of rain annually, with extreme variations. This has caused the nation to rethink the concept of reuse of their limited supply of water. Despite seemingly insurmountable barriers, water reclamation and reuse can enable communities to strategically link the distribution and use of locally available water resources, even to the point of supplying potable water, particularly in areas where sustainable water supply has become a major challenge. First developed in response to a crisis, DPR of wastewater has been practised in Windhoek for more than 50 years, since 1968. This was a milestone for the country, being the first place in the world where purified household sewage was reclaimed for drinking purposes. The Windhoek DPR facility remains crucial to the city during periods of both normal and abnormal water supply. During the 2014–2016 drought, conventional surface water supplies, which supply 75 per cent of what is required under normal conditions, almost entirely failed. In December 2016, these supplies were effectively replaced by temporary high volume withdrawals from the aquifer under the Windhoek managed aquifer recharge scheme, with direct potable reclamation yielding most of the remaining demand, reducing surface water supply to only 3 per cent of the total. Importantly, the DPR design is now developed with solid multi-barriers against several parameters, including the removal of micropollutants and contaminants of emerging concern. Reliable operations, diligent monitoring and keeping abreast of the latest emerging issues is key to maintaining trust to ensure the future of DPR as part of the potable supply to Windhoek. The municipality is painfully aware that a single blunder can destroy over 50 years of trust and hard work in a single heartbeat. This would be catastrophic for a city which currently relies on this source for about 30 per cent of its supply and is facing 6 per cent urban growth per year, with no viable alternatives.

Changes in Windhoek water supply to increase the reuse of treated wastewater as a result of a period of drought

The potable reuse nearly doubled and the non-potable reuse doubled

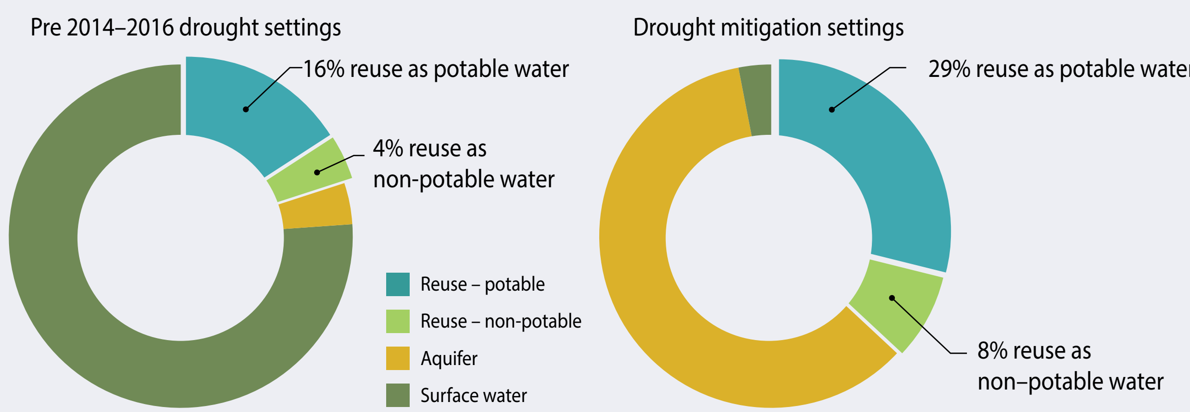


Figure 2.9: *Changes in Windhoek water supply to increase the reuse of treated wastewater as a result of a period with drought.*

Non-potable uses

Agricultural reuse

Agriculture currently accounts for 69 per cent of global water withdrawals. This water is mainly used for irrigation, but also includes water used for livestock and aquaculture. Agricultural use can represent up to 95 per cent of water withdrawals in some developing countries (United Nations 2021). The demand for wastewater use in agriculture is expected to increase and intensify in water scarce areas, especially Australia, western North America, and parts of the Middle East and Southern Europe (Sato *et al.* 2013). As an example, using a cropping intensity of 1.5 crops per year (1–2 crops per year) and average crop water requirements of around 6 000 m^3 per hectare (ha), the irrigation potential of the current volume of undiluted wastewater being produced would be 42 million hectares (Qadir *et al.* 2020). Reusing wastewater could bring new areas under irrigation and reduce reliance on fresh water in areas where agriculture relies on limited freshwater supplies.

In certain arid and semi-arid regions, the substitution of fresh water with wastewater for irrigation is already being practised (Drechsel, Qadir and Baumann 2022). It is widespread in several countries such as Australia, Israel, Tunisia (Dinar, Tieu and Huynh 2019) and Egypt. In 2012, Israel agreed to the Long-Term Master Plan for the National Water Sector through to 2050, setting out a vision and policy objectives with large-scale wastewater reuse a key component. According to a recent report by the Organisation for Economic Co-operation and Development (OECD), almost 90 per cent of the wastewater collected and treated in Israel is reused, mostly for agricultural production (OECD 2023). Between 2010 and 2018, freshwater withdrawal for agriculture decreased from 64 per cent to 35 per cent (OECD 2023).

The demand for safe wastewater reuse is expected to outpace the ability to produce reclaimed water, with the risk that untreated wastewater is used, for example, for agricultural production, increasing pollution and undermining human and environmental health. Pollution prevention is needed by the efficient removal of harmful industrial and domestic contaminants (pathogens, chemicals, human and animal pharmaceuticals). Interim technical and policy responses are needed until the required levels of wastewater treatment are achieved, in order to facilitate safe reuse. Such measures could include improved methods for handling untreated wastewater on farms and in farm communities, better guidance regarding crops and cultural practices most suitable for settings in which wastewater is the primary source of irrigation, and better methods for protecting farm workers and consumers from the potentially harmful pathogens and chemicals in wastewater (Qadir 2018).

Industrial reuse

Globally, industry is estimated to use almost a fifth of freshwater withdrawals (Ritchie and Roser 2018). For many applications, the water quality requirements are not as strict as those for drinking water consumption, and as such, industrial processes can use a lower standard of treated wastewater for cooling, feeding boilers for heating, washing and mixing. Other applications include direct water recycling within the same industry or reusing used operating water without treatment in other industrial processes. Using treated wastewater for these processes can reduce demands on freshwater withdrawals, as well as reducing discharge volumes (EIB 2022), with implications for cost savings and creating competitive advantage (International Labour Organization 2017).

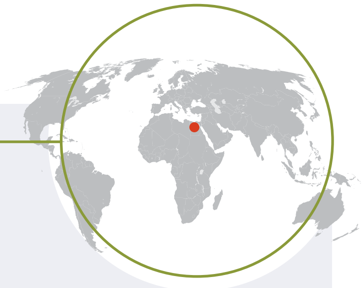
Landscape irrigation and other uses

Reused wastewater can provide an alternative water supply for the irrigation of urban landscape areas, such as parks, gardens and sports fields, as well as for street cleaning and, while not new, is a practice that is an increasing trend worldwide (Zalacáin *et al.* 2019).

Irvine Ranch in California, United States, is a satellite city developed in the 1960s. The planners developed the city with water reuse in mind and developed a separate pipe system for potable water and recycled water. The system means that 91 per cent of the water required for irrigation for municipal lands, parks and golf courses is met by the recycled water (Bauer and Wagner 2022).

The city of Madrid in Spain has been using reclaimed water for the irrigation of its park areas since the early 2000s, due to increasing water stress. Tertiary treated wastewater is sourced from several wastewater treatment plants and distributed to the parks via a pipe network. (Zalacáin *et al.* 2019).

CASE STUDY 3 [EXTENDED VERSION]



Reuse of nutrient-rich agricultural drainage water for food self-sufficiency in Fayoum, Egypt

Fayoum Governorate, Egypt, ongoing project funded by the Water and Development Partnership Programme, the Ministry of Foreign Affairs, Kingdom of the Netherlands

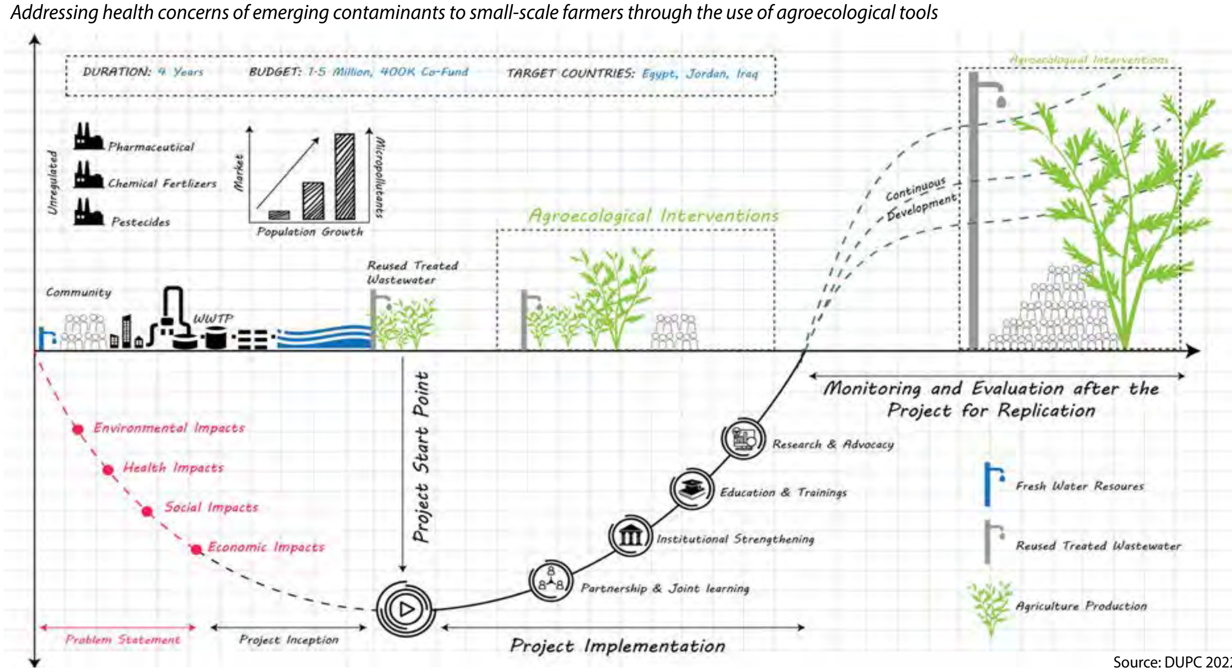
■ **Hadeel Hosney**, IHE Delft Institute for Water Education

South of the Great Sphinx of Giza in Cairo lies the Governorate of Fayoum. About 22 per cent of the population live in urban areas, and 60 per cent of the residents of the region live below the poverty line. Fayoum is located near the downstream end of the Nile River system where the only source of fresh water is the Bahr Youssef canal. Around 80 per cent of the water withdrawn from the canal is used for agriculture. As a result of limited freshwater supply throughout Egypt, including Fayoum, governments have relied on the reuse of agricultural drainage to reduce the gap between the water supply and agricultural demand. This drainage water contains a mixture of treated domestic and agricultural wastewater. In addition, some locations receive an illegal discharge of untreated domestic and industrial wastewater, with potential risks to human health and ecosystems.

The wastewater reuse policy has enabled Egypt to sustain agricultural activities in the valley and delta for decades, including Fayoum. However, such a policy risks adverse health, social and ecological consequences due to emerging contaminants from industrialization, excessive pesticide consumption and pharmaceutical products for human or animal use. The SafeAgroMENA project (IHE Delft Water and Development Partnership Programme 2023) addresses health concerns of emerging contaminants to small-scale farmers. The project will be implemented with the local community, to realize socially acceptable and sustainable safe agricultural drainage water reuse for improved water and food security in Fayoum.

Reuse of nutrient-rich treated wastewater for food self-sufficiency in the Middle East and North Africa

Addressing health concerns of emerging contaminants to small-scale farmers through the use of agroecological tools

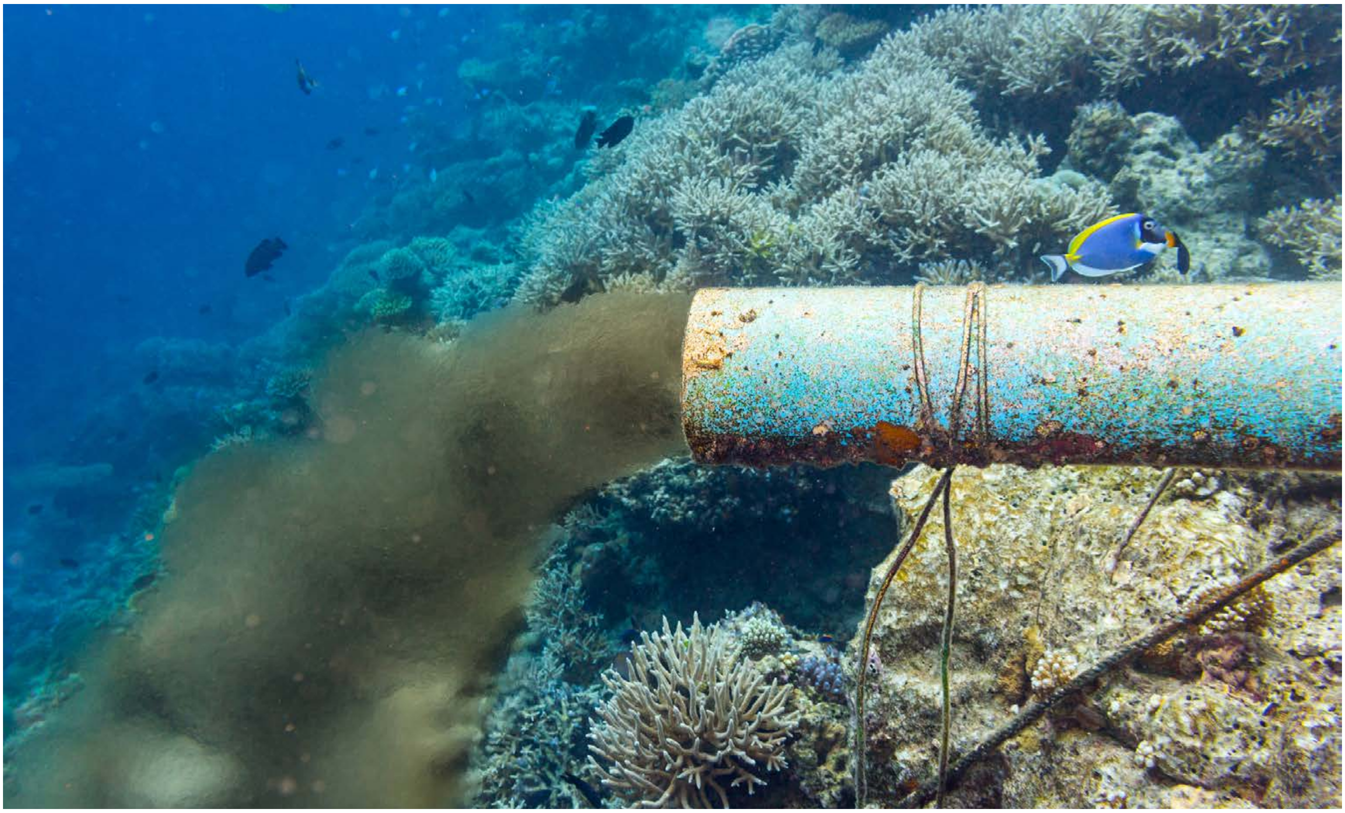


Source: DUPC 2022

Figure 2.10: *Reuse of nutrient-rich treated water for food self-sufficiency in the Middle East and North Africa region.*

Environmental flows

The overextraction, mismanagement and pollution of water risks undermining the ecological integrity of freshwater, estuarine and consequently marine environments. Assuming the treated effluent meets appropriate standards for treated wastewater and effluent discharges, wastewater can be used to maintain, restore or enhance water flows in streams and rivers, and water levels in lakes and wetlands (EU 2016; EIB 2022). This can sustain aquatic biodiversity and provide benefits for the environment and people. It has also been noted that appropriately treated wastewater can be used to recharge aquifers and protect groundwater from saline intrusion (EU 2016). However, unintentional aquifer recharge with untreated or insufficiently treated wastewater still occurs in many areas, which needs special attention as it can lead to human and environmental health risks (Zandaryaa and Jimenez-Cisneros 2017).



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Nutrient recovery

There are many reasons to develop nutrient recovery and reuse from wastewater, including addressing the social, environmental and economic costs of nutrient pollution. Controlling nutrient pollution can reduce eutrophication and the risk of dead zones developing (Schindler *et al.* 2016). It also has the potential to reduce reliance on conventional chemical fertilizers (Saliu and Oladoja 2021).

Nutrients can be recovered from a range of wastewater sources, including agricultural (aquaculture, animal production, abattoirs), industry (tanneries, yeast industry) and municipal (laundry, human urine, sewage) (Saliu and Oladoja 2021). The nutrients of primary focus are those that support plant growth –nitrogen (N), phosphorus (P) and potassium (K). These are valued for ensuring global food security, especially with the skyrocketing cost of fertilizer since 2020, due to global recession following the pandemic, exacerbated by the conflict in Ukraine, impacting production and supply chains (FAO and WTO 2022).

Qadir *et al.* (2020) calculated that the volume of municipal wastewater (see box 4) generated annually contains 16.6 million tonnes of nitrogen, 3 million tonnes of phosphorus and 6.3 million tonnes of potassium. Depending on the level of treatment and the type of nutrient recovery process, anywhere between 10–80 per cent of nitrogen and 33–96 per cent of phosphorus can be removed from wastewater flows (Kanter and Brownlie 2019). Sewage sludge contains around 2.4–5.0 per cent nitrogen and 0.5–0.7 per cent phosphorus (Tyagi and Lo 2013). Human urine is particularly rich in these nutrients (table 2.1) and Simha (2021) estimates that 25 per cent of the global nitrogen and phosphorus demand in agriculture could be met by just recycling human urine-derived nutrients (figure 2.11).

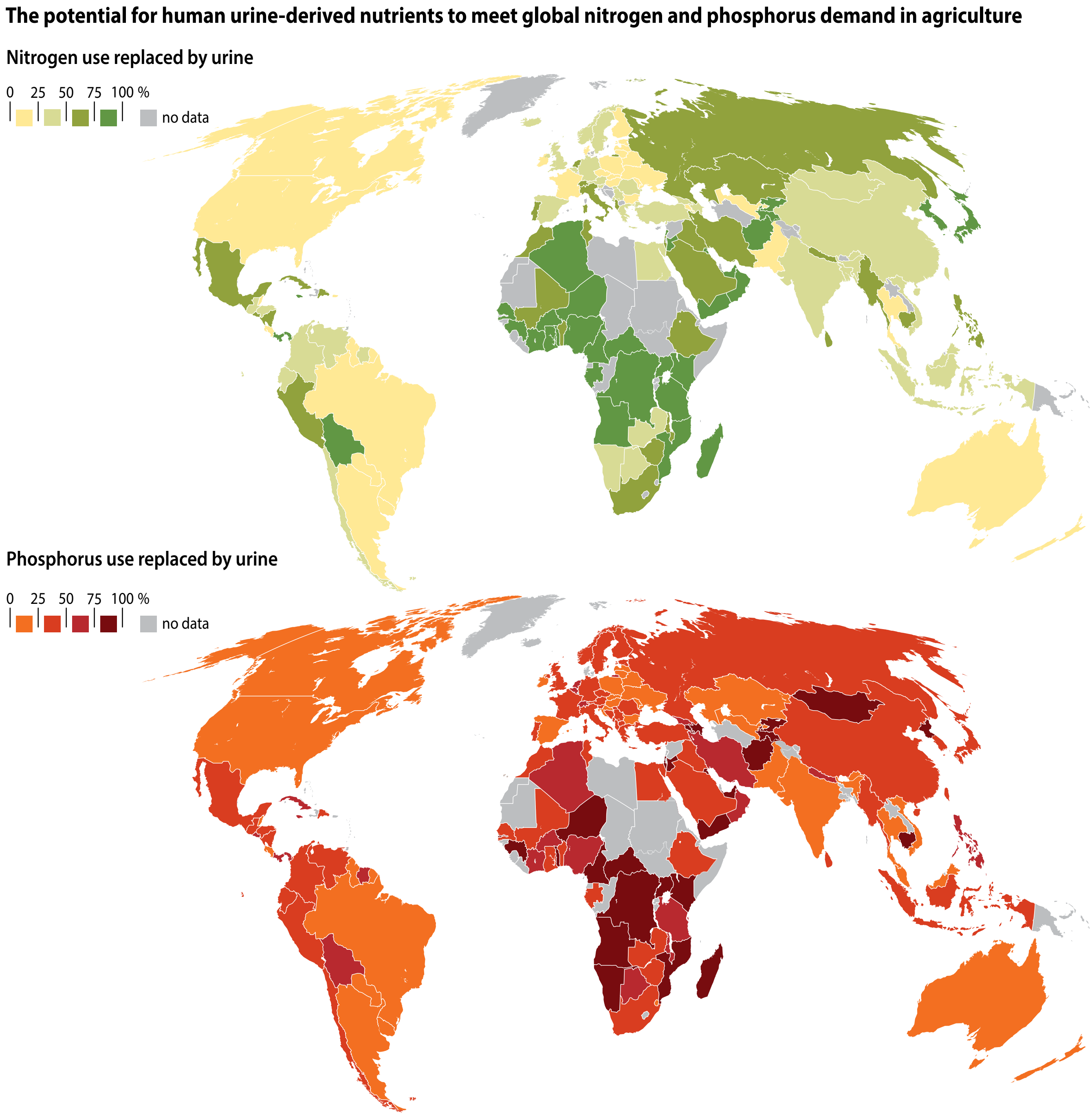


Figure 2.11: *The potential for human urine-derived nutrients to meet global nitrogen and phosphorus demand in agriculture.*

Globally, there is still a low rate of replacement of industrial fertilizer with wastewater derived nutrients. Whilst Kok *et al.* (2018) calculated that at its maximum potential, 20 per cent of global phosphorus demand for agriculture (approximately 19.1 million tonnes/year) could be met from the recovery of phosphorus from urban wastewater alone. However, because of continued but limited availability of cheap rock phosphate in the market only 0.8 per cent of the agricultural demand is actually currently economically feasible (calculated for 2015).

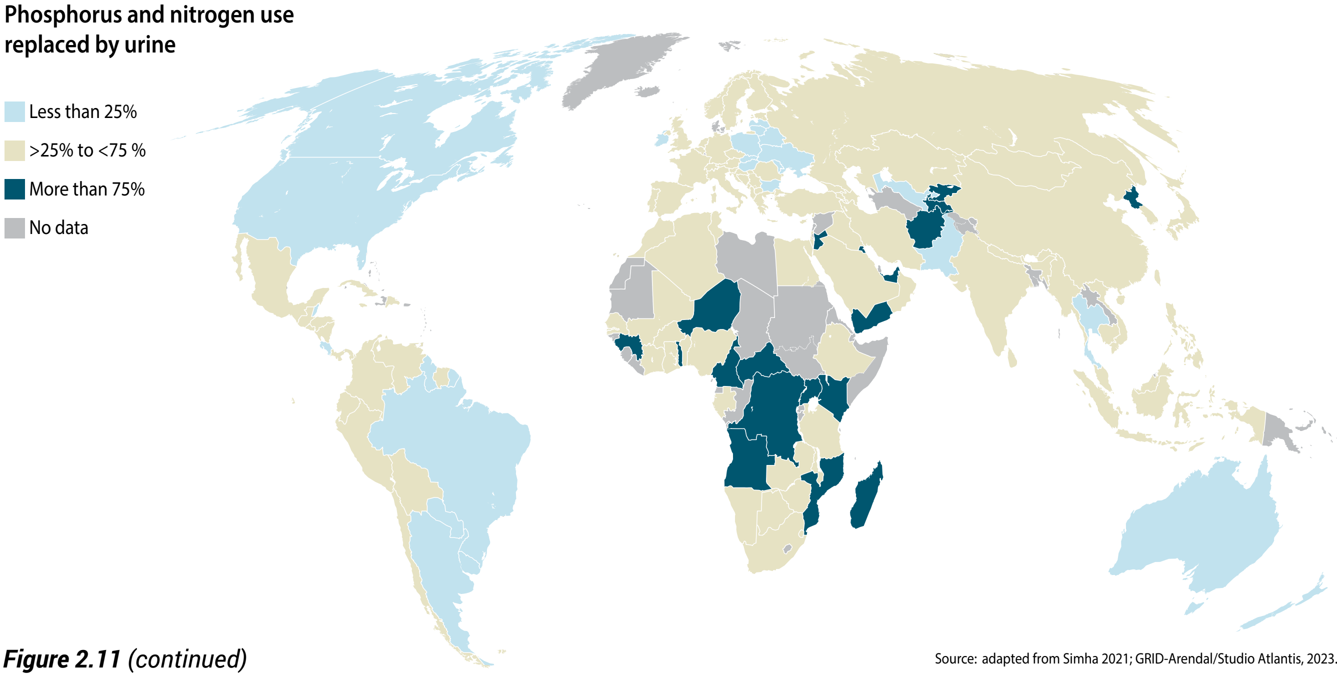


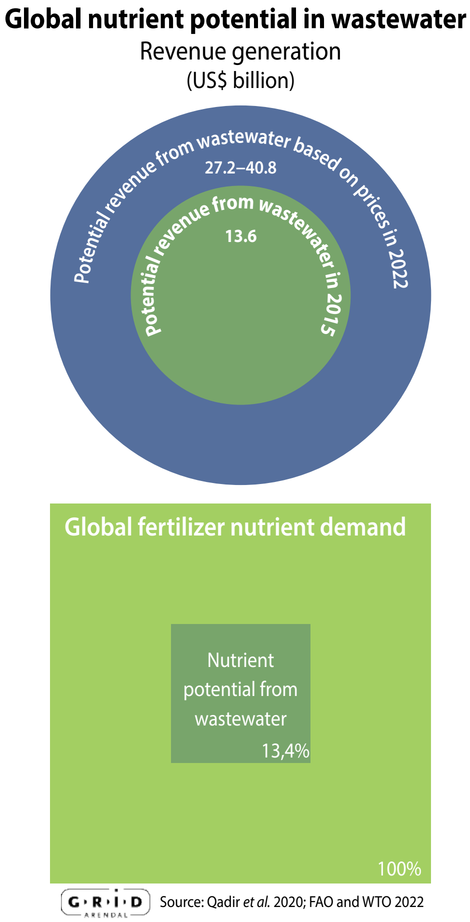
Figure 2.11 *(continued)*

Source: adapted from Simha 2021; GRID-Arendal/Studio Atlantis, 2023.

Table 2.1: *Composition of different fractions of household wastewater produced per person and year.*

	Unit	Urine	Faeces	Grey water
Wet mass	Kilogram (kg)	550	51	36 500
Dry mass	kg	21	11	20
Biological oxygen demand, 7 days	Gram (g)	–	–	9 500
Chemical oxygen demand	g	–	–	19 000
Nitrogen	g	4 000	550	500
Phosphorus	g	365	183	190
Potassium	g	1 000	365	365
Copper	Milligram (mg)	37	400	2 500
Chromium	mg	3.7	7.3	365
Nickel	mg	2.6	27	450
Zinc	mg	16.4	3 900	3 650
Lead	mg	0.73	7.3	350
Cadmium	mg	0.25	3.7	12
Mercury	mg	0.3	3	1.5

Source: Vinnerås et al. 2006.



The recovery of all nutrients from wastewater could offset 13.4 per cent of the global demand for fertilizer (Qadir *et al.* 2020). However, the current nutrient recovery technologies have not attained 100 per cent efficiency levels (Ward *et al.* 2018), although significant progress has been made in nutrient recovery from waste streams (Otoo and Drechsel 2018; Saliu and Oladoja 2021). There are promising developments in the use of decentralized source-separating systems to recover nutrients from human waste streams for agricultural application.

There are significant economic reasons to develop wastewater reuse. In 2015, Qadir *et al.* (2020) estimated that the recovery of nitrogen, phosphorus and potassium from wastewater could result in revenue generation of US$ 13.5 billion (figure 2.12), based on maximum theoretical volumes of wastewater produced. Taking into account recent increases in market prices, this value could be two to three times higher (FAO and WTO 2022). In addition to economic gains, there are critical environmental benefits, such as reducing eutrophication of waterways, which is caused by excess nutrients in untreated or inadequately treated wastewater discharge.

Figure 2.12: *Global potential of nutrients embedded in wastewater at the global level in 2015, and their potential to offset the global fertilizer demand in agriculture, as well as to generate revenue.*

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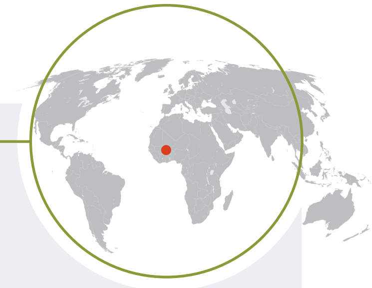
CASE STUDY 4 EXTENDED VERSION



Sustainable productive sanitation solutions in rural Burkina Faso

■ **Linus Dagerskog**

Burkina Faso is predominantly rural (74 per cent), with 85 per cent of the population involved in agricultural activities (Institut National de la Statistique et de la Démographie 2022). Water and sanitation facilities are improving, with a reduction of open defecation as a result of increased construction of pit latrines. However, there is poor nutrient recovery from these facilities. In regions such as rural Burkina Faso, where subsistence farming is dominant and access to commercial fertilizers is challenging, neglecting the fertilizer content of human excreta when introducing sanitation is a missed opportunity. The annual quantity of nitrogen, phosphorus and potassium in the urine and faeces from the average rural family in Burkina Faso is equivalent to 80 kg of commercial fertilizer, worth approximately US$ 40–80 per year (national prices for 2018–2022 from the Africa Fertilizer initiative), which is more than most households can afford. Extrapolated for the country of approximately 21 million inhabitants, available plant nutrients in excreta surpasses what is currently used as chemical fertilizers in Burkina Faso (figure 2.13) and has a fertilizer value of US$ 150–300 million.

Application of plant nutrients from chemical fertilizers in 2020 compared with nutrients available in human excreta in Burkina Faso

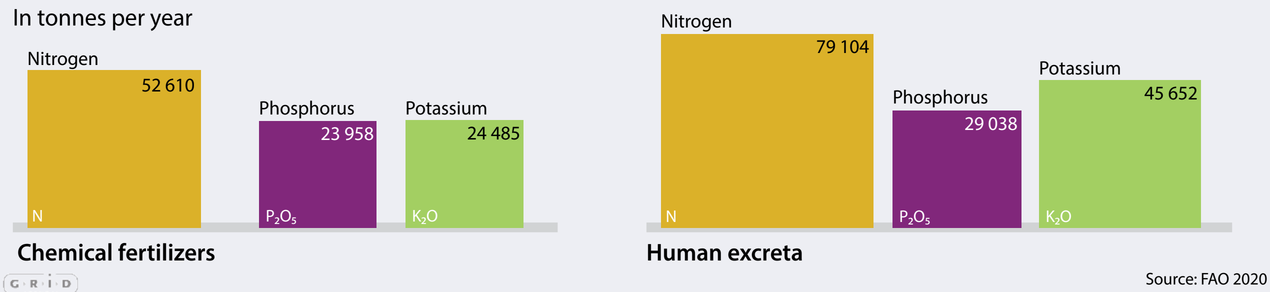


Figure 2.13: *Application of plant nutrients from chemical fertilizers compared with nutrients from human excreta.*

Table 2.2: *Annual quantity of nutrients in human excreta in Burkina Faso with the corresponding quantity of urea and NPK (15:15:15) (the most common fertilizers in Burkina Faso).*

	N (kg)	P (kg)	K (kg)
One person's excreta/year	3.8*	0.6*	~1.8**
This quantity correspond to what is found in 14.4 kg of chemical fertilizers (9.2 kg of NPK (15:15:15) and 5.2 kg of urea):			
9.2 kg of NPK (15:15:15)	1.4	0.6	1.2
5.2 kg of urea	2.4	–	–
Total	3.8	0.6	1.2
For an average rural household of 5.6 people, this implies roughly 50 kg of NPK and 30 kg of urea:			
Excreta from 5.6 people/year	21	3.3	10
50 kg of NPK (15:15:15) + 30 kg of urea	21	3.3	6.3

Notes: N and P are estimated based on the average daily protein intake in Burkina Faso according to the method proposed by Jönsson et al. 2004. Protein consumption data from FAOSTAT for the period 2015–2019 (Food and Agriculture Organisation of the United Nations [FAO] 2020). K is estimated based on the P/K relation of excreta in countries cited in Jönsson et al. 2004.

CASE STUDY 5

Producing urine-based fertilizer on the island of Gotland, Sweden

Prithvi Simha, Swedish University of Agricultural Sciences, Department of Energy and Technology, Sweden

Gotland, an island off the coast of Sweden, is a popular tourist destination, but suffers from severe water shortages and coastal eutrophication in the surrounding Baltic Sea, with wastewater treatment plants running at full capacity. In the ongoing N2Brew project on Gotland, which includes actors from the food and fertilizer industries, municipality, toilet rental companies and academia, the Swedish University of Agricultural Sciences and Sanitation 360 are demonstrating how the urine nutrient loop can be closed. Fresh urine from dry urinals is being collected, chemically stabilized on-site, dried centrally and applied on farms to fertilize malting barley, which is used to produce beer. Already this year, 300 litres of urine have been dried and used to grow 25 kg of barley, and the goal is to produce 10 tonnes of barley during the summer of 2023.

Barley fertilized with dehydrated urine-based fertilizer on the island of Gotland, Sweden.

Energy recovery

Wastewater is a carrier of carbon energy (chemical energy) and heat (thermal energy). Energy recovery and energy generation from wastewater have the potential to contribute to energy requirements and climate mitigation. There is about five times more energy in wastewater than is required for its treatment (Tarallo *et al.* 2015).

Wastewater typically has significant amounts of thermal energy. For example, in the Netherlands, householders heat 60 per cent of their water – water for showering is approximately 38°C and washing machines operate at 40–60°C (SenterNovem 2006). The wastewater is discharged into the sewer at a temperature between 10–25°C (Nagpal *et al.* 2021). Up to 90 per cent of this heat can be recovered and used for various domestic, urban and industrial heating and cooling purposes, through heat exchangers and heat pumps (Nagpal *et al.* 2021).

Heat recovery from wastewater can occur at four levels within a wastewater management system (Nagpal et al. 2021):

- at a component level within a building, e.g. at a shower or from cooking activities in a kitchen
- at a building level, especially for residential and non-residential buildings, with high volumes of wastewater flow
- at the sewer level
- at the wastewater treatment plant level, from the influent, partially treated wastewater or the effluent

There are several examples of heat recovery from wastewater at the various locations within a wastewater management system operating at full scale in various cities around the world. This includes recovery of energy for cooling and district heating at large wastewater treatment plants in Canada, China, Japan, the Russian Federation, Sweden, Switzerland and the Netherlands, among others (Funamizu *et al.* 2001; Mikkonen *et al.* 2013; Petersen and Grøn Energi 2018; Shen *et al.* 2018; Hao *et al.* 2019). An example is the use of wastewater for the year-round heating and cooling of the 28 storey high-rise office building Wintower in Switzerland, which exhibits about 600 kilowatts of heating energy extracted from wastewater directly from the sewer in winter months, and uses wastewater to absorb energy from the building for cooling it in summer months (Zandaryaa and Jimenez-Cisneros 2017).

It has been estimated that thermal energy recovery from wastewater effluent could result in up to 10 times more energy than the more conventional approach of energy recovery via biogas (Kehrein *et al.* 2020). Thermal energy derived from wastewater can be used for its own treatment (Hao *et al.* 2019). Chemical energy (the remaining 10 per cent of energy) that derives from organic substances present in wastewater can be recovered by digestion to produce methane or can be converted into biogas, but also into organic products. Methane is a powerful GHG; capturing it as biogas can contribute to climate mitigation (Fredenslund *et al.* 2023).

With an estimated global caloric value of 1 908 × 109 MJ (531 × 109 kWh), assuming full energy recovery and anticipating the average household electricity needs of 3 350 kWh, Qadir *et al.* (2020) reported that the energy embedded in the global volume of wastewater would be enough to provide electricity to 158 million households (that is between 474 million to 632 million people, estimating 3 or 4 people per household, respectively), or to fulfil the energy requirements of the facilities equipped with wastewater treatment systems.

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As the volume of wastewater increases over time, the energy embedded in wastewater in 2030 would be enough to fulfil the energy needs of 196 million households, increasing to 239 million households by 2050 (Qadir *et al.* 2020) (figure 2.14).

Sewage sludge from wastewater treatment plants is a source of carbon and nutrients with potential to fulfil future energy requirements. The sludge can be dried and used as a solid fuel in the form of sludge cake or pellets. Dried sewage sludge has been used for decades in the cement industry (Gold *et al.* 2017), and in the EU, over a quarter of all sludge generated is sent to incineration plants and used to generate district heating (Campo *et al.* 2021). In other instances, sludge can be carbonized via hydrothermal carbonization or pyrolysis to create a higher density fuel (char), as well as syngas, which can also be used for energy applications. However, the transformation of wastewater or sludge into biodiesel and other fuels, such as bioethanol, via technologies such as fermentation and transesterification is still not commercially viable at full scale.

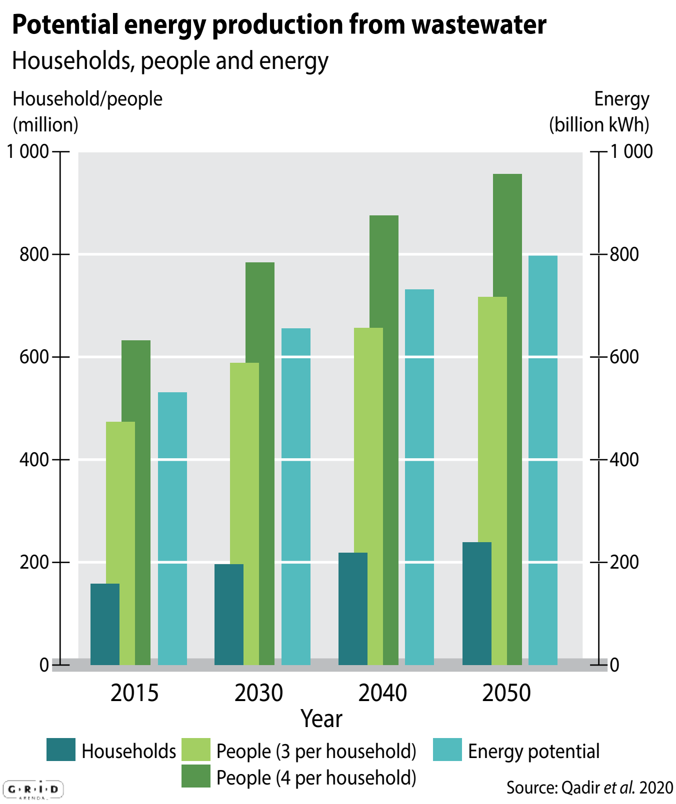


Figure 2.14: *Potential for energy production from wastewater based on the 2015 wastewater production data and scenarios over coming decades for the years 2030, 2040 and 2050, based on the expected increase in wastewater volume and assuming full energy recovery from the wastewater.*

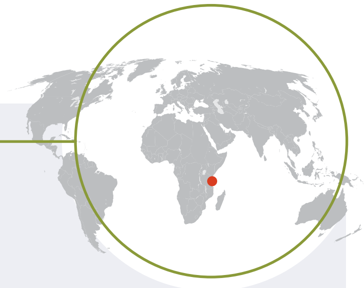
The cost of sludge treatment represents about 50 per cent of the total running cost of a wastewater treatment plant (Qian *et al.* 2016). By recognizing sludge as a source, not as a waste, valuable components can be recovered (Gherghel, Teodosiu and De Gisi 2019). The energy and fuels recovered from wastewater are an alternative to other energy resources and can limit associated carbon dioxide emissions and also reduce the 40 per cent of GHGs that are emitted by sludge in wastewater treatment plants (Pilli *et al.* 2015).

In current practices, the energy potential of wastewater is yet to be fully exploited (Otoo and Drechsel 2018). However, innovations in specific anaerobic wastewater treatment systems have extended the range and scale of anaerobic treatment applications to enhance dissolved methane recovery from wastewater. Such measures may end up in an energy-neutral wastewater cycle through on-site renewable energy production, together with improvements in energy efficiency in wastewater treatment facilities (Qadir *et al.* 2020).

In addition to technological innovation, legislative and financial approaches are essential to upscale energy recovery from wastewater. In Japan, the 2015 update to the 1958 Sewerage Act (“the Sewerage Act”) is being used to realize the full potential of the 2.3 million tonnes of biosolids produced each year by the 2 200 wastewater treatment plants. The energy potential is estimated to generate 160 gigawatt hours (GWh) electricity per year. The Sewerage Act requires wastewater treatment plants to utilize biosolids as a carbon-neutral form of energy and provides financial incentives as a fixed price feed-in tariff per kWh for the electricity generated from biosolids, in order to support the investment in energy recovery from biosolids by sewage operators (Zandaryaa and Jimenez-Cisneros 2017).

Wastewater treatment plants can produce the energy needed to treat wastewater and contribute to the energy needs of cities and municipalities that generate waste streams, as illustrated by the case studies presented from Dar es Salaam and the Hamburg Wasser wastewater treatment plant, although with varying success. Implementing current best management practices on sustainable energy recovery provides a viable resource recovery opportunity in countries where wastewater treatment is relatively low and energy needs are increasing.

CASE STUDY 6 EXTENDED VERSION



Resource-efficient decentralized wastewater treatment systems in Dar es Salaam, United Republic of Tanzania

- **Tim Fettback**, HafenCity University Hamburg
- **Charles Muhamba**, Bremen Overseas Research and Development Association Tanzania

In 2013, two decentralized wastewater treatment system (DEWATS) were implemented at a maternity hospital in Dar es Salaam, providing sustainable wastewater treatment, nutrient-rich water for irrigation and biogas. The system treats up to 100 m^3 of domestic wastewater per day and the project cost 96 000 euros. It is more economical to operate than a conventional septic tank system. The hospital is located in a flood prone area with no sewer connection. The wastewater collected from toilets, bathrooms and kitchens (domestic black and grey water) is treated in two DEWATS. DEWATS operate without any external energy and apply only locally available resources. The treated wastewater recovered from the process is successfully used for irrigation of the hospital complex, enhancing urban biodiversity, and is also stored for firefighting. The biogas produced by the treatment system was intended for use in the kitchen, but the potential users did not trust the stability and quality of the biogas production and were hesitant to invest in biogas stoves. Similar challenges have been observed at other small-scale biogas units in the United Republic of Tanzania, despite functional biogas production. The production of biogas from wastewater and faecal sludge is significant, but its utilization has to be well planned and requires further development.

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CASE STUDY 7

EXTENDED VERSION

Large-scale centralized wastewater treatment as an energy source in Hamburg, Germany

■ **Hendrik Schurig**, **Arnold Schäfer** and **Lüder Garleff**, Hamburg Wasser
■ **Tim Fettback**, HafenCity University Hamburg

The wastewater treatment plant in Hamburg, Germany, operated by Hamburg Wasser, is one of the largest municipal wastewater treatment plants in Europe, treating wastewater from an equivalent of 2.5 million people. Traditionally, such wastewater treatment plants have been among the largest energy consumers of a municipality. However, wastewater contains more energy and other resources that can be recovered for reuse than are needed for treatment. This is exactly what the Hamburg Wasser wastewater treatment plant has achieved, now producing even more energy than it consumes. The generated heat and electricity are used within the wastewater and sludge treatment processes, with surplus energy being fed to the public grid (as electricity and biomethane) and to the neighbouring container terminal (district heating).

©Kristina Steiner for Hamburg Wasser

In 2020, the wastewater treatment plant in Hamburg was able to deliver 23.5 GWh of renewable electrical energy and 34.6 GWh thermal energy to the public grid. This surplus also compensates the energy needed to operate the sewer network, including the pumping stations and building heating, adding up to 8.9 GWh of electrical energy and 4.4 GWh of thermal energy. As a result, Hamburg Wasser can compensate for unavoidable carbon dioxide emissions, achieving carbon neutrality as concerns the energy supply needed for both freshwater supply and wastewater treatment. Being energy self-sufficient is not only an ecological issue, but also has economic implications. Compared with 2007, the Hamburg wastewater treatment plant was able to cut down the energy cost by 35 per cent in 2021. At the same time, the market price for electricity went up by 241 per cent.

Other potential products from wastewater and their applications

Besides recovering water, energy and nutrients from wastewater, there is a wide range of other materials that can be recovered, and ongoing research continues to develop new possibilities. Some of the resource recovery options for which full-scale installations already exist include the production of cellulose, bioplastics, extracellular polymeric substances and volatile fatty acids (table 2.3).

Resource recovery options for which technologies exist, but whose commercial viability at large scale has not yet been proven, include the recovery of metals and single-cell protein. The challenges towards scaling up these resource recovery options mainly relate to process economics and logistics, environmental and health risks, social acceptance and policy barriers (Kehrein *et al.* 2020).

Table 2.3: *Overview of other resources that can be recovered from wastewater, with examples of locations where implementation has been done at full scale.*

Resource	Potential products and their applications	Relevant industries for product applications	Location of full-scale examples
Cellulose	• raw material for paper production • soil conditioner • fuel for biomass combustion plants • feedstock for fermentation • ingredient in asphalt and biocomposites (Mussatto and Van Loosdrecht 2016; Kehrein *et al.* 2020; Khan *et al.* 2022; Liu *et al.* 2022)	• pulp and paper • energy • agriculture • construction • chemicals	• Geestmerambacht wastewater treatment plant, the Netherlands (Crutchik *et al.* 2018; Palmieri *et al.* 2019)
Volatile fatty acids	Used in the production of: • polymers • solvents • pesticides • rubber • paint • biodiesel • food preservatives and flavours (Worwąg and Kwarciak-Kozłowska 2019; Kehrein *et al.* 2020; Elhami *et al.* 2022;)	• food and beverages • agriculture • chemicals • energy • pharmaceuticals	• Carbonera wastewater treatment plant, Italy (Frison *et al.* 2013; Longo *et al.* 2017) • Wuxi, China (Liu *et al.* 2018) • Verona, Italy (Crutchik *et al.* 2018)
Extracellular polymeric substances	Alginate polymers that can be used to make: • printing paste • fireproofing and waterproofing fabrics • seed coating • concrete coating • medical products • jewellery (Kehrein *et al.* 2020; Technical University Delft 2020)	• pharmaceutical • food and beverages • textile • agriculture • pulp and paper • construction industry	• Zutphen and Epe, the Netherlands (Dutch Water Sector 2020)
Polyhydroxyalkanoates	Bioplastics used in: • food packaging • composting bags • hygiene products packaging • industrial packaging (Prajapati *et al.* 2021)	• packaging • fast-moving consumer goods • agriculture • horticulture	• Manresa wastewater treatment plant, Spain (Larriba *et al.* 2020) • El Torno wastewater treatment plant, Spain (Akyol *et al.* 2020) • Carbonera wastewater treatment plant, Italy (Conca *et al.* 2020)

Persistent barriers and concerns to wastewater reuse and recovery

Despite successful wastewater resource recovery and reuse applications in many countries, persistent barriers and concerns linger, continuing to limit the widespread implementation of wastewater resource recovery and reuse at scale, and limiting progress in achieving circularity in water systems (Morris *et al.* 2021). The implementation of water reclamation, and the recovery and reuse of other products, suffers not only from the obvious technical barriers, but by challenges such as a limited institutional capacity, a lack of regulations and financial incentives, changing negative public perceptions towards and social acceptance of water recycling, reclamation and reuse, as well as the dire need for support by regulators and politicians.

Many of these barriers and concerns are integrated and assert complex connections on both the benefits and challenges associated with wastewater reuse (Morris *et al.* 2021). Several reviews to identify and categorize these barriers have been undertaken (Kehrein *et al.* 2020; Morris *et al.* 2021; Breitenmoser *et al.* 2022; EIB 2022). Different approaches and perspectives in these studies have resulted in different outcomes, in terms of the priority barriers. There seems to be agreement that while technological feasibility is a prerequisite for developing wastewater resource recovery and reuse, it is not considered to be the barrier, but rather it is the social, policy, economic and regulatory barriers that hamper successful development (Morris *et al.* 2021). Kehrein *et al.* (2020) identified economics and value chain barriers as the priority to be addressed, whereas Morris *et al.* (2021) and Breitenmoser *et al.* (2022) identify social, governance and regulatory barriers as of particular importance.

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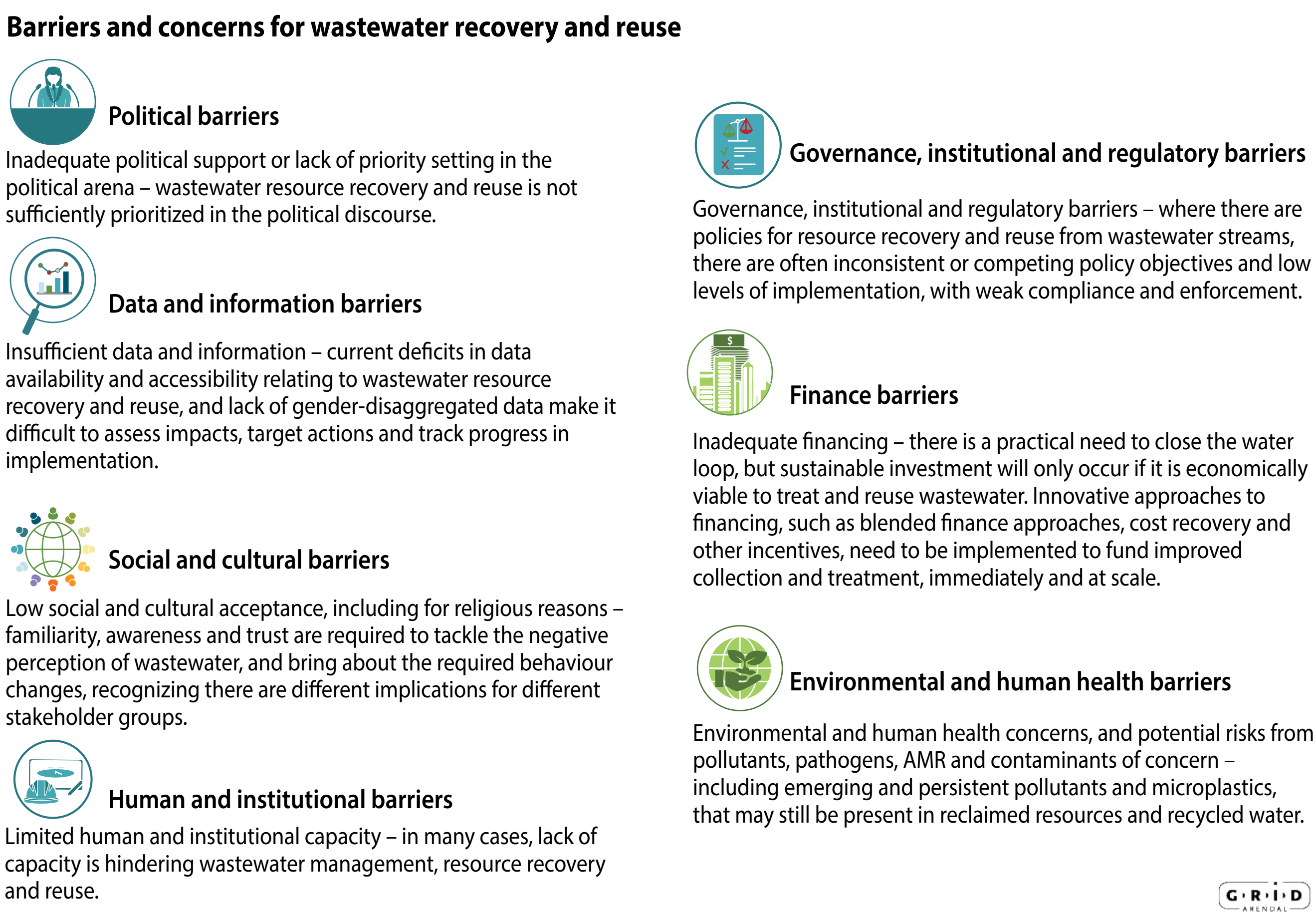

Figure 2.15: *The barriers and concerns relating to wastewater resource recovery and its safe reuse.*

This section considers the following barriers and concerns that need to be addressed:

- Inadequate political support or lack of priority setting in the political arena – wastewater resource recovery and reuse is not sufficiently prioritized in the political discourse.
- Governance, institutional and regulatory barriers – where there are policies for resource recovery and reuse from wastewater streams, there are often inconsistent or competing policy objectives and low levels of implementation, with weak compliance and enforcement.
- Insufficient data and information – current deficits in data availability and accessibility relating to wastewater resource recovery and reuse, and lack of gender-disaggregated data make it difficult to assess impacts, target actions and track progress in implementation.
- Inadequate financing – there is a practical need to close the water loop, but sustainable investment will only occur if it is economically viable to treat and reuse wastewater. Innovative approaches to financing, such as blended finance approaches, cost recovery and other incentives, need to be implemented to fund improved collection and treatment, immediately and at scale.
- Low social and cultural acceptance, including for religious reasons – familiarity, awareness and trust are required to tackle the negative perception of wastewater, and bring about the required behaviour changes, recognizing there are different implications for different stakeholder groups.
- Limited human and institutional capacity – in many cases, lack of capacity is hindering wastewater management, resource recovery and reuse.
- Environmental and human health concerns, and potential risks from pollutants, pathogens, AMR and contaminants of concern – including emerging and persistent pollutants and microplastics that may still be present in reclaimed resources and recycled water.

Inadequate political support or lack of priority setting in the political arena

Wastewater resource recovery and reuse is not sufficiently prioritized in the global water discourse, with low awareness of the issue. Elevation of this issue on the political agenda is required to establish an enabling political environment for addressing the other identified barriers and concerns (Morris *et al.* 2021), including governance, regulation, finance and capacity.

There is evidence of the impact that strong political will can have to solve complex problems. For example, in the 1990s, the Jordanian export market was severely affected when neighbouring countries enforced restrictions on the imports of fruits and vegetables irrigated with inadequately treated wastewater (Qadir *et al.* 2010). In response, the Jordanian Government implemented an aggressive campaign to install wastewater treatment plants, rehabilitate and improve existing treatment facilities, and introduce enforceable standards to protect the health of farmers and consumers. The intensifying water scarcity in the country has seen the need to prioritize wastewater management and water reuse in agriculture. The country has built infrastructure for wastewater collection and provided support to the operation and maintenance of wastewater treatment facilities. The efforts are supported by the relevant institutions, such as the Jordan Valley Authority and Water Authority of Jordan, appropriate policy interventions, and through the introduction and implementation of regulations and standards (Qadir *et al.* 2010).

In the Mediterranean, the Contracting Parties to the Barcelona Convention have successfully adopted a regional action plan on wastewater treatment under the Land-based Sources of Pollution Protocol (UNEP 2021a), which legally commits the Contracting Parties to a series of measures, including to promote the recovery and reuse of wastewater.

In a recent example, the French Government in March 2023 announced its "water sobriety" plan, which will prioritize water as an issue of national importance and include a political shift to increase wastewater reuse. Currently, only 77 of the 33 000 wastewater treatment plants in France can recover any resources and only 0.1 per cent of treated wastewater produced is reused (Basso 2023).

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Governance, institutional and regulatory barriers

Governance structures, including those relevant to wastewater management, resource recovery and reuse, are very context-specific and vary both between and within countries (Otoo and Drechsel 2018). Given the cross-sectoral nature of wastewater management and reuse, actors across sectors and governance levels should cooperate to develop and implement related policies and laws, despite their potential inexperience with working together or despite there being no established institutional mechanisms to facilitate this type of cooperation. This becomes increasingly complex where responsibilities are divided across national and subnational administrations.

Where there are policies in place to promote resource recovery and reuse from wastewater streams, there is often poor cooperation between competent organizations, or sectors potentially duplicating function and resulting in incoherent policies and legislation, and intersectoral conflict – all of which hinders progress (Qadir *et al.* 2020; Morris *et al.* 2021; Breitenmoser *et al.* 2022). There are associated challenges in lack of coordinated implementation actions, lack of monitoring and weak enforcement of regulations and standards.

Morris *et al.* (2021) identified the importance of addressing policy and regulatory barriers. They demonstrated that many small companies can be incentivized to respond to legal requirements, but the absence of clear and coherent policies and legislation can prevent uptake of wastewater use.

In India, Breitenmoser *et al.* (2022) identified five barriers limiting progress in developing wastewater management and reuse, despite there being a clear political ambition:

1. Unclear responsibilities between central, state and local government bodies to implement schemes
2. Inadequate technological designs, which do not adequately consider long-term development plans of the areas, and which hamper treatment efficacy
3. Significant delays in project execution
4. Weak monitoring of compliance
5. Lack of adequate financing strategies for cost recovery of wastewater treatment services

They identified the lack of an overarching and clearly defined policy or law at the central government level as a key limiting factor to overcoming these barriers, and made the following recommendations for the future governance of wastewater treatment and reuse in India:

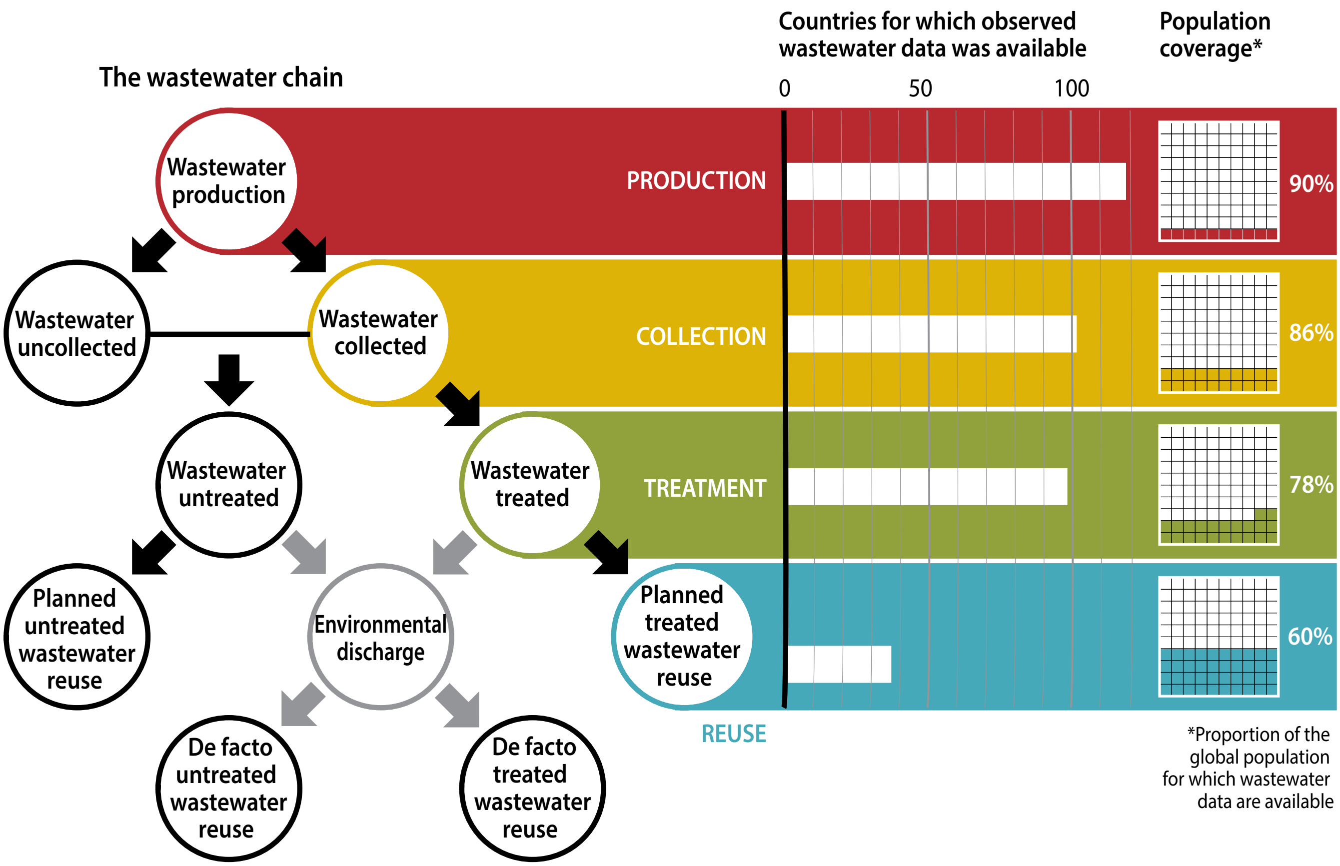
- Target-based regulations, defined national reuse standards for treated sewage and effective enforcement strategies need to be developed.
- Policy and guiding frameworks need to establish detailed guidance on sewage treatment and reuse technologies (fit-for-purpose treatment).
- Effective financing mechanisms (funds, taxes, tariffs) that permit sufficient cost recovery for long-term operation and maintenance of sewage treatment infrastructure should be established.
- Institutional and monitoring capacity needs to be strengthened, and engagement and collaboration of key stakeholders tackled, to increase acceptance of waste-recycled products.

Insufficient data and information

The current deficits of wastewater production, collection, treatment and reuse data availability and accessibility, as well as the lack of gender-disaggregated data, make it difficult to track progress in implementation of wastewater management and reuse.

Before 2010, the availability and reliability of data were identified as major challenges to realizing the potential of wastewater for resource recovery and reuse. Access to data and information across all aspects of the wastewater management chain (figure 2.16) is essential for informing policy to protect the quality of water resources, track progress towards environmental and sustainability goals, and to better understand and unlock the potential for wastewater reuse. Additionally, gender-disaggregated data can also be collected to assess any positive or negative impacts to inform policies that mainstream gender as a development issue. The use of gender sensitive indicators can also reveal information to identify challenges experienced by people in assessing the extent of gender inequalities.

Availability of data across the wastewater management chain



Source: Jones *et al.* 2021; GRID-Arendal/Studio Atlantis, 2023.

Figure 2.16: *Availability of data across the wastewater chain including the number of countries for which wastewater data were available; and the percentage of population coverage (i.e. the proportion of the global population for which wastewater data were available).*

Information that is available is typically provided either in databases that report wastewater data at country level (Global Water Intelligence, FAO, Eurostat, United Nations Statistics Division), or at the individual plant level for wastewater treatment (e.g. Urban Wastewater Treatment Directive [91/271/EEC], Clean Watersheds Needs Survey, Atlas Esgotos). At the country level, the data are typically highest for wastewater production, and decreases down the wastewater management chain i.e., for collection, treatment and reuse, both in terms of number of countries and population coverage (figure 2.16).

Since 2010, there has been progress in improving the collection availability, accessibility, quality and consistency of data across countries, but there are still challenges (UN-Habitat and WHO 2021). While undertaking a comprehensive assessment of the status of wastewater data at the national level, Sato *et al.* (2013) found that in the 181 countries surveyed, only 30 per cent had data available on three key parameters (wastewater production, treatment, use), while there was no data or even approximate numbers available for 31 per cent of the countries. Most data accessed by Sato *et al.* (2013) were old, with only 37 per cent of the data classified as recent (2008–2012).

Particular ongoing challenges include (i) the need to be able to include reuse within the SDG indicator 6.3.1, which given the language of SDG Target 6.3 should be a priority and (ii) the need for developing gender-disaggregated data to support understanding progress in the equitable implementation of measures towards this target.

Inadequate financing

There are many examples of successful investments in water-related infrastructure (see case studies presented in OECD 2020), but widespread investment in wastewater reuse will only occur if it is economically viable. While it is true that investments in wastewater collection and treatment are mainly from public funds, water reuse and resource recovery offer opportunities for private funders to develop resource recovery business initiatives. Innovative approaches to financing, such as blended finance (e.g. private investment in development projects), cost recovery and other incentives, need to be developed to fund improved collection, treatment and reuse.

Financial and economic barriers can be divided into short-term financial barriers and long-term economic viability (Morris *et al.* 2021). The short-term financial barriers are finding the necessary capital investments needed to build infrastructure and adapt processes to produce and reuse resources from wastewater. The perspective of long-term economic viability ties into the larger picture of managing water use into the future, for example ensuring the ongoing operation and maintenance costs are appropriate to the context or that that it is feasible to develop markets for any recovered resources (Morris *et al.* 2021).

There are often inadequate public budgets for water-related spending in most developing countries. Investments in treatment facilities have not kept pace with population growth, urban development and the associated increases in wastewater volume (UN-Water 2020). Investment is patchy, and rural areas are often excluded. Hanjra *et al.* (2015) reported that the perceived high costs of technology for using unconventional water resources, and the lack of economic analyses and appropriate financing mechanisms, are restricting the development and scaling of wastewater resource use. In Europe, the driver for wastewater investment has been the Urban Wastewater Treatment Directive (91/271/EEC), estimated at 100 billion euros annually, with significant variation between countries, and several countries still failing to comply (OECD 2020). The OECD (2020) estimated that an additional 289 billion euros will be required by 2030 to support full compliance for all EU Member States. As part of the European Green Deal, a proposal for a revision to the Urban Wastewater Treatment Directive is under consideration (see box 8), which will increase ambition to tackle the new challenges that have emerged over the past 30 years and require additional investment. At the same time, financial incentives are sometimes misaligned or contradicting goals for increasing resource recovery. In Kenya, for example, subsidies are provided by the government for synthetic fertilizers, but not for organic fertilizers, such as excreta-derived fertilizers (Ddiba *et al.* 2020), and this hinders the financial viability of nutrient recovery initiatives.

Our current economic system fails to account for the value of water, which leads to the excessive and unsustainable use of finite freshwater resources (Global Commission on the Economics of Water 2023). In addition, how water is costed is approached very differently in different countries, and in many cases, water remains heavily subsidized (World Economic Forum 2023). The price of wastewater is often higher than the price of fresh water, acting as a barrier to its use (Morris *et al.* 2021). Until treated wastewater can reach a more competitive price point, for example, through technology improvements and efficiencies, or until fresh water is priced more appropriately, this will remain a barrier to uptake by users (Breitenmoser *et al.* 2022). Pricing of water can help to incentivize responsible use of finite water resources, and any pricing mechanism must guarantee equitable access for all to meet their basic human rights, particularly those that are most vulnerable.

Low social and cultural acceptance, including religious reasons

Despite the need for the resources that can be reclaimed from wastewater, reuse remains controversial, with fears over safety (EIB 2022). Often, these concerns are not related to actual risk levels so much as misconceptions and perception, but they are recognized as a key barrier to realizing the opportunities from wastewater at different stages of the value chain (Morris *et al.* 2021; Breitenmoser *et al.* 2022; EIB 2022). Familiarity, awareness and trust are required to tackle the negative perception of wastewater reuse and bring about the required behaviour changes, recognizing there are different implications for different stakeholder groups.

There are a diverse range of issues that can limit social and cultural acceptance of reclaimed resources by individual and industry consumers. These can include cultural taboo, social stereotypes, price, choice and the option to use non-waste alternatives, or the perception of quality (Otoo and Dreschel 2018). Different cultural and religious perceptions about water in general and/or about using treated wastewater can be a factor of social acceptance (Zandaryaa and Jimenez-Cisneros 2017). These issues are affected by education, awareness, communication, trust, and observing how others around you behave (Morris *et al.* 2021).

Low transparency and communication can contribute to a lack of trust towards public and regulatory authorities, resulting in barriers between these authorities and implementing actors, such as end users and businesses (Morris *et al.* 2021). This can be further exacerbated by a lack of information on procedures and quality standards, decreasing trust in the competence of authorities to implement reuse properly and safely, and reduced levels of acceptance in the reuse of resources from wastewater (Morris *et al.* 2021).

Engagement and participation of stakeholders, in particular end users and potential consumers, has been shown to be an important aspect to ensure solutions are socially and culturally acceptable, equitable and just. Where there is an open and transparent process of information flow and ability to communicate, this builds ownership, trust, and can lead to successful acceptance and implementation (Morris *et al.* 2021).

The public's acceptance of planned reuse varies widely and depends on a range of factors, such as the degree of contact between the water and the user, education and risk awareness, the degree of water scarcity or availability of alternative water sources, economic considerations, cultural barriers, as well as the public's involvement in decision-making and prior experience with treated wastewater (EIB 2022).

CASE STUDY 8 EXTENDED VERSION

Social barriers to urine recycling in decentralized sanitation systems

Prithvi Simha

Using our own urine as fertilizer? Source-separating sanitation systems, which separate and recycle different fractions of wastewater, have been proposed as a disruptive approach to transition to a circular economy model (Simha, Zabaniotou and Ganesapillai 2018; Simha *et al.* 2020). However, there are real challenges scaling such approaches. Mainstreaming any circular system will need a broad range of actors to accept and support them (Simha 2021). A survey of farmers in Southern India (Simha *et al.* 2017) found that while recycling cow urine as fertilizer is common practice, farmers did not believe in using urine from people, but despite this, 60 per cent were willing to apply human urine to their farms. The study found that there is a lot of social stigma surrounding human urine.

When asking consumers whether they would be willing to eat food fertilized by human urine, there was a lot of variability between countries, ranging from 15 to 80 per cent acceptance (Simha *et al.* 2021). On average, 68 per cent favoured recycling human urine, 59 per cent stated a willingness to eat urine-fertilized food, and only 11 per cent believed that urine posed health risks that could not be mitigated by treatment. Literature on the social aspects of recycling urine (Lienert and Larsen 2009; Larsen, Udert and Lienert 2013; Simha *et al.* 2017; Simha *et al.* 2018; Guo *et al.* 2021; Simha *et al.* 2021; Zhou *et al.* 2022) clearly suggests that there is sufficient interest and willingness among end users (farmers, toilet users/homeowners, food consumers) to adopt new behaviours and sanitation systems to recycle urine. Therefore, the resistance to such new and disruptive innovations likely lies elsewhere in the circular sanitation chain. Presumably, there are other actors with high stakeholder power and high interest in maintaining the status quo.

CASE STUDY 9 EXTENDED VERSION

When farmers' acceptance is challenged by consumers' buy-in and the quantity and quality of the effluents, Ouardanine, Tunisia

Olfa Mahjoub

In Ouardanine, Tunisia, farmers face limited natural water resources and are forced to rely on wastewater reuse to irrigate their crops. The supply can be erratic in both quantity and quality, due to the illegal discharge of industrial effluents into the sewer system. This has resulted in a lower quality of irrigation water and an increased risk to human and environmental health, both leading to lower trust of consumers and low acceptance of produce irrigated by wastewater, especially peaches, which have historically been an important crop in the region. So, while there is a willingness of farmers to use treated wastewater, there is a reluctance of consumers to purchase their produce on the local market. This has caused farmers to adapt the types of crops they grow, moving to cultivating non-food plants or food plants that either require ground-level drip irrigation, or that have a skin that is not eaten, thus reducing pathogen-related risks. Moves to establish new fit-for-purpose standards and updated national regulations for the quality of water that can be reused will be important to enable farmers to sustain their businesses and to build the trust of consumers.

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Limited human and institutional capacity

In many cases, lack of capacity is hindering wastewater management, resource recovery and reuse, including in the lack of technical expertise to operate and maintain wastewater treatment plants with resource recovery, or in implementing reuse practices (Morris *et al.* 2021). As indicated earlier in the report, there is an increasing volume of wastewater being produced, and an ever-growing gap to fill in order to be able to reach the targets set out in SDG 6, and hence an ever-widening human capacity gap. The WWAP (2016) recognized that the expertise required for the future of wastewater management for a circular economy will need to evolve, with skills to work across interconnected issues at multiple scales. The formal wastewater treatment sector is currently male-dominated, particularly in technical and professional roles, with IWA (2014) reporting that, based on studies in 15 developing countries, women accounted for an average of just 17 per cent of all staff, with women often being excluded from entry to technical and other professional positions (International Labour Organization 2017). To build capacity and establish diverse leadership will require the increased participation of not only women, but also youth.

An effective wastewater treatment system relies on efficient collection, and in many places, this is still an important gap in the wastewater management chain. If wastewater is not collected, it cannot be treated or reused. It may take decades to achieve full-scale wastewater collection and treatment systems that are needed for the safe reuse of recovered resources. Public authorities in low-income and lower-middle-income countries often do not have sufficient expertise and knowledge of the technical and management options available to reduce the environmental and health risks of wastewater reuse and disposal. These authorities also have limited capacity to enforce regulations leading to safe management and productive use of treated wastewater. Besides, fear of economic consequences in agricultural trade, which could result from any potential health risk, may make governments hesitant to address the use of untreated wastewater for irrigation.

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Environmental and human health concerns

The One Health approach views animal, human and environmental health as a single, interconnected entity, with impacts on one sphere affecting all others, both directly and indirectly (WHO 2021). This is a useful lens through which to consider health concerns related to the reuse of wastewater resources.

Human health concerns

Unmanaged or inadequately managed wastewater is recognized as a serious human health risk (IPBES 2019). The type and the extent of the risk to health depends on factors including the level of treatment and how the wastewater is being used (EIB 2022), with potable water having the highest potential risk. Being able to consistently deliver sufficient high-quality water is critical to safe and economically viable reuse and can be a challenge to achieve (Salgot and Folch 2018). It is estimated that 10 per cent of the global population rely on food from crops that are irrigated with wastewater and, where this is insufficiently treated, contains persisting pathogens that can cause bacterial, parasitic and viral infections, particularly in young children and women (Ungureanu, Vlădu and Voicu 2020). Women and children are more vulnerable to associated health issues as they spend more time in contact with wastewater during field labour, after which they prepare meals for the family. Unless there are facilities for good hygiene, there is potential to spread pathogens (Ungureanu, Vlădu and Voicu 2020).

Pathogens

Untreated wastewater contains many pathogenic microorganisms and parasites, which can be harmful to human health. Municipal wastewater contains human bacterial pathogens, such as Salmonella spp., Escherichia spp., and more, which are major human health concerns related to potable water reuse. In DPR or IPR, the choice of water treatment processes is crucial to eliminate microbial risks. Human health concerns are also associated with the presence of pathogens in water reuse for agricultural irrigation. Pathogenic microorganisms can be waterborne or food-borne, especially if the food has been irrigated with contaminated water, or with untreated or partially treated wastewater (Zandaryaa and Mateo-Sagasta 2018). Approaches are necessary to prevent pathogens from entering agricultural food production chains through wastewater irrigation.

Box 6: Health implication for children exposed to the use of untreated wastewater

The potential impact of wastewater-irrigated areas on the health of children is an issue that deserves greater attention, especially considering the widespread use of untreated or inadequately treated wastewater for agricultural irrigation. A study conducted by Grangier, Qadir and Singh (2012) investigated the health implications of wastewater irrigation on children between the ages of 8–12 years in the peri-urban Aleppo region of Syria. The study compared the occurrence of waterborne and non-waterborne disease in villages within the wastewater-irrigated area with those from an area irrigated with fresh water. The study also investigated eczema, which may stem from water or non-water sources. Gastroenteritis (a waterborne disease) and eczema had significantly higher prevalence rates in wastewater-irrigated areas as compared with freshwater-irrigated areas.

These results suggest that the children going to the field to play or work with their parents in wastewater-irrigated areas seem to have a higher risk of getting waterborne diseases than the children from other areas. It was also found that the annual health cost per child was 73 per cent higher in wastewater-irrigated areas than the health cost for the same age group in freshwater-irrigated areas. Monitoring water quality and hygiene education for the appropriate handling of wastewater are important where untreated or inadequately treated wastewater is being used.

Increase of antimicrobial resistance

It is estimated that between 2000 and 2015, human antibiotic use, expressed as defined daily doses per 1 000 people per day, increased by 39 per cent (Klein *et al.* 2018). According to WHO, antibiotic use has increased 91 per cent worldwide and 165 per cent in low and middle income countries during the same period (figure 2.17). The increase in use of antibiotics both in humans and animals has driven a rise in AMR. Modelling suggests that in 2019, there were an estimated 4.95 million deaths associated with AMR, with the highest percentage in western sub-Saharan Africa (0.27 per cent of the population [Murray *et al.* 2022]). However, antibiotic use is vital to combat certain diseases and prevent deaths of millions of people. More people in low and middle income countries still die from lack of access to antibiotic medications than from AMR (Sriram *et al.* 2021). A large fraction of consumed antibiotics (30–90 per cent of intake) is excreted in faeces and urine (Du and Liu 2012). The One-Health concept recognizes the link between human and animal health and the environment (WHO 2021). AMR is a key priority for the One Health approach, as AMR is due to the poor management and excessive use of antimicrobials in livestock and people.

Wastewater treatment plants are known to be potential sources of AMR, as they receive a variety of human and animal waste streams, including those from hospitals. Numerous studies have investigated the occurrence and prevalence of AMR in treated wastewater. There is abundant evidence that conventional treatment does not always effectively remove many contaminants, including antibiotics, antibiotic resistant bacteria (ARB) and antibiotic resistance genes (ARGs).

ARB and ARGs are not yet fully understood in the contribution of wastewater reuse to the dispersal of antibiotics. Recently, Slobodiuk *et al.* (2021) reviewed the impact of both treated and untreated wastewater used for irrigation on adjacent areas. They found that irrigation with untreated wastewater was clearly associated with increased ARBs and ARGs in soil. But they found that the results for the use of treated wastewater varied, with about 50 per cent of the studies showing an increase in the abundance of ARBs and ARGs in soil and adjacent waterways. A European study found similar variability. Cacace *et al.* (2019) examined the receiving waters of 16 wastewater treatment plants and found that the abundance of ARGs was inversely correlated with the amount of biological treatment, specifically the sedimentation of activated sludge (a secondary wastewater treatment process). Other studies have looked at treatment options for effective removal of ARBs and ARGs (reviewed by Pant *et al.* 2022). The choice of advanced treatment technologies will depend on the intended use of the treated wastewater (level of removal efficiency required), the investment required and the economic viability (figure 2.18).

Assessing the risk and taking action to prevent the release of antibiotics, ARB and ARGs from wastewater treatment plants has gained momentum. Despite the lack of a practical regulatory framework, preventive measures promoting reduction at the sources (at the point of release, upstream of the wastewater treatment plant), education and public awareness for appropriate antibiotic consumption, and controlling antibiotic waste disposal through adequate handling and management of medicinal wastes are recommended strategies.

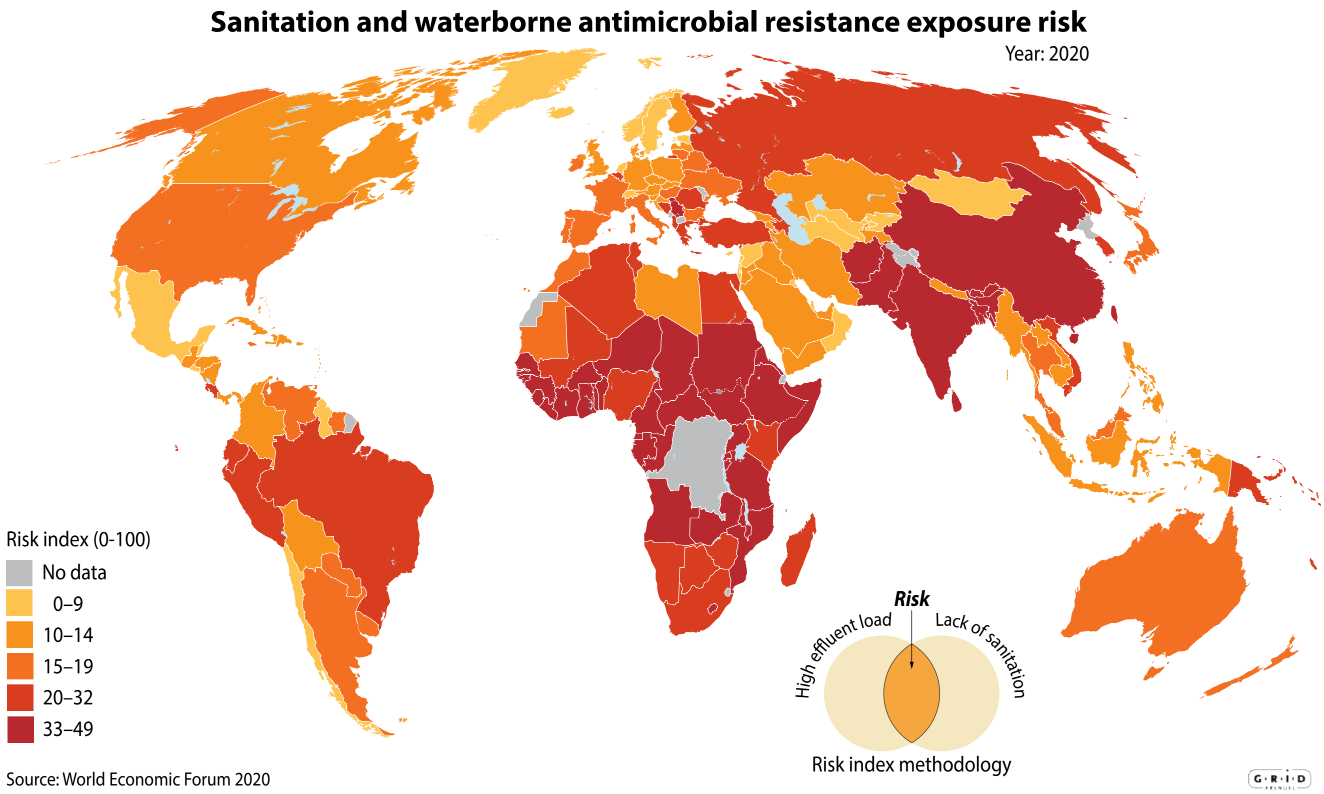


Figure 2.17: *Sanitation and waterborne antimicrobial resistance exposure risk.*

Level of effectiveness and relative cost of various treatment methods for the removal of antibiotics

	Advantages	Disadvantages
Conventional treatment	Cost-effective Flexible and simple	Sludge retention time Recycling Insignificant removal
Biological removal	Low-cost Economically attractive	Require management Slow process
Electrocoagulation	Simple Easy to operate Low-cost	Electrodes are impermanent High chemical consumption Use of electricity
Adsorption	Low-cost High performance Easy operation	Weak selectivity Waste product
Advanced oxidation process	Eco-friendly Non-hazardous	Oxidative by-products High-cost

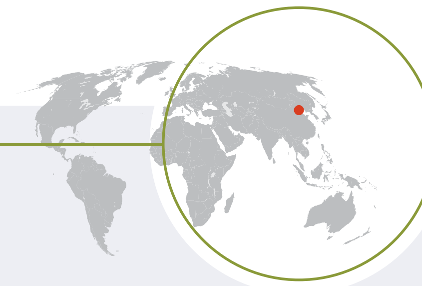
Source: Mansouri *et al.* 2021

Figure 2.18: *Level of effectiveness and relative cost of various treatment methods for the removal of antibiotics.*

Biodiversity and ecosystem health

Wastewater is a globally important source of pollution, in particular nutrient and pathogen pollution can lead to serious negative impacts on terrestrial, freshwater and marine ecosystems and biodiversity, undermining ecosystem health and nature's contribution to people (UNEP 2017; CBD 2022) (see box 7). Some impacts include causing eutrophication in freshwater and coastal waters, which in extreme situations can lead to dead zones – extremely low-oxygen environments, which kill most aquatic life (Breitburg *et al.* 2018) and direct damage to organisms and shifts in species composition (CBD 2022). Improved management of wastewater can control this source of nutrient pollution by 50 per cent (CBD 2022) and successfully reduce eutrophication (Schindler *et al.* 2016). A commitment to reduce nutrient pollution was adopted within the Kunming-Montreal Global Biodiversity Framework agreement to protect and restore biodiversity (CBD 2022). Achieving the Kunming-Montreal agreement target for pollution (Target 7) will be important for the protection and restoration of biodiversity, and consequently for reaching other related targets for climate and human health (CBD 2022).

CASE STUDY 10



Reuse of treated municipal wastewater for industry and ecosystem health in Lingyuan City, China

Lingyuan City, Liaoning Province, China, has been facing acute water scarcity, threatening groundwater resources, economic development and ecosystem health. One opportunity that was identified was to invest in improvement of wastewater collection, treatment and reuse, to realize and address the challenges of water scarcity. The project required an investment of US$ 40.1 million, covered by the city government, with a loan from the World Bank, to develop storm drainage, sewers, a reclaimed water network, connection of an existing wastewater treatment plant and building of a new wastewater treatment plant to reclaim water. About half of the effluent is subject to tertiary treatment, used to supply industry and to replenish the urban lake, maintaining an aquifer around the lake. The other half of the effluent is discharged after secondary treatment into the local river, downstream of the city, supporting the regeneration of the urban landscape, riparian ecosystem, increasing biodiversity and improving the liveability of the city (World Bank Group and Global Water Security & Sanitation Partnership 2020).

Box 7: Wastewater undermining the resilience of coral reefs – an ecosystem on the brink

Coral reef ecosystems are globally distributed, and on which around a billion people depend for their livelihoods (UNEP 2004). They are incredibly important to the health and livelihoods not only of these dependent communities, but also those further away. They are also one of the world's most threatened ecosystems (IPCC 2018; IPBES 2019), due to a combination of global and local pressures, including the impacts of climate change, overexploitation, pollution and land-use change.

The input of nutrients from land-based sources, such as wastewater discharge, is of high concern for many inshore coral reefs (CBD 2022; International Coral Reef Initiative 2022), with many of the contaminants associated with agricultural, industrial and domestic wastewater having adverse impacts on coral reef health, even in very small volumes (UNEP 2017).

It has been shown that corals are more susceptible to thermal stress when they are also exposed to chronic wastewater pollution, and less able to recover. Minimizing land-based pollution through improving circularity of water management is a vital and feasible response, which can improve water quality and increase resilience of coral reefs in the face of the more global overlying pressures resulting from global climate change (UNEP 2017).

Contaminants of concern

Emerging pollutants

Emerging pollutants present a particular challenge in water reuse and resource recovery. Wastewater contains not only known pollutants, but also new and emerging ones. Emerging pollutants, which are also referred to as contaminants of emerging concern, are defined as "any synthetic or naturally-occurring chemical or any microorganism that is not commonly monitored or regulated in the environment with potentially known or suspected adverse ecological and health effects" (UNESCO 2015). The main categories of emerging pollutants present in wastewater include human and veterinary pharmaceuticals, hormones, personal care products, agricultural chemicals (pesticides and herbicides) and industrial chemicals. Many emerging pollutants are endocrine disruptors, with potential effects on the growth and reproduction of aquatic organisms.

Emerging pollutants can still be present in treated wastewater, as conventional wastewater treatment and water purification processes are not effective in fully removing them (UNESCO 2015). Advanced wastewater treatment technologies (membrane filtration, nanofiltration, ultrafiltration and reverse osmosis) can partially remove some chemicals and pharmaceutically active compounds (González *et al.* 2016). Potential human health risks of emerging pollutants through exposure via water reuse for potable use and agricultural irrigation, as well as biosolid applications as fertilizer, remain a concern. Water reuse may also contribute to the spread and introduction of emerging pollutants into the environment, soil and aquatic environments through irrigation water reuse and the application of biosolids onto the land as fertilizers (Zandaryaa and Mateo-Sagasta 2018).

Microplastic pollution

The amount of microplastics entering wastewater treatment plants is variable (Hidayaturrahman and Lee 2019). Gatidou, Arvaniti and Stasinakis (2019) collated data on influent from 69 wastewater treatment plants and found that microplastic particle numbers varied from negligible to over 7 000 per litre. Iyare, Ouki and Bond (2020) found that primary and secondary treatment were effective in removing the majority of particles (on average 72 per cent in the wastewater treatment plants examined). Some studies indicate that the removal of microplastic particles can be higher in some treatment processes (Lares *et al.* 2018; Hidayaturrahman and Lee 2019; Iyare, Ouki and Bond 2020). For example, Gatidou, Arvaniti and Stasinakis (2019) found that up to 99.4 per cent of microplastics of less than 5 millimetres in size can be removed, with most removal occurring during the primary and secondary stages of treatment.

Despite the efficiency of wastewater treatment plants in decreasing the number of microplastic particles in released effluent, the huge volume of effluent discharged means that wastewater treatment plants are still a major contributor of microplastics to the environment. For example, three wastewater treatment plants in New Zealand were found to contribute an estimated 240 000 particles per day to receiving waters (Ruffell *et al.* 2021), with an estimated 37 per cent of microplastics in the marine environment coming from the wastewater pathway (UNEP 2021b). Ingestion of microplastics by animals can cause physical injury, changes in physiology, and impaired feeding, growth and reproduction rates (Prinz and Korez 2020). Due to challenges of transboundary impacts and a need for coherent regional approaches, addressing the release of microplastics from land-based sources, including from wastewater effluent and biosolids, is a priority for collective regional action under several Regional Seas Conventions and Action Plans.

However, removing microplastics from wastewater is unfortunately not the end of their journey, as they are concentrated into the sewage sludge fraction. Sewage sludge and its treated derivative biosolids are used as fertilizer on agricultural land in many countries. For example, in Australia, the EU, North America and the United Kingdom, 40–75 per cent of biosolids are used as fertilizer (Okoffo *et al.* 2021). The recirculation of these nutrients to agricultural land is an essential element of sustainable agriculture. However, the process for turning sewage sludge into biosolids does not remove microplastics (microplastic particle concentrations of up to 1.4 x 104 particles per kg have been found in biosolids [Crossman *et al.* 2020]). It has been suggested that the annual input of microplastics to agricultural land in Europe and North America (a combined maximum total of more than 650 000 tonnes) could exceed the amount of microplastics estimated to be in the surface waters of the ocean (a maximum of 214 000 tonnes [Nizzetto, Futter and Langaas 2016]). A recent study in Germany estimated that the majority of the 13 000 tonnes of plastic entering the environment each year comes from sewage sludge (Istel and Jedelhauser 2021).

PART 3

The solution – Optimizing wastewater resource recovery and preventing pollution

The transformation needed to move away from seeing wastewater as a waste management issue to a valued resource in a circular economy is increasingly urgent. It can only be delivered by combining technical solutions with a clear strategy to create an enabling social, cultural, regulatory and institutional environment.

This report identifies three key areas for action:

1. Reduce the volume of wastewater production: Freshwater resources must be used more responsibly. Reducing water consumption will lower the wastewater volumes produced, making the task of recovering and reusing wastewater more achievable by reducing energy requirements and the cost of collection and treatment. It will also reduce pollution and risks to people and nature.
2. Prevent and reduce contamination: More attention must be paid to what is put into water when it is used and, where feasible, separating and eliminating compounds at source before they enter the wastewater flow. By reducing and restricting the contaminants of concern in our water (e.g. pharmaceutical compounds, chemicals and synthetic compounds, microplastics or nanoparticles), it is easier and cheaper to treat and safer to reuse the resources in wastewater or to release treated water back to the environment.
3. Sustainably manage wastewater for resource recovery and reuse: Collection is a prerequisite to treatment. There are many solutions for the collection and treatment of wastewater to recover resources of appropriate quality standards depending on its application. Investments are needed to expand the capacity for wastewater collection and treatment that includes the recovery of resources for reuse. Investment is also needed to address the neglect or insufficiency of existing wastewater management facilities to ensure they are fit for purpose.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Implementing the key actions to expand the reuse of wastewater will require some foundational building blocks:

- ensuring effective and coherent governance and legislation to create an enabling political and regulatory environment
- mobilizing adequate and sustained investment and access to financing to optimize the wastewater value chain, create markets for resource recovery and facilitate business opportunities and investment by the private sector
- enhancing human, technical and institutional capacity at all levels (from local to global) to empower others to act on a shared vision
- enabling technical and social innovation to establish new approaches and equitable solutions that are appropriate to different socioeconomic-environmental situations
- delivering robust data collection and information management to support implementation, learning and ensure accountability
- increasing communication, awareness and transparency to build trust to support behaviour change and social acceptance

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Box 8: The EU Green Deal and wastewater management for reuse

Wastewater sits in multiple policy areas. The EU Member States have adopted the European Green Deal – a cross-sectoral plan for sustainable economic transformation. With regards to water policy, wastewater recovery and reuse appears in several strategies, including the Zero Pollution Action Plan (COM/2021/400) (EU 2021) and the Circular Economy Action Plan (COM/2020/98) (EU 2020). In 2015, only 2.4 per cent of treated urban wastewater was reused. The new EU Green Deal will increase the ambition of water reuse in Europe.

As part of the EU Green Deal package, a new water reuse regulation (2020/741) came into force on 26 June 2023 with the progress in implementation due to be reviewed in 2028. The principal aim of this regulation is to address water scarcity and drought by encouraging circular approaches to water reuse in agriculture and industry. The ambition is to increase water reuse to 6 billion m^3/year by 2025 (up from 1.1 billion m^3/year reused in 2015).

Of the total volume of recycled water, 52 per cent is used for irrigation, with 32 per cent for agricultural irrigation and 20 per cent for landscape irrigation. If the entire volume of treated wastewater in Europe was reused, it would ensure 44 per cent of agricultural irrigation needs (Ungureanu, Vlădu and Voicu 2020).

To ensure cross-sectoral coherence, related regulations, including the Urban Waste Water Treatment Directive 91/271/EEC, Sewage Sludge Directive 86/278/EEC and the Industrial Emissions Directive 2010/75/EU will be reviewed and revised as required to ensure they are coherent with the Green Deal.

Source: Water reuse and the European Green Deal, Webinar March 2021

Action areas

Action area 1: Reduce the volume of wastewater produced

Between 2015 and 2030 the volume of wastewater is projected to increase by approximately one third (Qadir *et al.* 2020; Jones *et al.* 2021). The steady increase in production is creating challenges for management. It is estimated that half of urban domestic wastewaters still enter the environment without adequate treatment (UN-Habitat and WHO 2021; Jones *et al.* 2021). Globally the volume of untreated wastewater from agriculture and industry is unknown but recognized to be significant. To meet the SDG target 6.3 to reduce the flows of untreated wastewater by half and substantially increase reuse by 2030, Jones *et al.* (2022) have projected that there will need to be huge increases in the capacity for wastewater collection and treatment. This first action area is therefore to stop treating water as an endless resource to reduce volumes of water used in the first place. This will also be an important adaptation strategy for increasing resilience to climate change impacts on water availability (IPCC 2023). Water conservation measures can reduce the volume of water that is being used, resulting in a lower volume of wastewater to be collected and treated with implications for the cost and energy required for its management. Conventional wastewater treatment systems are major consumers of energy, accounting for 3 per cent of global electricity consumption (Dickin *et al.* 2020).

In recent decades, there has been considerable discussion about the need to use water resources responsibly, reducing per capita use and encouraging technologies that create closed systems to keep water in use longer before discharge. It is time “to walk the talk” and stop wasting water. Urgent actions to use water responsibly and sustainably are needed in our farms, factories, homes and cities.

The proper recognition of the economic value of sustainably supplying and managing water can help to incentivize the responsible use and conservation of water and increase acceptance of embedding circularity principles in water and wastewater management. This is a mechanism that can be used by governments to encourage efficient water use at the household level, ensuring that pricing guarantees equitable water access for all. Some uncertainty exists about how effective pricing is, with suggestions that water pricing mechanisms need to be used in combination with other approaches, such as education and awareness to increase water conservation behaviours (European Environment Agency 2017).

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Reducing the volume of wastewater in agriculture

Agriculture, including crop and animal production is the largest consumer of fresh water, accounting for 69 per cent of freshwater use (United Nations 2021) and the primary source of nutrient pollution (CBD 2022). Due to the diffuse nature of agricultural run-off, wastewater from this source is rarely collected or treated (UNEP 2016) and data on agricultural wastewater are sparse (Jones *et al.* 2021). Subsidies in agriculture also contribute to continued excessive freshwater consumption, as they reduce the need for innovative and more sustainable solutions for irrigation such as wastewater use. Phasing out these subsidies is critical (Global Commission on the Economics of Water 2023). There are solutions available to reduce freshwater withdrawal and reduce wastewater production in agriculture, including:

- Combining new technologies and traditional approaches (such as big data and artificial intelligence to support monitoring and irrigation scheduling) and further developing traditional technologies to support water-use efficiencies. One example is capturing and storing rainwater to reduce reliance on freshwater sources.
- Identifying and using safe sources of treated wastewater that are appropriately treated for the water's intended use.
- Adopting cultivation approaches that support water conservation such as the use of organic mulch and covering crops to retain moisture; selecting and implementing drought-resistant crops and nature-based genetic improvements that can increase the performance of crops exposed to extreme conditions such as drought and flooding, as well as reducing losses to pests and disease.
- Improving irrigation efficiency, selecting the most appropriate irrigation technology for the respective crop – for example, drip irrigation can help achieve higher yields using less water.
- Scheduling irrigation for optimal timing to reduce evaporation losses or waste, such as watering in the evening or night time.
- Phasing out subsidies that could contribute to excessive freshwater consumption.

Reducing the volume of wastewater in industry

Industries can reduce water consumption and wastewater discharge by recycling and reusing water, either through water swaps between different industry processes or internally via a closed loop system (Bauer and Wagner 2022; EIB 2022). Recycling water reduces the demand for fresh water as well as the volume of wastewater to be treated. This may cut costs in the longer term and can help companies meet regulatory requirements (EIB 2022). The IPCC (2023) AR6 report identifies such measures as important adaptation strategies to reduce risks to the most water-intensive industries from climate change.

The concept of industrial symbiosis supports the transition to a circular economy through the cycling of materials and energy between businesses where wastes are converted into inputs (Ayres and Ayres eds. 2002). For example, by replacing clean water with reused wastewater from another business, one company can reduce waste while enabling another company to reduce input purchase costs and the reliance on potentially limited resources (Fraccascia and Yazan 2018).

Zero liquid discharge systems can maximize water-use efficiency and minimize liquid waste discharged from industrial processes as well as reduce freshwater withdrawals (Tong and Elimelech 2016). Such an approach aims to keep the treated water within the system, allowing for on-site recovery of chemicals (Jahan *et al.* 2022). The push to develop this strategy, which has been applied for example in textile manufacture and desalination plants, has been driven by increasing water scarcity, increasingly stringent regulations on wastewater discharge and associated costs (Tong and Elimelech 2016). Benefits include reduced water withdrawals, reduced risk of pollution, reduced cost of regulatory compliance, reduced cost of wastewater disposal, and the recovery of other resources, such as chemicals for reuse (Tong and Elimelech 2016; Jahan *et al.* 2022).

It may also be possible to reduce the flow of water, consider waterless or lower water-use technologies or installing automatic shutdown valves to avoid accidental overuse of water.

Reducing the volume of domestic and municipal wastewater

Many of the solutions to reduce wastewater volumes at the domestic and municipal level are already known and require a combination of technology, appropriate gender-responsive policies and regulations, and behaviour change to realize the desired impact.

Using optimal technologies such as low flush toilets or composting toilet systems, water-saving taps and shower heads (Bauer and Wagner 2022). Using smart water meters provides real time feedback to users and increases self-awareness on their water-use habits (United Nations 2023b). EEA (2017) estimated that use of domestic water¬-saving appliances could reduce water consumption by 40 per cent per year per household. There are also changes that can be made in developing decentralized systems at the building level in order to collect and make use of grey water and/or rainwater locally for example for flushing toilets or watering gardens. Residential direct reuse of grey water such as for toilet flushing can reduce domestic water consumption.

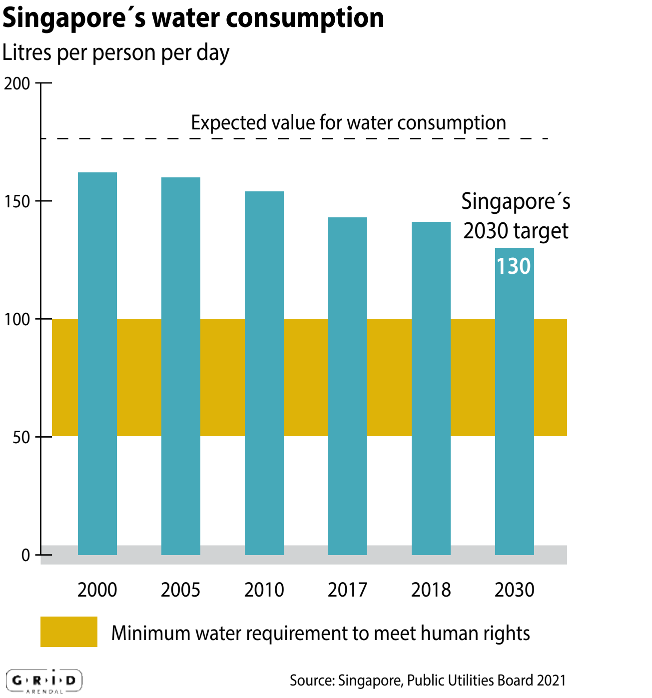

Figure 3.1: *Trends in per capita water consumption in Singapore.*

Community awareness and engagement must also form part of the solution. As part of its water security strategy, Singapore set an ambitious target to reduce per capita consumption of water from 160 litres per person per day to 130 litres per person per day by 2030 (figure 3.1). This effort, over a period of three decades, is being achieved through a combination of awareness campaigns and community participation to encourage sustainable water-use behaviour across sectors. Measures include a toilet replacement programme, awards for water efficiency and water efficiency labelling schemes (Singapore, Public Utilities Board 2021).

Despite China exhibiting rapid economic development and having the second-largest population in the world, its water use has not increased and has in fact been declining since a peak in 2013 (figure 3.2). Water conservation policies implemented in 2005, affecting agricultural, industrial and municipal water consumption could be one the drivers of this change (Xu *et al.* 2020).

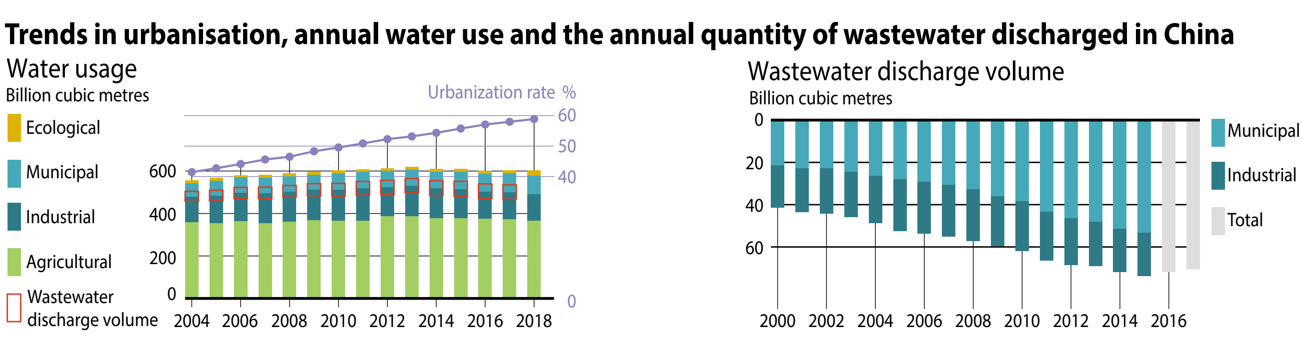

Figure 3.2: *Trends in urbanization, annual water use and the annual quantity of wastewater discharged in China. Despite urbanization increasing, water use has decreased (left) and total wastewater discharge has, between 2014 and 2016, also now started to decrease (right).*

Action area 2: Prevent and reduce contamination in wastewater flows

The fewer pollutants that are introduced into wastewater, the easier and cheaper it is to treat the wastewater and recover safe, usable resources.

Clean, safe water is characterized by physical, chemical and biological quality parameters. As water is used, the quality deteriorates, for example through the addition of nutrients, chemicals, pathogens, heat and microplastics. In addition, new and emerging contaminants, such as pharmaceutical and personal care products, hormones, dioxins, pesticides, nanomaterials and surfactants are increasing all the time (Ahmed *et al.* 2021). If not adequately treated, these contaminated flows pose a threat to the safe reuse of water further downstream as well as to the biodiversity and function of the receiving ecosystems (Jones *et al.* 2022; van Vliet *et al.* 2021). Pathogens and nutrients, both prevalent contaminants in wastewater, result in waterborne disease and eutrophication.

Conventional treatment processes are not designed to completely remove many of these emerging contaminants, resulting in detrimental long-term and in some cases yet-unknown impacts on human and ecosystem health. Mahjoub and Chmengui (2021) demonstrated the spread of pharmaceutical compounds in the coastal environment in arid and semi-arid countries. In the Baltic Sea region the release of contaminants such as pharmaceuticals is concerning due to the low flushing rate and long retention time of these pollutants, and has been the subject of regional action through the Helsinki Commission (United Nations Educational, Scientific and Cultural Organization and the Helsinki Commission 2017). To assess the presence and to evaluate potential impacts, monitoring programmes are required at the country and regional levels.

Given the wide range of contaminants and their ubiquity, preventing the input of contaminants into water or separating and eliminating them prior to their discharge or before reaching the wastewater collection system are considered to be more efficient and less costly approaches than collecting and waiting to treat the problem as an end-of-pipe approach.

Preventing input of contaminants

There are a wide range of potential actions at the household, municipal, industry and farm level that can help reduce input of contaminants into wastewater in the first place. All require some degree of change in behaviour or business practice.

Reducing the input of contaminants in the agriculture sector

- Applying smart agriculture innovations to ensure efficient use of nutrients and any chemical inputs. This can range from low-tech solutions, using crop rotation to control nutrient deficiency, rainwater harvesting, through to the application of high-tech solutions such as robotics, digital communication between machinery (the Internet of Things), artificial intelligence and cloud computing to reduce the quantities of chemicals and fertilizers that need to be applied.
- Implementing science-based nutrient management strategies to reduce environmental losses. Monitoring soil quality before application can inform what additional nutrients are needed as well as the most appropriate timing and rate of application in the right places.
- Using cover crops to return nitrates to the soil and reduce the need for additional fertilizer.
- Moving towards no-till field management strategies.
- Optimizing the use of veterinary medicines and antibiotics for livestock breeding. The overuse of antibiotics and artificial growth hormones in industrial farming results in the release of their residues into soil, groundwater and surface waters (Zandaryaa and Mateo-Sagasta 2018).

Reducing the input of contaminants from industry

- Phasing out use or self-regulating certain contaminants, for example through the Wastewater Zero call to action by the World Business Council for Sustainable Development (WBCSD 2020).
- Investing in the development of suitable alternatives to products that are less harmful, e.g. in plant-based exfoliating skincare products to replace plastic microbeads.
- Implement zero liquid discharge systems allowing for the recovery of chemicals, e.g. as implemented in textile, chemical and power industries (Jahan *et al.* 2022) and applied to commercial complexes such as hotels and malls (Mubarak *et al.* 2018).

Reducing the input of contaminants from domestic sources

- Lobbying industry to make safe biodegradable products.
- Education and awareness to inform the choice of household cleaning products and personal care products.
- Ensuring appropriate use and disposal of pharmaceutical products.
- Selecting appliances that can reduce input into the wastewater flow, e.g. compost toilets, source-separating toilets that separate urine and faeces.
- Using washing machine filters to reduce microplastics from textiles.
- Avoiding excessive consumption of dietary protein, adhering to the recommended dietary requirements for good health would reduce pressure on wastewater treatment capacity.*

Policies and regulations for reducing the input of contaminants

- Regulating the production, use and/or disposal of particularly toxic contaminants or other non essential products that increase the cost or difficulty of wastewater treatment, e.g. certain ingredients used for sunscreen (oxybenzone and octinoxate) have been banned due to their impact on marine life.
- Applying the polluter pays principle to incentivize avoidance of environmental damage and hold polluters responsible for costs resulting from pollution events.
- Providing safe and accessible disposal options for substances of concern (e.g. take-back schemes for unused or out-of-date household and veterinary pharmaceutical products).
- Running public education and awareness campaigns to reduce the input of contaminants into the sewage network, targeted at the different stakeholder groups.
- Supporting innovation and uptake in changes of practice or technology to avoid or limit pollutant- and nutrient-rich waste streams.

*Almaraz *et al.* (2022) concluded that if United States citizens reduced current excessive levels of protein consumption to meet the recommended dietary requirements, projected nitrogen excretion rates would decrease by 27 per cent by 2055, despite population growth.

Separation and elimination of contaminants prior to discharge

The separation of contaminants at source has been shown to improve treatment capacity. Appropriate and advanced pre-treatment or full treatment at source can remove critical pollutants, producing a high-quality effluent and reducing the pollutant load on the municipal sewage and wastewater treatment plants that they might otherwise not be able to manage. Reduced wastewater output can reduce levels of discharge fees, providing additional economic incentive for on-site treatment and recovery of wastewater (WBCSD 2020).

Separating contaminants at source from domestic sources

- Promoting source-separating toilets that collect urine and faeces separately, making it possible to remove nitrogen and phosphorus from urine, which carries higher levels of resources and lower levels of contaminants (see case study from Malmö), lowers cost of wastewater treatment (Otto and Drechsel 2018) and reduces environmental impact, for example by preventing eutrophication (Mayer *et al.* 2016).

Separating contaminants at source from municipal and industrial sources

- Identifying municipal services and industries that have sector specific contaminants, such as hospitals, factories, intensive animal production and develop on-site, decentralized treatment before the effluent can be released into the municipal sewer systems (State of Green and Danish Water Forum 2016).
- Trading with other industries locally or within the value chain, e.g. where lower-quality standards are required, potentially reducing investment and operational costs.

CASE STUDY 11

Urine separation – Alkaline dehydration in practice in Malmö, Sweden

Prithvi Simha, Swedish University of Agricultural Sciences, Department of Energy and Technology, Sweden

As part of the ongoing research project REWAISE, co-funded by the EU, a urine-separating toilet integrated with a urine dryer was installed at the offices of VA SYD, the company that manages water and wastewater treatment in Sweden's Skåne region. The toilet has been co-developed with the design firm EOOS NEXT and makes use of the space below the wall-mounted toilet. It has the capacity to evaporate 10 litres of urine per day and needs to be serviced only once a month. It is equipped with a sensing platform that controls urine inflow and overflow and drying conditions, and alerts maintenance staff when it is time to empty the drying container and collect the dried urine. VA SYD's motive for testing urine source separation is to reduce the nitrogen load to their Sjölunda treatment plant, which serves Malmö, Sweden's fastest growing city. Two more toilets drying urine on-site are scheduled to be installed, in Brunnshög, Lund and Sege Park, Malmö.

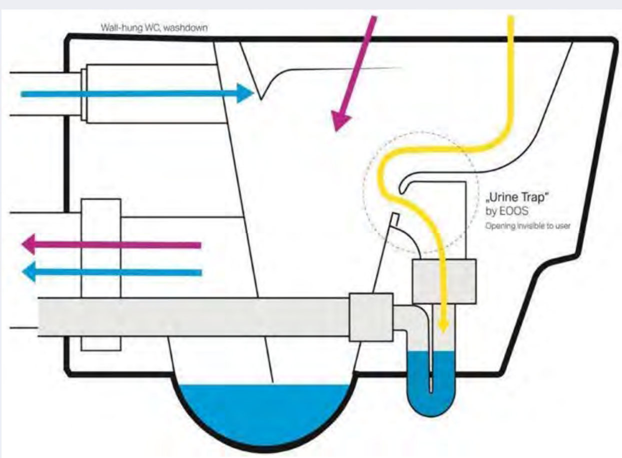

Figure 3.3: *Laufen's Save! toilet has an EOOS "Urine Trap" to separately collect human urine at source. Source: Laufen and EOOS.*

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A Save! urine-separating toilet integrated with an alkaline urine dehydrator implemented at the offices of VA SYD in Malmö, Sweden.

Action area 3: Sustainably managing wastewater for resource recovery and reuse

Wastewater must be adequately treated so that its safe circularity can be realized. To be treated it must first be collected. This action area presents some options for improving collection and treatment of wastewater to increase the potential for reuse.

Approximately 63 per cent of global domestic and manufacturing wastewater is collected and 52 per cent of globally produced wastewater is treated. When looking at the domestic and manufacturing wastewater that is collected, 84 per cent is subject to some level of treatment (Jones *et al.* 2021). Estimates of wastewater treatment have shown some improvements since 2015 (UN-Habitat and WHO 2021), particularly for domestic wastewater. Despite these improvements, there is still a large variation between the percentage of wastewater collected, treated and reused in different regions (figure 3.4), with much of the progress occurring in developed countries. In countries where access to sanitation and wastewater services is low, a large percentage of wastewater cannot be collected and consequently cannot be treated.

Collection infrastructure can either be centralized, with wastewater treated off-site, or in decentralized on-site sanitation systems. Both centralized and decentralized systems can vary in complexity. Once collected, wastewater can undergo various forms of treatment. UN-Habitat and WHO (2021) report that wastewater that is collected in centralized sewers is more likely to be treated than wastewater from decentralized systems.

Treatment can also be managed centrally or through decentralized approaches that incorporate wide variety of solutions using physical, biological and ecological processes, or combinations of these. Wastewater treatment can range from the simple, such as screening and sedimentation (primary treatment), to the biological, such as using activated sludge (secondary treatment), and to more advanced technologies such as membrane filtration, disinfection and carbon adsorption (tertiary treatment) (figure 3.5). The degree to which treatment practices exist and reduce contaminant levels (Jones *et al.* 2021) and the proportion of (treated) wastewater relative to stream flow (Ehalt Macedo *et al.* 2022) are crucial determinants of how the recovered resources can be used as well as of the impact on the quality of receiving waters (Jones *et al.* 2021; Mateo-Sagasta, Raschid-Sally and Thebo 2015).

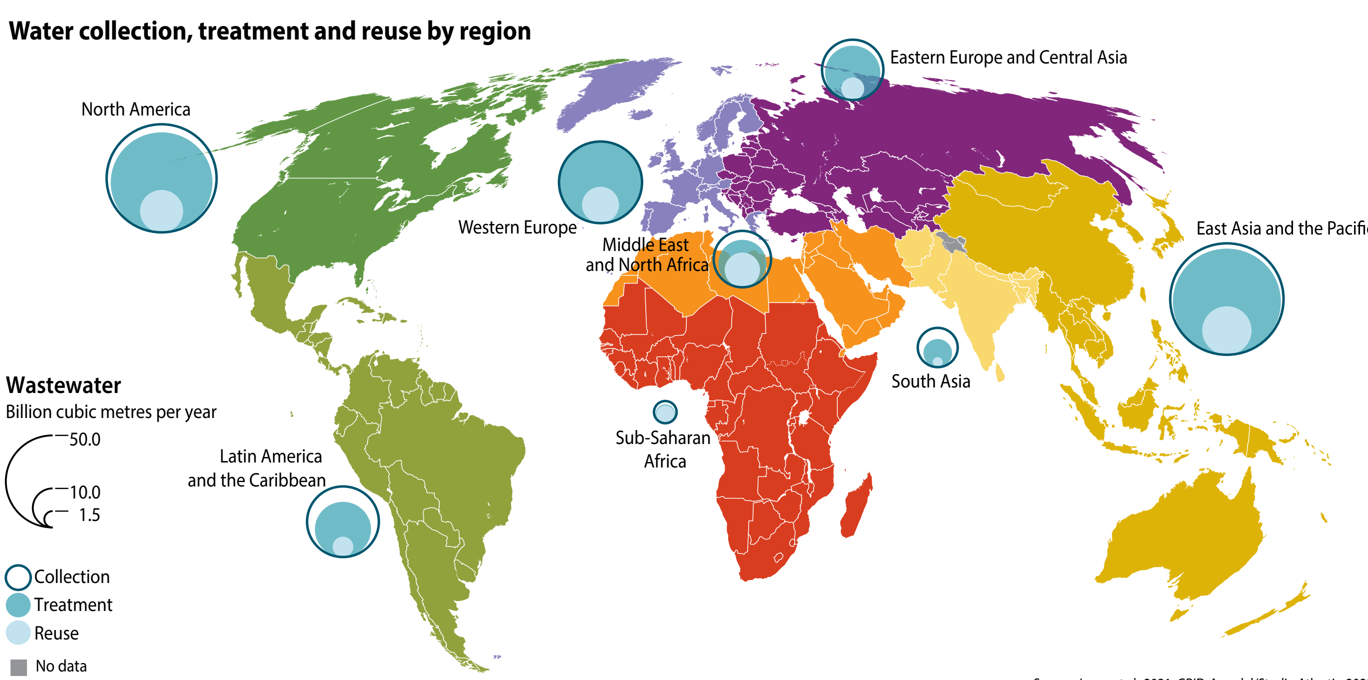
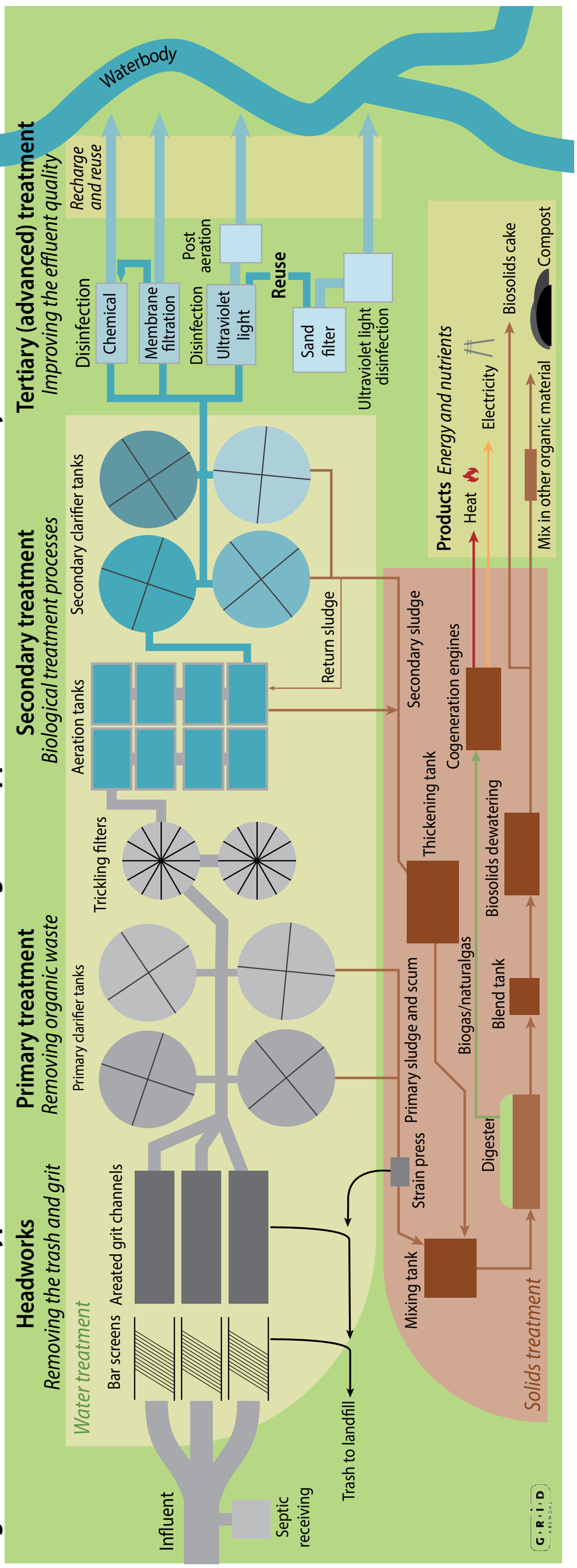


***Figure 3.4:** Water collection, treatment and reuse by region.*

A generalised schematic of typical wastewater treatment stages and opportunities for resource recovery



Box 9: Note on wastewater treatment statistics

Quantifications of wastewater treatment both at the plant and national levels must be considered with caution due to several factors, such as: (1) wastewater treatment plants typically operate at capacities below the installed capacities (Mateo-Sagasta, Raschid-Sally and Thebo 2015); (2) wastewater plants may be entirely non functional after installation due to lack of funding and maintenance in the pre-installation phase, yet the associated wastewater volumes are reported as treated; (3) numbers on “wastewater treatment” may include any form of wastewater treatment, including simple filtration and sedimentation; and (4) issues with wastewater treatment plants that may not be appropriately designed for the incoming wastewater, such as treatment facilities designed for domestic wastewater receiving significant volumes of industrial wastewater mixed with domestic wastewater (Qadir *et al.* 2010).

Compliance with water quality and pollution reduction regulations has tended to be the driver for wastewater treatment (Salgot and Folch 2018; Morris *et al.* 2021). However, using this “flush-and-forget” approach means it is very complex and energy intensive to safely recover resources like nutrients, water and energy at the end-of-pipe. To achieve SDG 6, the paradigm must shift, and the focus should be on resource recovery facilities to help realize the value of wastewater (Morris *et al.* 2021). Successfully closing the loop for water will require a wastewater collection, treatment and reuse framework that will go beyond the technical solutions and infrastructure, but also take a holistic approach that considers the local, political, social, environmental and economic context.

The current spatial distribution of wastewater treatment plants reaffirms that there are many more facilities in high-income countries. Conversely, many developing countries have very limited or non-existent wastewater collection infrastructure and treatment facilities.

Change our communication and language to reflect the desired future

Branding and information dissemination are important aspects of water reuse and resource recovery, contributing to a positive public perception of reclaimed water and recovered resources such as fertilizers. For example,

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in Singapore, reclaimed water is branded as "NEWater" (Zandaryaa and Jimenez-Cisneros 2017). In 2015, the United States Government took the step to refer to "water resource recovery facilities" and not "wastewater treatment plants" at the request of the water treatment community to reflect the shift towards a circular economy perspective (National Science Foundation, United States, Department of Energy and Environmental Protection Agency *et al.* 2015).

Expand capacity for collection and resource recovery

Reaching the SDG 6.3 target to improve wastewater treatment and reuse requires considerable expansion in wastewater collection and treatment systems. Jones *et al.* (2022) identified that the largest expansions for wastewater treatment will need to be in the three largest industrialized nations: China, the United States and India. These three countries account for around 45 per cent of the required expansion. Figure 3.6 shows that 30 countries account for 87 per cent of the total required expansion to meet the target. However, meeting the target is not just about the numbers, but about ensuring the development is equitable, leaving no one behind.

The infrastructure required for wastewater collection and treatment is very expensive and technologically challenging, requiring large investment of public funds. States with access to finance and technology have made significant advances in the last decade, but there are also many options for the application of decentralized and affordable low-tech solutions. Some examples are presented in the sections that follow.

Expansion in wastewater treatment capacity required by 2030 to achieve SDG 6.3 for the top 30 wastewater producing countries

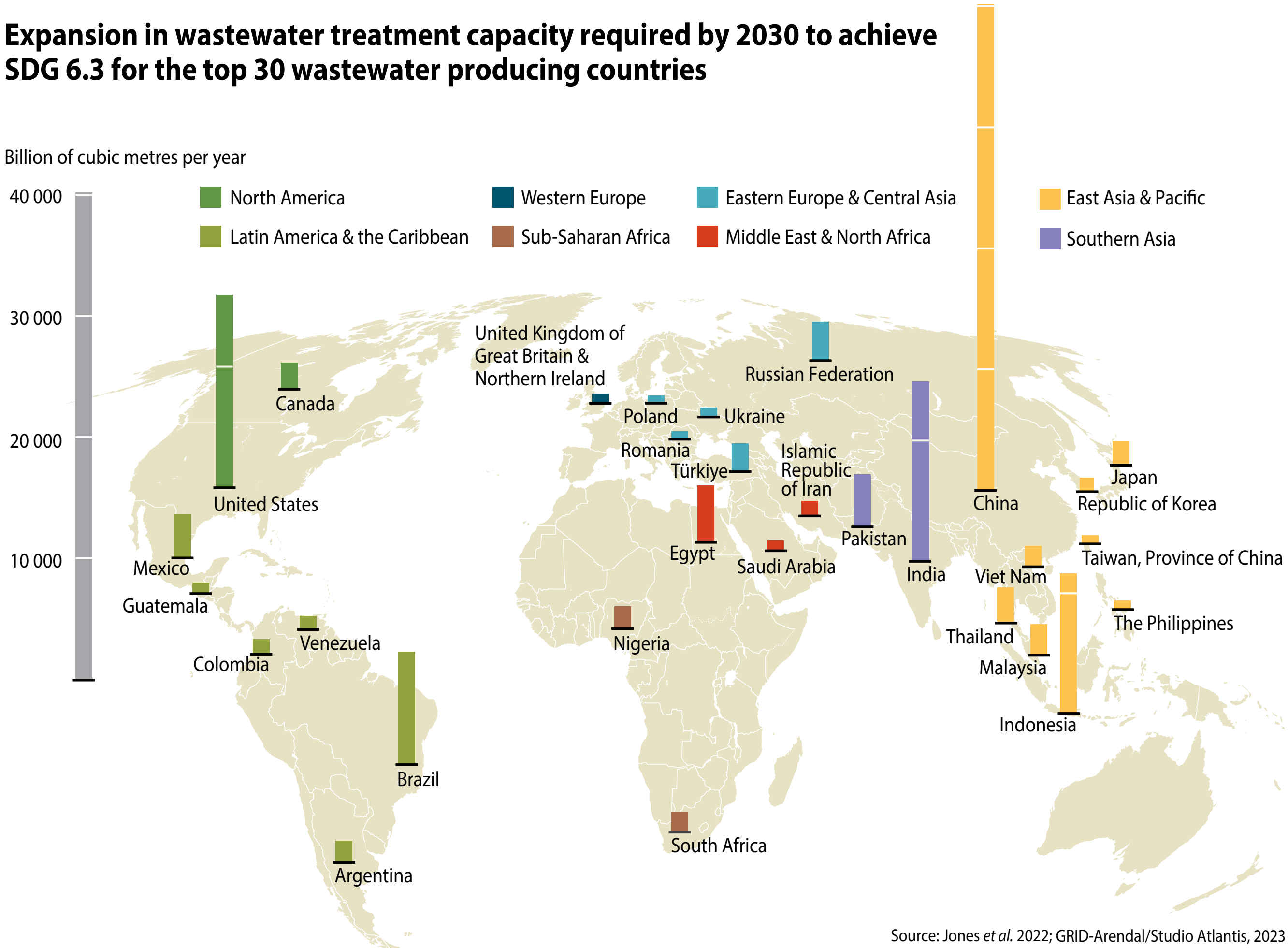

***Figure 3.6:** Expansion in wastewater treatment capacity required by 2030 to achieve SDG 6.3 for the top 30 wastewater producing countries.*

Solutions that are fit for purpose

There are a wide variety of options for wastewater treatment for resource recovery. There are different technologies for different types of resource recovery and each will have advantages and disadvantages (Zhang *et al.* 2023). Biological and ecological systems have been used with success for nutrient and energy recovery but can be slow and struggle to treat some pollutants. Some of the newer, higher-tech processes have greater potential to remove pathogens and other pollutants of concern but are more expensive and require access to the appropriate human capacity (Zhang *et al.* 2023).

The optimal choice will require a decision based on the local context and specific objectives and is likely to also require adaptation (Salgot and Folch 2018; Zhang *et al.* 2023) (figure 3.7).


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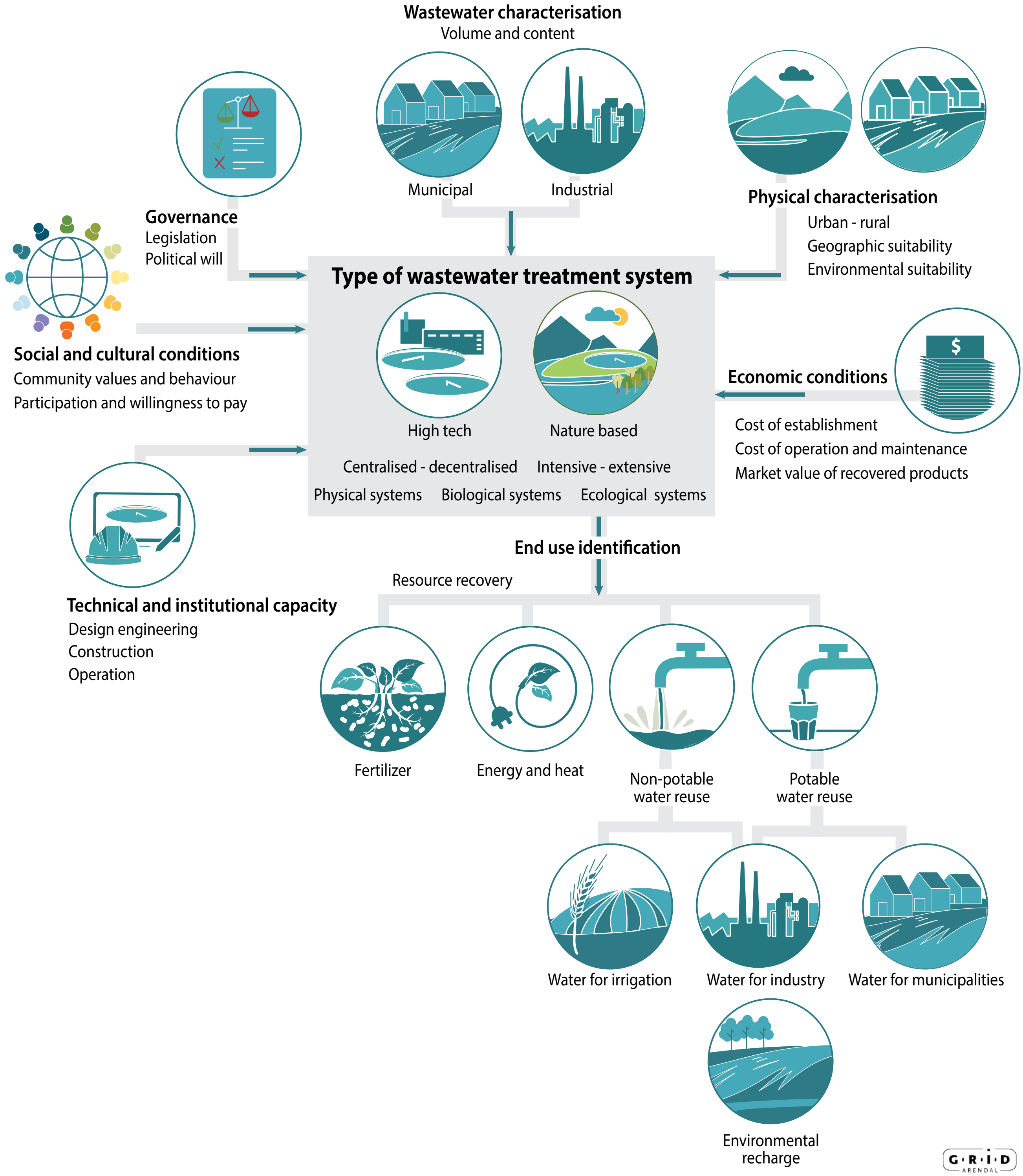


***Figure 3.7:** Finding the optimal solution to treat wastewater for resource recovery.*

Table 3.1: *Different processes for black wastewater treatment and associated products.*

Process	Recovered resource			
	Solid	**Liquid**	**Gas**	**Energy**
Aerobic composting	Compost			
Anaerobic co-digestion	Biogas residue	Digestate	Biogas	Biogas
Membrane distillation		Reusable water		
Membrane bioreactors		Water to discharge		
Upflow anaerobic sludge blankets	Biogas residue	Digestate	Biogas	Biogas
Electrochemical		Reusable water		
Microwave		Pathogen-free water		
Constructed wetlands	Plant biomass	Irrigation water		
Microbial fuel cell				Electricity
Microbial electrolysis cell			Hydrogen	Hydrogen
Struvite precipitation	Struvite			
Microalgae treatment	Microalgae biomass			

Note: Adapted from Zhang et al. 2023.

Centralized systems for resource recovery

Centralized wastewater systems are dedicated networks connecting homes, business, services and some industries that collect wastewater and treat it off-site. Such systems are suitable for treating large volumes of wastewater and are typically developed in highly populated urban areas to take advantage of the economies of scale (Pasciucco, Pecorini and Iannelli 2020). While conventional wastewater treatment has been designed to collect wastewater and treat it centrally and discharge (Thompson Rivers University 2020), the focus here is on the application of treatment for resource recovery and reuse. Pasciucco, Pecorini and Iannelli (2020) suggest that centralized wastewater systems are suited to producing reclaimed resources that require higher-quality standards, such as potable water.

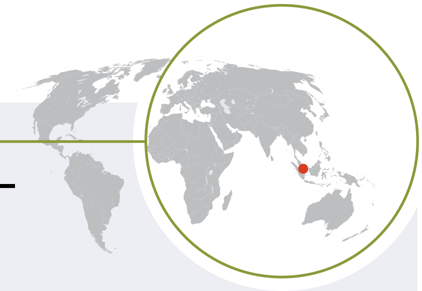
Between 2015 and 2020 China invested US$ 81.6 billion in municipal wastewater systems to accelerate capacity in wastewater treatment. In the United Kingdom, a 10-year, £5 billion project started in 2015 to update the 150-year-old London sewer system focusing on improving collection capacity to reduce leakage of untreated wastewater. In India, Delhi, there are ambitious plans under way to expand wastewater treatment alongside work to connect unsewered areas in the city by 2031.

The projected expansion requirements present a significant challenge in terms of financial, institutional and human capacity. In 2015, the United States Environmental Protection Agency estimated that US$ 600 billion needs to be spent on national water infrastructure improvements over the next 20 years, in large part due to existing infrastructure reaching its end of life (National Science Foundation *et al.* 2015). This however has been identified as an opportunity to ensure investment is made in infrastructure with economic, social and environmental benefits. The Billund Biorefinery in Denmark and the Hamburg Wasser wastewater treatment plant in Germany are examples of conventional wastewater treatment plants that have been converted for resource recovery. While expenditure on infrastructure improvements can be very high, a World Bank report (Rodriguez *et al.* 2020) gives several examples where a relatively small investment has provided significant economic and environmental gains. For example, in a Chilean town, a US$ 2.7 million retrofit of a wastewater plant enabled the production of biogas, which generated an annual net profit of US$ 1 million.

Decentralized systems for resource recovery and reuse

There are many cases where centralized systems are not appropriate, for example in rural areas as well as in low and middle income countries where there are no

CASE STUDY 12



The challenges of keeping up with the demands of a growing city – expanding wastewater treatment capacity in Delhi, India

■ **Avantika Singh**

The population of New Delhi, the capital city of India, is currently at 18 million people and growing rapidly, putting tremendous pressure on the city's water and wastewater systems. The city produces approximately 3 268 million litres of sewage per day, while the current system has an operational capacity of only 2 756 million litres/ day (it does not operate at full capacity so that figure is closer to 2 083 million litres/day). Only 50 per cent of the population of Delhi is served by a sewerage system and the sewage generated from the remaining population joins the Yamuna river through a number of surface drains. The source of about 80 per cent of the water pollution in the Yamuna is domestic sewage flowing through drains from authorized/ unauthorized areas (India, Government of Haryana 2020). The Delhi Jal Board has an ambitious sewage master plan to connect all unsewered areas by 2031 (India, Delhi Jal Board and AECOM WAPCOS 2014). To cope with the increasing load, the city is planning to expand treatment capacity by more than 20 per cent by mid-2023. This involves upgrading existing plants and constructing 48 new treatment plants. The largest of the upgraded treatment plants, located in the south of the city at Okhla, can process 564 million litres of sewage/day. The plant has the capacity to remove nutrients from the wastewater, which when treated will be used for non-potable purposes such as groundwater recharge, lake regeneration and industry. The facility also has a sludge management system which includes a solar drying system (The Pioneer 2021).

CASE STUDY 13

The London Super Sewer – Improving the collection of wastewater

■ **Claire Rumsey**

London is currently being served by a sewer system built in the 1800s. The population has more than doubled since then, and sewage leaks out into the River Thames when it rains, making the system no longer fit for purpose. A 10-year, £5 billion project, started in 2015 to update the 150-year-old system known as the Super Sewer, includes 25 km of tunnels designed to collect the overflow from the old system and transport it back to the sewage treatment plant. It is expected that this new infrastructure will reduce the overflow into the River Thames by 95 per cent and ensure regulatory requirements for wastewater pollution are met. In addition, the project is anticipated to have social, economic and environmental co-benefits through the creation of jobs, enabling continued housing development and improving the environmental health of the river.

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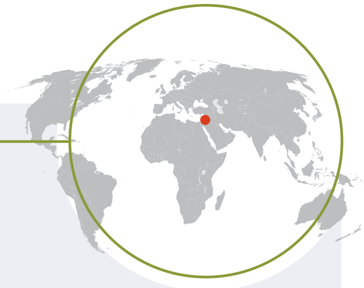
CASE STUDY 14 EXTENDED VERSION



Advanced wastewater treatment for reuse in small off-grid settlements in the Israeli Negev Desert

Aviad Avraham, **Amit Gross** and **Roy Bernstein**, Zuckerberg Institute for Water Research, Ben-Gurion University of the Negev, Israel

Living in an arid environment emphasizes the fact that water is a valuable resource. One way of coping with water scarcity is to reuse reclaimed wastewater for irrigation after proper treatment. On-site (decentralized) wastewater treatment is used globally and is often crucial to developing countries, temporary settlements (i.e. refugee camps) and remote regions that have no access to centralized wastewater treatment facilities. A new wastewater treatment system designed for small, off-grid settlements was tested on a farm located in the Israeli Negev desert to see if the proposed system would be able to produce a high-quality effluent product, year-round and across seasonal variation that would be approved by governmental regulators for unlimited irrigation. The system, which has been running for nearly two years, has shown promising results in producing clean effluents that are used for irrigating crops. Dissolved organic carbon content had decreased by up to 90 per cent in addition to the complete removal of the bacteria E. coli after ozone disinfection and membrane filtration. The water quality met government regulations for year-round use and the system was approved for use by the Israeli Ministry of Health. As the world is slowly transitioning to a hybrid model of combined centralized and decentralized wastewater treatment, there is great potential and opportunities for replicating this wastewater treatment system. The Ramat Negev regional municipality aims to replicate this system in dozens of farms in the region. The system has proved to be efficient at reclaiming water for safe reuse in arid environments, but as the system heavily relies on biological treatment, extremely cold environments might pose a challenge and act as a geographic limiting factor

Dissolved organic carbon and suspended solids before and after treatment

Source: Avraham 2022

Figure 3.8: *Dissolved organic content and total suspended solids concentrations before and after treatment in the wastewater treatment plant, as compared with the Israeli Government guidelines for unlimited irrigation.*

existing or functioning centralized sewer and wastewater treatment facilities (Capodaglio 2017). They have high capital investment costs and high demand for constant energy supply, financial resources and human capacity to operate and maintain. Decentralized treatment solutions are implemented at the site level, at the scale of the household, business, municipal service (e.g. a hospital) or small community. There are different types of decentralized solutions using chemical, biological and ecological mechanisms that can be used independently or combined depending on the source and intended reuse, including advanced wastewater treatment to be able to meet regulatory standards for irrigation. Decentralized systems can also be combined with centralized systems to create hybrid systems.

The decentralized wastewater treatment approach

DEWATS is a wastewater recycling approach designed to be part of a comprehensive wastewater strategy. It is designed to treat wastewater where it is generated for either reuse or disposal. The approach is adaptable to the specific socioeconomic conditions and is scalable. The approach allows for locally adapted infrastructure and capitalizes on natural physical and biological processes, keeping energy requirements low and ensuring there is local capacity for sustainable management. The systems can produce water for irrigation or toilet flushing, produce biofuel and soil conditioner (Gutterer *et al.* 2009). A case study has been provided for the implementation of this approach for a maternity hospital in Dar es Salaam in Tanzania to provide sustainable wastewater treatment, irrigation water and biogas production.

Combining centralized and decentralized solutions

Combining centralized and decentralized systems can be most advantageous to address issues of scale. In large urban areas, combining solutions for on-site and off-site sanitation systems as well as centralized and decentralized wastewater management facilities can be suitable to address the issue of infrastructure and service expansion, while offering benefits of decentralization such as reduced investment, low operation and maintenance costs, and customizability to local conditions (Zandaryaa and Brdjanovic 2017). An example is distributed systems, which represent a flexible, localized and highly networked approach, where the central infrastructure plays an arterial role, while smaller, tailored systems operate and interact with users at a more localized level.

Nature-based solutions for wastewater management and reuse

NBS have been identified as a low-tech, lower-cost set of solutions that can be used to manage and treat wastewater, including for resource recovery and reuse, supporting climate change adaptation and mitigation as well as enhancing biodiversity.

In 2022, the United Nations Environment Assembly agreed to define NBS as:

> *"actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services, resilience and biodiversity benefits, and recognizes that nature-based solutions:*
> *(a) Respect social and environmental safeguards, in line with the three "Rio conventions" (the Convention on Biological Diversity, the United Nations Convention to Combat Desertification and the United Nations Framework Convention on Climate Change), including such safeguards for local communities and indigenous peoples;*
> *(b) Can be implemented in accordance with local, national and regional circumstances, consistent with the 2030 Agenda for Sustainable Development, and can be managed adaptively;*
> *(c) Are one of the actions that play an essential role in the overall global effort to achieve the Sustainable Development Goals, including by effectively and efficiently addressing major social, economic and environmental challenges, such as biodiversity loss, climate change, land degradation, desertification, food security, disaster risks, urban development, water availability, poverty eradication, inequality and unemployment, as well as social development, sustainable economic development, human health and a broad range of ecosystem services;*
> *(d) Can help to stimulate sustainable innovation and scientific research" (UNEP/EA.5/Res.5).*

NBS have been employed to treat wastewater for year-round reuse in irrigation, fish farming and enhancing biodiversity (for example through urban greening). NBS that promote plant growth can increase carbon dioxide sequestration, provide flood protection and improve human well-being.

There is a wide range of NBS approaches being used for wastewater treatment (figure 3.9). The type of NBS selected depends on the source of the water, contaminants, volume and intention for reuse. There are standards and standard designs based on loading, water quality and temperature which influence the choice of design. While NBS have predominantly been used for domestic wastewater treatment, there has been some application of NBS to industrial wastewater flows, including the use of constructed wetlands for dairy shed waste (WWAP 2018).

NBS have been found to be cost-effective both in terms of construction and operation (WWAP, 2018). When designed and implemented appropriately, they can provide an affordable and reliable option for decentralized wastewater treatment and resource recovery for application in a range of geographic contexts, including small island developing States, such as in the Solomon Islands. At the regional scale, the Contracting Parties of the Barcelona Convention have agreed to promote the use of NBS to the extent possible for smaller communities (i.e. less than 2 000 persons equivalent) (UNEP 2021b)

Source separation

Source separation has been discussed under action area 2 as a strategy for eliminating contaminants prior to discharge. The use of source-separating approaches such as urine-diverting toilets merits reference again here as a decentralized wastewater treatment option. Source separation offers a radically different approach for society to manage all three challenges to the recycling of essential nutrients like nitrogen and phosphorus, inactivation of pathogens like parasitic worms and the removal of micropollutants like pharmaceuticals. Human urine contributes just 1 per cent to the volume of domestic wastewater, but contains 80 per cent of the nitrogen, 50 per cent of the phosphorous and potassium, 64 per cent (+/– 27 per cent) of the pharmaceuticals and has a very low pathogen load compared with faeces (Vinnerås 2006; Lienert, Bürki and Escher 2007).

Human urine can be collected separately from faeces by using urine-diverting toilets and unisex urinals. Since the 1990s, urine separation has been practised in

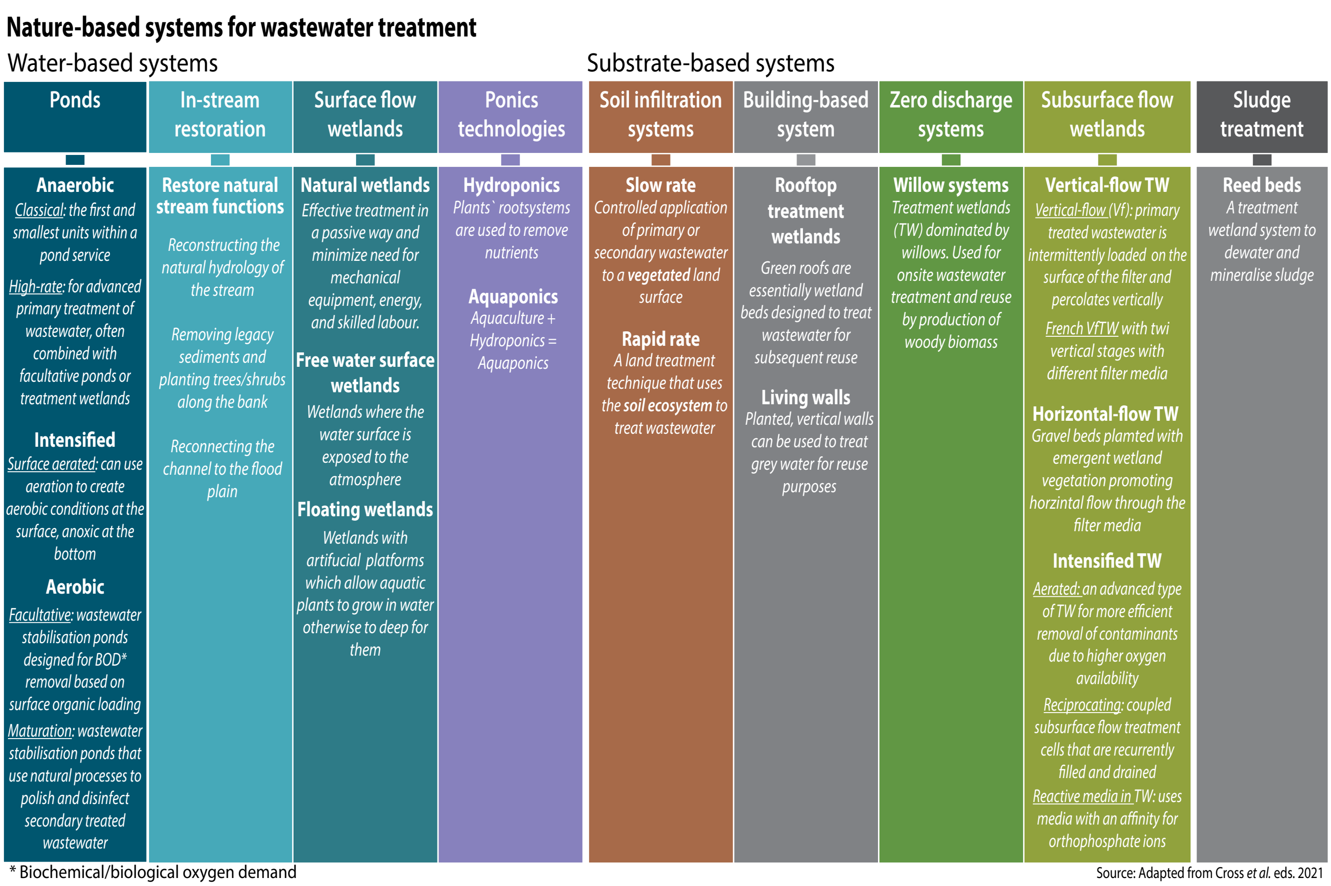
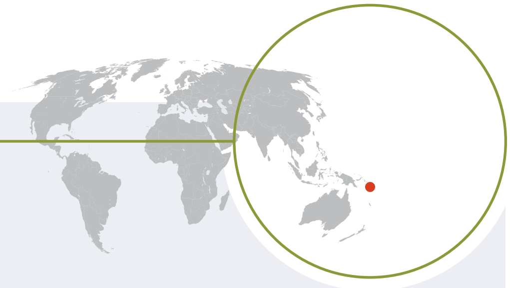


Figure 3.9: *NBS systems for wastewater treatment.*

CASE STUDY 15



Nature-based solutions to treat wastewater for resource recovery and reuse – the Solomon Islands Urban Water Supply and Sanitation Sector Project

To improve water and sanitation, the Solomon Islands is currently implementing a US$ 92 million internationally funded urban water supply and sanitation sector project (Solomon Islands Water Authority 2020). The project was approved in 2019 and is due for completion in 2027. In addition to improving drinking water, the project includes developments to stop the release of untreated sewage. At present, 76 per cent of the urban population and only 18 per cent of the rural population of the Solomon Islands are connected to basic sanitation. The impacts of poor water and sanitation services disproportionately affect women, who have primary responsibility for cleaning, cooking, washing and caring for children and sick family members (World Bank 2019). For those living in the capital Honiara, there are many locations and a surrounding area that are not connected to the sewer (about 90 per cent of the population). The septic tanks are serviced by contractors who pump out the septage and transport it to a non-engineered landfill where it overflows into a nearby creek. Among the project's activities, the proposed improvements include the use of NBS, including via the construction of a reed bed filter treatment plant that can accommodate 60 m^3 of septage per day (current volumes are estimated at 40 m^3/day). The treated water flowing out of the filter system will be pumped to the nearest wastewater treatment plant for discharge, while the sludge will be periodically removed from the reed beds and used for fertilizer.

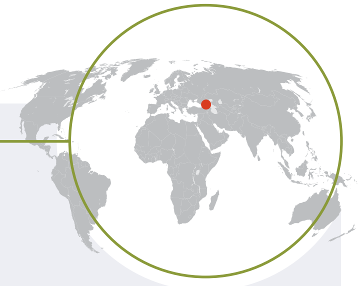
many countries. In Durban, South Africa, the eThekwini Municipality installed 100 000 of these toilets, which are serviced by the municipality to collect the urine. In Sweden, there are an estimated 135 000 urine-diverting toilets, mostly installed in holiday homes (Kvarnström *et al.* 2006). Latest designs like Laufen's Save! toilet can separate urine using just surface tension and an outlet that is not visible to toilet users (Gundlach *et al.* 2021). Unlike old designs where the toilet had separate bowls for urine and faeces, the Save! toilet appears just like any other non-separating toilet. The collection and storage of urine can also be adapted to single private/public toilets and multistorey buildings.

Stored human urine has been shown to be an effective crop fertilizer (Mkhize *et al.* 2017), but only practical at a small local scale due to the challenges of managing the large volumes of urine (Larsen, Udert and Lienert 2013). Urine is 95 per cent water by composition and every person excretes 550 litres per year (table 1). To fertilize 90 kg of nitrogren per hectare, 15 000 kg of urine would need to be spread by farmers, compared with only 200 kg of synthetic urea. To tackle this problem, there have been many attempts to develop treatment technologies that can reduce the volume of urine or to recover the valuable resources it contains (see Larsen, Udert and Lienert, 2013; and Harder *et al.* 2019 for an overview).

There are two broad categories of technologies that can be applied for recovering nutrients from urine.

Alkaline dehydration: where human urine is converted to a solid fertilizer (<link to case study: Malmo>). It involves dosing fresh urine with sparingly soluble (<10 g/L) alkaline chemicals like calcium hydroxide (US$ 0.08/kg) that increase the urine pH from 7 to >10. This prevents the natural degradation of urea to ammonia (Vasiljev *et al.* 2022; Simha *et al.* 2022). Urea, the most widely used fertilizer globally, makes up 85 per cent of the nitrogen in urine but is degraded by the enzyme urease. Urease is excreted by ubiquitous environmental bacteria that tend to form biofilms in toilet pipes. When alkalized urine is dehydrated, a high-quality solid fertilizer containing >15 per cent nitrogen, >2 per cent phosphorous and >5 per cent potassium is produced (Simha *et al.* 2021; Simha *et al.* 2022; Vasiljev *et al.* 2022), that also fulfils WHO's microbial safety guidelines (Senecal *et al.* 2018) and is being tested in the production of barley for beer.

Nitrification-distillation: where human urine is converted to a concentrated liquid fertilizer. It involves stabilizing urine after it has been hydrolysed by partial biological nitrification. This converts half of the ammonia nitrogen to nitrate, which reduces the pH from >9 to <6 and stabilizes the other half of the ammonia nitrogen as ammonium ions (Udert and Wächter 2012). The nitrified urine is then concentrated by distillation to produce a liquid fertilizer containing 4.2 per cent nitrogen, 0.4 per cent phosphate, and 0.13 per cent phosphorous and 1.5 per cent potassium. The product called "Aurin" is approved as a fertilizer by the Swiss Federal Office for Agriculture.



CASE STUDY 16 EXTENDED VERSION

Sustainable wastewater and nutrient management in rural Georgia to address pollution in the Black Sea

Bistra Mihaylova, Women Engage for a Common Future

As at 2022, only 34 per cent of the Georgian population had access to safely managed sanitation services and 71 per cent of the population were connected to water supply (WHO 2023; Todradze and Apkhaidze eds. 2021). Many rural households use pit latrines for sanitation and wells for drinking water. With increasing prosperity and water supply more households installing flush toilets, but without the connection to sewage meaning that 246.3 million m^3 of untreated wastewater is discharged into waterbodies each year. While the Government is investing in the construction of water treatment facilities in the bigger cities, this is not yet the case in rural areas (Todradze and Apkhaidze eds. 2021). The discharge of untreated sewage waters, infiltration of animal manure and land erosion are issues of particular concern on the 310 km of Georgia's Black Sea coast. Between 2014 and 2016, a UNEP-funded project was implemented by Women Engage for a Common Future in cooperation with the Rural Community Development Agency to work with two villages to explore affordable options for simple decentralized sanitation systems as well as the safe reuse of resources that could be recovered from domestic and farm wastewater. The project was highly participatory and focused on empowering women in the community to act as multipliers. As a result of the training and awareness-raising activities, 43 households expressed a willingness to invest in the installation of urine-diverting dry toilets and adapted technology solutions for sustainable wastewater management. The advantage of urine-diverting dry toilets is that they do not need to be connected to a sewage system and, unlike pit latrines, are above ground and do not pollute the groundwater. The project results showed that women were motivated by this sanitation solution for the reasons of increased comfort, hygiene and water protection and the production of good fertilizers for the gardens (faecal matter and urine are treated and then reused as fertilizer). To date, all constructed facilities continue being used properly by local families including women-headed households, demonstrating an integrated way to treat the household wastewater streams. Most of these households have been using urine as fertilizer in their gardens. Faeces are composted to be used after a two-year treatment that kills pathogens and results in a safe fertilizer and soil improvement.

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Through a combination of affordable and effective measures such as community-managed initiatives, increased recycling and composting and simple wastewater filters, the project has contributed with replicable examples of how to reduce the pollution in the Black Sea along the river Khobi in Georgia.

Source: WECF 2015

The building blocks for systems change

If the three action areas presented above are to succeed, they will need a breakthrough in addressing some persistent barriers and concerns (see part 2). Some of the building blocks that can help start to address these issues are presented with examples of possible actions and opportunities to develop these building blocks at different scales. As with the three action areas – success requires efforts to address all the building blocks – a piecemeal, fragmented approach cannot succeed. It is also vital that these building blocks are developed in an equitable manner to ensure the benefits and opportunities resulting from success are available to all. Gender-responsive measures should be considered in sustainable water management. Gender equality can be embedded into policy at all levels, decision-making and establishing an enabling environment on water and wastewater to ensure the participation of women.

The six building blocks (Figure 3.10):

- Governance and legislation – Create an enabling political and regulatory environment
- Financing – Realize adequate and sustained investment and access to financing for implementation
- Capacity development – Ensure there is sufficient human, technical and institutional capacity
- Innovation – Technical and social innovation in processes, ways of working, conceptualization
- Data – Strengthen data and information to support implementation and accountability

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- Awareness and behaviour change – Create increased social acceptance based on increased greater awareness, accountability and trust

While the recovery and reuse of wastewater products may not be an appropriate solution in all circumstances, the sharp increases in water scarcity, costs of fertilizer use and the need to diversify our energy production worldwide are likely going to push communities to consider unconventional sources of water in an open minded manner. If the concerns and barriers, real or perceived, can be addressed, wastewater resource recovery and reuse practices can provide a wide range of benefits for communities, which translates into creating value for the public and the environment.

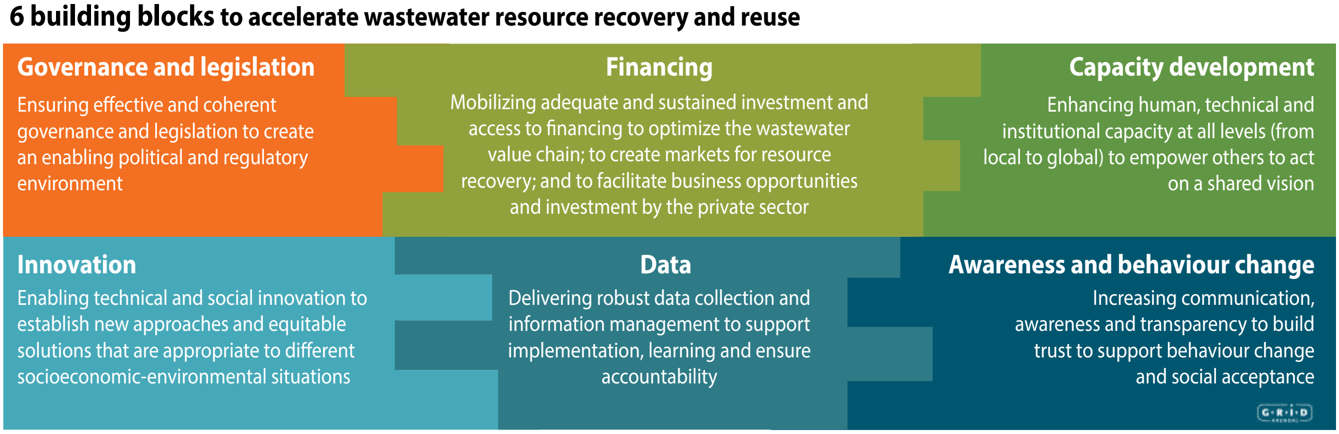

Figure 3.10: *Six building blocks to accelerate wastewater resource recovery and reuse.*

Effective and coherent legislation and governance

Implementation of three action areas will require increased political awareness, improved coherence across water-related policies and regulations, better alignment between sectors and engagement of all relevant stakeholders (UNESCO and the Water Security and Sustainable Management [i-WSSM] 2020; Bauer and Wagner 2022). Efforts to develop coherent multisectoral, multilevel and transboundary governance can unblock the barriers for reuse and resource recovery. For example, the promotion of energy generation in waste treatment facilities as part of their renewable portfolio would create the opportunity to provide the same incentives to the waste treatment utilities that they would offer to the energy sector. The stronger regulation of landfill use could provide incentives to promote the beneficial use of biosolids; or the appropriate pricing of fresh water could help the switch for industries to shift to using treated wastewater instead (UNESCO and i-WSSM 2020).

The role of urban planning in water reuse at the subnational and city levels has been identified as an important area for the development of sustainable, more water-resilient cities (Bauer and Wagner 2022). Integrating the development of water reuse sources with the intended end-user applications can help understand the strategies, guidelines and measures that may be needed for successful wastewater reuse and the transition to a circular economy (Voulvoulis 2018; Bauer and Wagner 2022).

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Table 3.2: *Possible actions to develop effective and coherent legislation and governance.*

	Building blocks	Opportunities to develop the building block
International	• Ensure wastewater management and reuse is explicit and visible in the global water agenda to build awareness and raise the profile of this issue at the international level. • Use wastewater management and reuse as an entry point to deliver in other policy areas.	• Showcase commitments made under the United Nations Water Action Agenda (see box 10) to address circularity in the water sector and increase resource recovery and reuse; ensure that wastewater is an issue that is high on the agenda for a United Nations Special Envoy on Water, once appointed. • Increase support for the "UNESCO WWAP water and gender working group 2021 call to action for accelerating gender equity across the water domain" to ensure that wastewater resource recovery and reuse is explicit in this call to action. • Use the outcomes of the in-depth review of SDG 6 at the high-level political forum on sustainable development in July 2023 and the SDG Summit in September at the midpoint of the 2030 Agenda for Sustainable Development. • Engage with the work of the Water and Climate Coalition and other relevant initiatives to ensure that wastewater is visible in the development of this discussion at COP 28.
Regional	• Support regional coordination to help find solutions to transboundary aspects of this issue. • Facilitate cooperation and exchange of best practices on wastewater resource recovery and reuse between countries and across different regions.	• Engage with regional offices and Regional Seas Conventions to share experiences and facilitate regionally relevant approaches, e.g. the adoption of a regional action plan for wastewater reuse under the Barcelona Convention.
National	• Develop national policies to provide a framework for circular water management and ensure coordination across water-related policies and regulations. • Engage with business and industry to co-develop solutions.	• Establishment cross-sectoral policy working groups to help foster improved coherence. • Ensure that wastewater management and reuse is included in national development plans and connected to other national planning tools for e.g. climate adaptation strategies and National Biodiversity Strategies and Action Plans, e.g. the United States National Water Reuse Action Plan adopted in 2020 to drive national progress in water reuse.
Local and municipal level	• food packaging	• Engage cities in water reuse for climate adaptation and resilience through the Megacities Alliance on Water and Climate, hosted by UNESCO's Intergovernmental Hydrological Programme.
Industry	• food packaging	• Support and build awareness of the Wastewater Zero Commitment Initiative under WBCSD.

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Box 10: The United Nations Water Action Agenda

The United Nations Water Action Agenda on advancing SDG 6 for water and sanitation is a key outcome of the United Nations 2023 Water Conference and is the collection of all water-related voluntary commitments to accelerate progress in the second half of the Water Action Decade 2018–2028 and second half of the 2030 Agenda.

The United Nations Water Action Agenda aims to use the political momentum created by the Water Conference to mobilize action across countries, sectors and stakeholders to better coordinate efforts to meet the global water- and sanitation-related goals and targets.

The voluntary commitments are also guided by the SDG Global Acceleration Framework, which was launched in 2020 to mobilize stakeholders around five interdependent accelerators critical to achieving SDG 6: finance; data and information; and capacity development, innovation and governance.

The United Nations Water Action Agenda will be presented to the General Assembly and the SDG Summit in September 2023, and then reviewed annually during the high-level political forum to maintain the momentum through to the end of the Water Action Decade 2018–2028 and the 2030 Agenda.

UNEP's role in advancing the environmental aspects of SDG 6 to tackle the triple planetary crisis

The world is facing a triple planetary crisis of biodiversity loss, pollution and climate change, which is disproportionately affecting our waterbodies. As a follow-up to the 2023 Water Conference, UNEP will continue its efforts to protect, restore and manage aquatic ecosystems sustainably and advance the environmental aspect of the SDGs, including SDG 6.

As part of the efforts towards the United Nations Water Action Agenda, UNEP will support governments and key stakeholders in addressing challenges related to wastewater and nutrient management, the implementation of Integrated Water Resources Management, and the state and quality of freshwater, marine and coastal ecosystems. This will be done through different programmes and projects and specifically through data collection, action plans and strategies, as well as by implementing and scaling up solutions against the triple planetary crisis.

The three types of voluntary commitments under the UN Water Action Agenda

Figure 3.11: *The three types of voluntary commitments under the United Nations Water Action Agenda.*

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The Wastewater Zero Commitment Initiative, Global

The Wastewater Zero Commitment Initiative under WBCSD (2020) provides a framework for business action to eliminate wastewater pollution from industry by 2030 and contribute to achieving biodiversity, climate and water security objectives. Launched through a call to action in 2020, the commitment is founded on three pillars of ambition for zero pollution, zero freshwater impact (treating wastewater so it can be reused to replace freshwater withdrawals) and low carbon wastewater treatment. To help implement this commitment is an action framework encouraging circularity, developing science-based metrics and encouraging partnerships across industry sectors, value chain partners and with regulators to ensure an enabling environment to realize the goals. Additionally, the Wastewater Impact Assessment Tool (WBCSD 2022) allows users to understand which aspects of wastewater treatment in a facility cause major changes in terms of water quality, water availability and greenhouse gas emissions. The tool displays the local water security context on maps and uses some of these global indicators, together with local data on industrial withdrawals, discharge and pollution load to assess the changes caused by the facility's wastewater management and point to possible interventions.

Action framework and commitment mechanism

Source: WBCSD 2020

Figure 3.12: *The action framework and commitment mechanism of the Wastewater Zero Commitment Initiative.*

Mobilize adequate and sustained investment

Water and sanitation services have suffered from historical underfunding worldwide. From a long-term economic perspective, the spending that will be needed on water, sanitation and hygiene services to achieve SDG 6 between 2015 and 2030 has been estimated to be between US$ 74 billion and US$ 166 billion per year (Vorisek and Yu 2020). This figure does not account for funds required to achieve SDG 6.3 and so is likely to be much higher. OECD projected that the current global financing of water infrastructure as a whole will need to increase from US$ 6.7 trillion by 2030 to US$ 22.6 trillion by 2050 (OECD 2019).

The price of water is important in controlling use and demand as well as encouraging how individuals and businesses use water. Not all uses for recycled water require the same quality, so ensuring that the level of treatment and quality of water produced is fit for purpose can help to rationalize costs (Morris *et al.* 2021).

Unless water resources are properly valued (HLPWP 2017), it will be difficult to promote resource recovery initiatives. The inadequate valuation of water also leads to improper pricing of water resources and water services, which in turn can deter public and private sector investments in wastewater resource recovery projects due to uncertainty in terms of returns (UNESCO and i-WSSM 2020).

Financial solutions must respond to the diverse realities, needs and market possibilities of the specific country.

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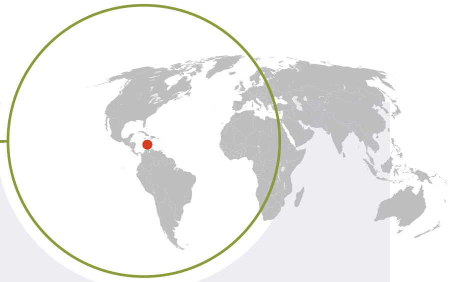
Table 3.3: Possible actions to mobilize adequate and sustained investment.

	Building blocks	Opportunities to develop the building block
All levels	• Urgent strategic and sustainable prioritization of and investment in the three action areas is critical to realizing the opportunities of reuse of resources from wastewater. • Use the circular economy principle to help identify marketable opportunities. • Development of innovative funding mechanisms.	
International	• Increased priority of wastewater reuse on the political agenda and explicit mention in global policy ambitions can help prioritize resource allocation in national budgets and for funding bodies.	Through the United Nations Water Action Agenda: • The Asian Development Bank committed to investing US$ 11 billion in the water sector in Asia and the Pacific and US$ 100 billion to water globally by 2030. • The United States has allocated US$ 700 million to support 22 countries under their Global Water Strategy 2022–2027 (Global Waters 2022) - which clearly reflects the importance of increasing water efficiency and reuse. • Explore opportunities through the Global Climate Fund to strengthen wastewater resource recovery and reuse initiatives within national adaptation strategies.
Regional	• Regional actions by international financial institutions.	• Development of regional strategy papers for water and wastewater management.
National	• Regulating clear and fair pricing of reclaimed water, biosolids and energy to foster innovation and investment in resource recovery projects (UNESCO and i-WSSM 2020). • Establish appropriate and fair economic regulation of water resources. • Tariff reform (see case study from Colombia). • Increased public funding allocations.	
Local and municipal level	• Decentralize financing to the local level to better reflect investment needs for wastewater management and reuse in cities.	• Legal penalty or financial incentives to wastewater reuse (Morris *et al.* 2021).
Private sector	• A clear, coherent policy and regulatory framework that supports leveraging additional revenue streams will facilitate private sector engagement and create an enabling environment for investment.	• Application of blended finance approaches, combining public financing with private equity and debt financing recovered through user tariffs and resource recovery revenues (Rodriguez *et al.* 2020).

CASE STUDY 18



Financing wastewater treatment and reuse in Latin America and the Caribbean 2019 – 2024. Part of the GEF CReW+ Project

Pedro Moreo, GEF CReW Project Coordinator

Water and sanitation services have been persistently underfunded in Latin America and the Caribbean, with rural populations of many countries having the lowest levels of wastewater treatment. Less than 50 per cent of the rural population in Guatemala, Bolivia and Haiti had access to adequate sanitation services in 2015 (Bertoméu-Sánchez and Serebrisky 2018), and only 26 per cent of wastewater was collected and treated in the entire region. The collection and treatment statistics only reflect urban areas; in rural zones the collection and treatment of water are reported to be much lower although the available data is very limited (Bertoméu-Sánchez and Serebrisky 2018).

The second phase of the Caribbean Regional Fund for Wastewater Management (CReW+) is a multiple-donor cooperation project under the Global Environment Facility. It implements practical and innovative solutions at a small scale for integrated water and wastewater management in order to reduce the negative impact on the environment and the people in the wider Caribbean region, while promoting new and innovative financing mechanisms at small-scale local, community and national levels. To support the primary objectives, the project supports the promotion of policy, legislative and regulatory reforms for integrated water and wastewater management (IWWM), knowledge management and advocacy on the importance of IWWM to assist in achieving the SDGs and in particular SDG 6 on water and sanitation.

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The project has successfully supported a number of examples of national-level financing of IWWM – stepping stones in a much larger scale of actions that will unfold in 2023 and 2024 and that can be replicated in the other participating countries and the international community, including:

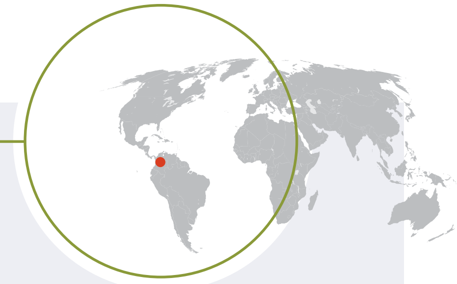
- The development of a business case for the wastewater treatment plant in Innswood for the reuse of treated wastewater in Jamaica.
- Advances in reforming the Belize Wastewater Revolving Fund.
- The identification of possible financing mechanisms for installed ecotechnologies and for operating the existing treatment plants in Quintana Roo, Mexico.
- Elaboration of a proposal for integrating reuse and promoting policy coherence in the tariff system in Colombia.
- The baseline for the development of a technical-financial mechanism to improve access to financing for sanitation projects in Costa Rica.

To ensure the sustainability of these national activities, the project has facilitated several subregional and regional capacity-building activities through the GEF CReW+ Academy, including:

- Financing wastewater infrastructure and cost-benefit analysis.
- Gender lens investing.
- Credit improvements in the water and wastewater sector.
- Business models towards the socioeconomic and environmental sustainability of reuse.
- Multi-stakeholder dialogue for the search for financing of the adequate management of wastewater within the basins.

Legal barriers pose an important challenge for the implementation of financial mechanisms. Taking into consideration that the outsourcing of water and sanitation services is regulated through specific institutions and mechanisms in several countries, introducing new mechanisms like public-private partnerships requires changes to existing policies, legislation and regulations.

CASE STUDY 19



Tariff reform to support wastewater treatment and reuse in Colombia, 2020-2023, Part of the GEF CReW+ Project

■ **Pedro Moreo**, GEF CReW Project Coordinator

Problems of water availability have been increasing in Colombia, mainly due to the unsustainable exploitation of water sources, the excessive transformation of forests into agricultural or livestock lands and the low capacity to confront the phenomena of climatic variability. This has increased the priority to invest in the conservation and protection of natural ecosystems or “Green Infrastructure”. However, green infrastructure actions like protecting the watershed are not explicitly recognized in water tariffs and operate differently from those included in the rates.

Although Colombia has developed a circular economy policy for water and sanitation, implementation has proved challenging, requiring nuance in the conceptual and regulatory frameworks. Adopting circular economy principles in the water and sanitation sector requires water conservation practices and the promotion of wastewater reuse as a keystone to reducing freshwater withdrawals and changing the use chain. The Commission for the Regulation of Drinking Water and Basic Sanitation (abbreviated as CRA in Spanish) is looking at incentives to promote investment in wastewater treatment, resource recovery and reuse and how the tariff formula could be broadened to include public services related to conservation and environmental sustainability. The ambition of the tariff reform is to contribute to widespread water reuse across the country.

The GEF CReW+ project has been working with the Colombian Government through CRA, the Ministry of Environment and Sustainable Development, and the Ministry of Housing to achieve “improvement in the efficiency and effectiveness of the investments in water and basic sanitation through a reform in the tariff regulation”, in particular through:

- Institutional, policy, legislative and regulatory reforms for integrated water and wastewater management
- Sustainable and tailor-made financing options for urban, peri-urban and rural IWWM

The project produced an analysis of the possible impacts of the tariff regulation for reuse, taking into consideration the effects of the different components of the tariff and how these could be stabilized to find a balance between creating incentive for reuse and protecting the end users from high costs. The analysis provided proposals of the incentives for water reuse, including decreasing environmental taxes for the operator, lower operational costs in the treatment systems and harnessing of reuse income.

At the time of writing, the tariff analysis had been submitted to the authorities responsible for the development of the new tariff framework for their consideration. Based on the analysis, this new tariff framework may include integrating a tariff provider for the delivery of treatment and transport of wastewater for reuse, but this may only be applicable whenever there is an economic agent interested in using the wastewater. Another possibility is to include remuneration for the costs of the service of treatment and disposal of wastewater, so service providers could recuperate these costs similarly as it is done in cleaning services.

Legal and policy changes are political decisions under the responsibility of the relevant national authorities. For projects like GEF CReW+ to provide support and input effectively it is important to consider the timing of political debate and decision-making cycles as well as working with the different political stakeholders to avoid delay or impede successful outcomes. Working with a tariff report made it necessary to solicit different points of view, not only concerning incentives, but also regarding any concerns or risks to end users.

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Enhancing human, technical and institutional capacity at all levels (local to global)

The required changes to policies and regulations, increased cross-sectoral collaboration and technologies will require development of human, technical and institutional capacity in terms of the types of skills and arrangements in place as well as their scale. Such development will help empower stakeholders to act towards the shared policy ambitions.

Human and technical capacity: ILO (2017) identified a growing problem with staff shortages in the water treatment industry in many countries, attributed to an ageing workforce, a strong gender bias in the formal employment sector, a failure to expand the required human resources and a lack of investment in professional training needs. As efforts to reach the SDG target 6.3 on treatment and reuse progress, demand for wastewater treatment and resource recovery facilities (Jones *et al.* 2022) will also increase opportunities for green jobs in this sector. In many Asian countries these efforts are taking place alongside rapidly growing economies. In Viet Nam, ILO (2017) identified a shortfall of 8 000 skilled workers as at 2020. The European Commission suggested that a 1 per cent increase in the growth of the water sector in Europe could create 20 000 new jobs (European Commission 2014). Increasing opportunities and incentives to attract people across the sector will be vital.


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Institutional capacity: There is a need for increased coordination between institutions responsible for sanitation services, water supply, water treatment and the various end users (Rodriguez *et al.* 2020). This must go hand in hand with the strengthened political drive and enabling and coherent policy and regulatory environment mentioned above. Increased capacity for monitoring and enforcement will play an important role for increasing circularity and safe reuse, with appropriate administrative arrangements and mandates in place for the authority to impose sanctions (UNESCO and i-WSSM 2020).

Table 3.4: *Possible actions to enhance human, technical and institutional capacity.*

	Building blocks	**Opportunities to develop the building block**
Local to national scale	• Ensure appropriate institutional arrangements are in place to support a circular water management approach	• Developing networks of knowledge and practitioners within and between sectors, producers and users to share experiences and continue to innovate will be critical to helping progress towards ambitions of safe reuse.
Local to national scale	• Establish coordination mechanisms to support institutional collaboration across sectors and governance levels.	• Water-basin-level planning. • Creation of a water/wastewater central institution such as the National Water Commission in Mexico (Rodriguez *et al.* 2020). • Establishing contractual arrangements to help develop collaboration between sectors/different parts of the administration.

Technical and social innovation

The urgent need to embrace circularity in how water is used and the realization of used water as a resource is bringing us to a time of rapid change. In 2020, the annual global wastewater treatment market was over US$ 263 billion and projected to reach US$ 500 billion by 2028 (Fortune Business Insights 2020). Technical and social innovation will be critical to finding the diversity of fit-for-purpose solutions that will be needed to provide equitable access to solutions and reach global ambitions. Technical innovation is an important element in any large scale transition (Fam and Mitchell 2012). However, because of the way water use is integrated into all aspects of society, including the close connection with personal aspects of our everyday lives, the systems change will fail without social innovation – changes to culture, institutions, markets, in partnerships and financing mechanisms.

Fam and Mitchell (2012) found that technical top-down innovation initiatives in the sanitation sector have struggled to gain acceptance and that strategies are needed to manage the social and cultural acceptance and adoption of novel technologies all the way from the value chain to the end user.

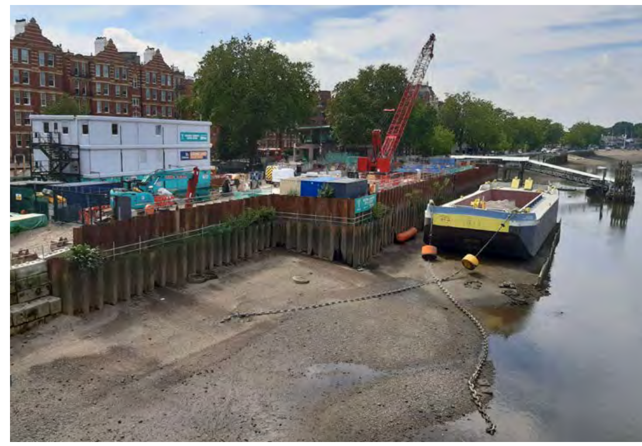

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Table 3.5: *Possible actions to encourage technical and social innovation.*

Building blocks	Opportunities to develop the building block
• Ensure policies support and encourage both innovation and the adoption of new technologies, which need to be in place and aligned across governance levels.	• The 2013 Botswana Integrated Water Resources Management and Water Efficiency Plan (Botswana, Department of Water Affairs 2013) engages across sectors and promotes innovation to achieve its objectives of efficient water management, including reuse. • The 2022 Global Water Strategy of the United States – which leverages across federal departments and agencies to provide global leadership on building the systems, financing, infrastructure and data needed to increase water security and access to sanitation, including the wastewater sector.
• Pay attention to developing the social organization around the novel technology.	• Use social experiments to help identify early adopters and working with them to champion innovation.
• Encourage the development of innovative partnerships to advance knowledge in the intersections of water reuse policy areas.	
• Support multidisciplinary research and development to ensure that the implementation of the innovation is a core part of its development.	• The innovation programme of the Water Research Foundation takes a multidisciplinary approach to bringing water technologies into practice effectively (Water Research Foundation n.d.).

Stronger data and information

What cannot be measured cannot be managed. Improving and expanding monitoring efforts to strengthen data is needed to inform progress, learning and ensure accountability. There is a need to improve consensus on wastewater terminology and address issues of data availability, accessibility, quality and consistency to advance our understanding of wastewater dynamics, the impact of our water-use activities in terms of water availability and quality, and its reuse.

There are initiatives that continue to address the challenges of data and information to track SDG 6. The Integrated Monitoring Initiative for SDG 6 was launched in 2015 by UN-Water at the beginning of the 2030 Agenda for Sustainable Development and funded by the Governments of Austria, France, Germany, the Netherlands, Sweden and Switzerland. The initiative has four phases which run through to 2030 and aims to accelerate the achievement of SDG 6 by increasing the availability of high-quality data

Table 3.6: *Possible actions to deliver stronger data and information.*

Building blocks	Opportunities to develop the building block
• Strengthen the indicators required to track the different aspects of wastewater management resource recovery and reuse including the monitoring and data required to assess the indicators.	• Draw on scientific and traditional knowledge systems as well as citizen science. • Work with the custodians of relevant SDG indicators to fill data gaps.
• Continue to strengthen metrics for SDG 6.3.	Support ongoing initiatives including IMI SDG 6 to: • Strengthen the reporting of data related to wastewater production, collection, treatment and reuse by sector. • Progress the ongoing discussions to develop gender disaggregated data for on wastewater production and reuse to support measuring progress on SDG indicator 6.3.1. • Start collecting wastewater data at the basin level.
• Improve wastewater monitoring.	• Use innovative monitoring approaches to fill wastewater data gaps. Promising technological advances and innovative monitoring techniques include new sensors, computerized telemetry devices and innovative data analysis tools (Zandaryaa and Brdjanovic 2017).
• Build capacity for monitoring, data management and reporting on wastewater and reuse issues at the global, regional, national and subnational levels.	• Develop or strengthen peer learning, massive open online courses and training courses to support the development of data and information that can inform policy and decision makers at relevant governance levels, for example Open Wash Data, an international community funded by ETH Zurich that applies open practices to data in the water, sanitation and hygiene sector to build open science competencies and community.

for evidence-based policymaking, regulations, planning and investments at all levels.

The project "Water in the world we want" was developed to address the challenge of missing data and the enabling environment for generating consistent, reliable evidence recognizing the risk that this could undermine achieving global policy objectives (United Nations Office for Sustainable Development, United Nations University Institute for Water, Environment and Health, the International Centre for Water Security and Sustainable Management and K Water 2022). The project developed an SDG 6 Policy Support System to support data-limited countries. It helps them to use the evidence and capacity that was available from multiple sectors, identify where there are gaps and develop the enabling environment to address these gaps. The ambition of the project was to progress delivery of SDG 6 in terms of the development of appropriate capacities, policy and institutions, ensuring integrity, financing, gender considerations and addressing disaster risk reduction.

Increase communications, awareness and accountability

The application of appropriate technology is critical for the safe reuse of resources recovered from wastewater. However, this is not sufficient to ensure success in the uptake of resources recovered from wastewater. The issue of trust is at the heart of changing perception of wastewater reuse and increased acceptance and the required behaviour change both individually and collectively. However, confidence and trust are built slowly over time and can be lost quickly, rapidly undermined by failure. They require transparency and accountability across the responsible governmental and industry bodies delivering wastewater reuse options. Clear and transparent regulations, awareness, training and communication are key to building trust (Salgot and Folch 2018).

Education and awareness: These apply to those working in the sector as well as the end users and public. Salgot and Folch (2018) identified that sufficient training is needed to ensure there is appropriate capacity so that practices for producing the resources from wastewater are safe to use. There is also a need to train the eventual end user so that resources can be applied in a safe and appropriate way. In addition, they identify clear, honest communication as being critical to changing attitudes and behaviour, being inclusive to engage all sectors of society including women, youth, Indigenous Peoples and marginalized communities. The integration of gender perspectives should be considered in planning, and implementation activities including training which should be gender sensitive, ensuring participation of both women and men.

Examples of quality standards

In the United States, specific regulations are established by the states, with no federal-level regulations specifically governing water reuse. The state of California enacted a regulation for water reuse in agriculture as early as 1918, making it the first state in the United States to distinguish between two types of recycled water: that for non potable applications and potable applications. Non-potable regulations are separated into four different levels of treatment depending on the intended application. Potable recycled water-use applications are managed by the California Water Code (section 13561) and are separated into "direct potable reuse", "indirect potable reuse for groundwater recharge" and "reservoir water augmentation" (California State Water Resources Control Board 2021).

China has developed highly detailed standards to support the development of water reuse. The Chinese Government has enacted a series of regulations for a variety of reuse applications over the past 20 years. In comparison, the European Union has only provided guidance on the minimum requirements for water reuse in 2020, with a requirement that this should have been transposed into national law by 26 June 2023 (Bauer and Wagner 2022).

Quality standards: Quality standards for the reuse and return of wastewater to the environment have been evolving since the 1910s (figure 3.13) (Santos *et al.* 2021). Standards are an important prerequisite for the safe and sustainable reuse of unconventional water sources and other recovered products – they provide a basis for accountability and in turn can help build social and cultural acceptability (Salgot and Folch 2018; Taron, Drechsel and Gebrezgabher 2021; Bauer and Wagner 2022). The establishment standards for water quality form an important mechanism for ensuring human and environmental safety and can provide reassurance to increase trust (Salgot and Folch 2018). These standards will vary according to the respective country and end user to ensure the resource is fit for purpose. Of course, the existence of standards and regulations does not mean these are implemented effectively. Ensuring sufficient monitoring and enforcement capacity is required to ensure the standards are consistently delivered to ensure the reclaimed resource can be used with an acceptable risk (Salgot and Folch 2018).

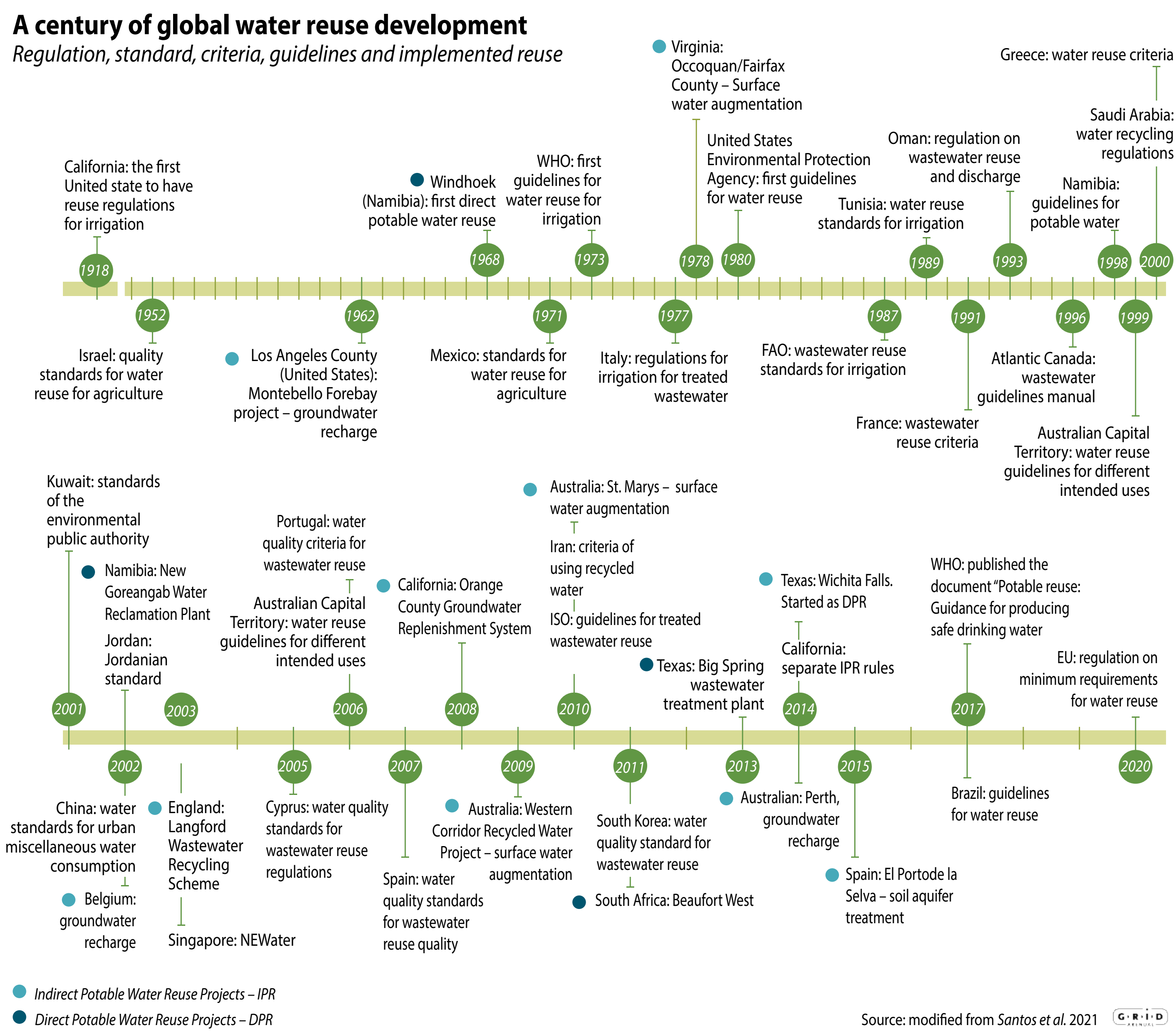
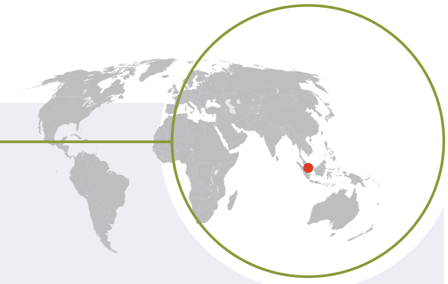


Figure 3.13: *A timeline of the development of regulation, criteria and guidelines from 1918 to 2020.*

CASE STUDY 20



NEWBrew – Raising awareness with a beer from 100 per cent recycled wastewater, Singapore

To meet its national water needs, Singapore has four principal sources to build a reliable supply of water, including from the local catchment, maximizing rainwater collection; through importing water from Malaysia under an agreement until 2061; desalination through five plants as at 2022; and through production of NEWater, recovered from wastewater since 2003. Treatment includes advanced membrane technologies and ultraviolet treatment meeting the most stringent drinking water standards.

The goal for Singapore is to have a resilient and self-reliant water supply by 2060 with an expectation that 55 per cent of this will be produced by NEWater, reducing reliance on water imports. As an awareness-raising drive to highlight the issue of water security, climate change and the innovative measures being implemented, the National Water Agency first collaborated with a craft brewery, Brewerkz, in 2018 to produce and bring to market a beer made from 100 per cent recycled water. The beer proved to be a success and a tropical blonde ale developed for the 2022 Singapore International Water Week, with the beer going on sale to the public for the first time.

Sources: Tortajada 2020; Brewerkz 2022; Singapore, Public Utilities Board 2022.

©NEWBrew

Conclusions

One in four people live without access to safely managed water services or clean drinking water; over 1.7 billion people lack basic sanitation, affecting mostly vulnerable groups including women and girls; half a billion people practise open defecation; one third of the global population live in water scarce regions (Ruiz 2020) and it is expected that water scarcity could displace up to 700 million people by 2030 (Global Water Institute 2013). Millions of women and girls spend hours every day fetching water, which reduces their opportunities for productive activities or education (United Nations 2023a). Amid this already dire situation, the demand for water continues to grow, as well as the need to rapidly increase food production and reduce our reliance on fossil fuels for energy. At the opening of the 2023 Water Conference, the United Nations Secretary-General cited the urgent needs to close the water management gap and increase recycling, reuse and conserve water as critical to bringing about the needed change (United Nations 2023c) and realizing the potential of this resource.

Wastewater is an essential component of the circular economy (Otoo and Drechsel 2018) and a resource that can provide sustainable and safe solutions to address societies multiple crises, including water security, the impacts of climate change, biodiversity loss and pollution – a valuable resource that must be managed for beneficial use, but is as of now drastically underutilized.

We are not starting from scratch. Wastewater management and reuse is a complex issue, but there is experience that must be built on and strengthened. This report highlights where there are existing solutions to build momentum, maximize resources and avoid fragmentation.

All sectors of society contribute to the problems of wastewater pollution. The transition to a circular approach including through resource recovery and reuse will require collective and coherent action by all, meaning us individuals, communities, businesses, industry sectors and governments. The actions and solutions identified cannot be successful in isolation but will need to be implemented coherently.

There is no one solution that fits all. The optimal solution or combination of solutions will depend on circumstance

Significant events and initiatives since 2010

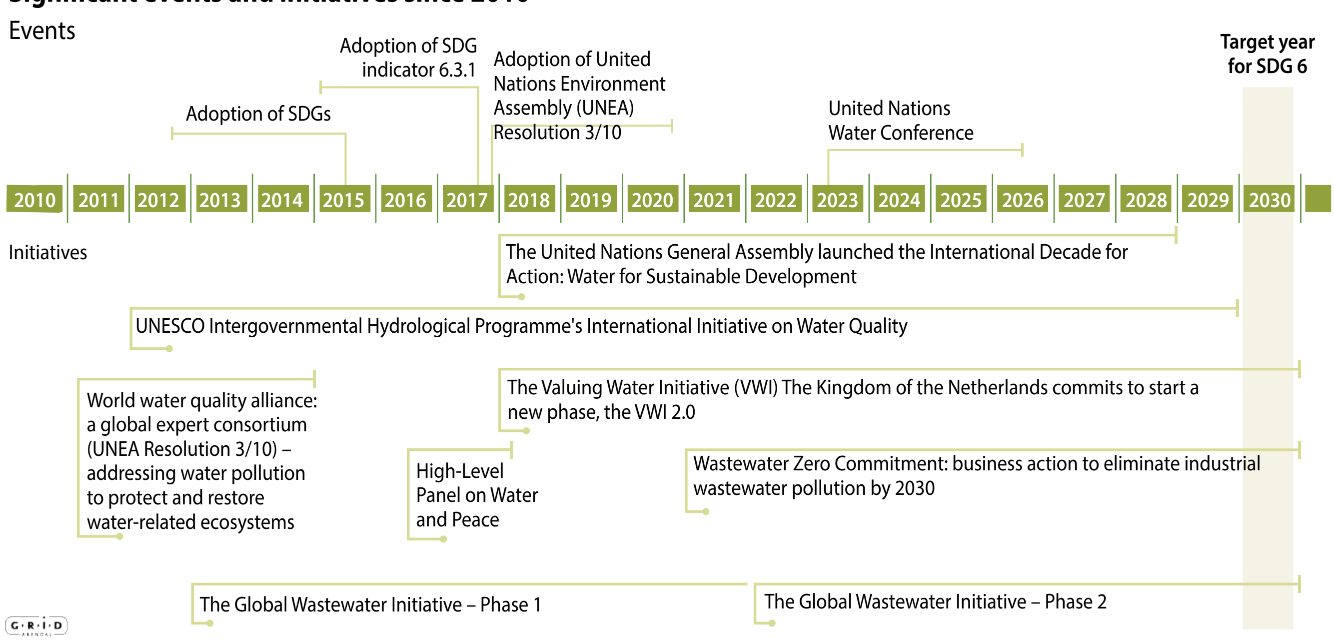


Figure 4.1: *Timeline showing examples of significant initiatives relevant to wastewater resource recovery and reuse since 2010.*

and must fit the economic, environmental, social and cultural contexts, aiming for appropriate actions, learning, adapting and innovating. Acknowledging this complexity is important for success. This report draws on examples and case studies from different contexts as illustrations of different approaches.

This report identifies three action areas which must be addressed in conjunction and at multiple governance levels engaging individuals, businesses, industry sectors and governments to:

1. Reduce the volume of wastewater produced
2. Prevent and reduce contamination of wastewater flows
3. Sustainably manage wastewater for resource recovery and safe reuse

To succeed, the action areas must constitute a systems change: There needs to be effective and coherent legislation and governance, mobilization of adequate and sustainable resources and investment, developing capacities and capabilities, innovation, equitable access to the solution, shifting behaviours, developing trust and monitoring to inform and track the success of measures as well as technical and social innovation. The SDG 6 Accelerator Framework provides a useful frame to implement the building blocks needed to close the loop on wastewater resource recovery and reuse. It can also help align the actions presented with the United Nations Water Action Agenda and SDGs. Behaviour change, social acceptance and equity are important additional accelerators.

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