United Nations University

POLICYBRIEF

No. 15, 2024

Revitalising Resource Efficiency For Industrial Water Reuse In The Circular Economy

Serena Caucci, Zeynep Ozkul

Highlights

The Circular Economy approach to water reuse is an essential and strategic facet of addressing the water resource crisis, and its implementation stands to maximise the economic value of water resources by reducing water inefficiency and enhancing water security.

Industrial water reuse systems provide water-intensive industries with better comprehension of and control over water and wastewater costs and can aid in reducing dependencies on external water supplies.

Fit-for-purpose water regulations enable water reuse based on the quality requirements of the targeted use combined with financial incentives, such as reduced tariffs for reclaimed water use or subsidies to companies – thus providing the pathway for circular practices.

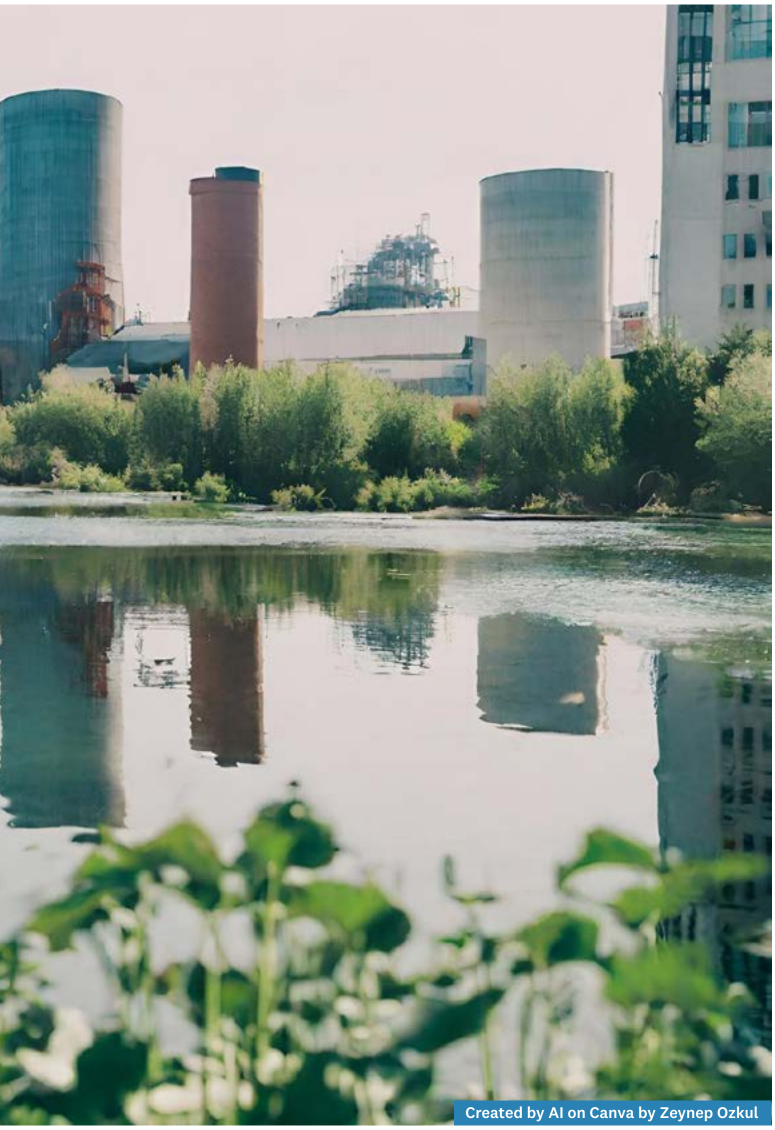
The public acceptance of water reuse remains a key step to achieving a transformative shift towards coherent governance processes to manage wastewater for reuse purposes effectively.

Conducting comprehensive human and environmental impact assessments and promoting resource-efficient practices, all while considering community acceptance and nurturing positive attitudes toward the use of wastewater, is of critical importance.

In addressing the global challenges of water stress and urban transformation, synergies must be identified in order to increase the resilience of urban areas. Fostering the industrial use of wastewater through Public-Private Partnerships (PPPs) will enhance the resilience of urban systems and achieve tangible progress towards the 2030 Agenda for Sustainable Development.

UNU

unu.edu/flores



Created by AI on Canva by Zeynep Ozkul

Background

Increased demand for water to facilitate anthropic activities has resulted in declining freshwater resources worldwide. Additionally, escalating weather extremes have modified the conditions under which industries and businesses could suffer. Freshwater plays both a crucial and strategic role for many industrial processes within the product value chain, while companies operating across seven major sectors – encompassing textile, food, energy, manufacturing, mining, chemicals, pharmaceuticals and– strongly impact natural resources such as water, despite their reliance on it (CDP, 2018). Indeed, these industries simultaneously affect more than 70% of global freshwater use and pollution (CDP, 2018; UNESCO, 2023).

Although those regions with robust economic and institutional coping capacities and low hydrological complexities (such as Western Europe, Japan, and Canada) are projected to see a modest increase in industrial water demand, the potential impacts of climate change on water resources remain a major concern (Wada et al., 2016; Ritchie & Roser, 2017). In the case of those regions in the Global South, however, the same projections have indicated a highly concerning surge in industrial water demand over the coming decades, with some of the emerging African economies expecting increases by 800% and 250% in parts of Asia (Boretti, 2019).

Bearing these projections in mind, the vulnerability of industry to water scarcity will correlate to increased energy demand due to a heavy reliance on resources within supply chains. It is for this reason that many companies – particularly multinationals – have begun to conduct geographical assessments of water-related risks, although the efficiency of these efforts may yet be undermined by gaps in governance, market failure, cultural barriers, and trust deficits (UNESCO, 2023).

In anticipating and assessing the elevated value of water for industrial use in the years to come, industries that minimise dependencies on freshwater resources will be better positioned to confront the challenges of climate change, as opposed to companies with high water requirements (IPCC 2022, German Environment Agency, 2019). In the long term, the businesses and industries that leverage water reuse to optimise resources stand to save money, reduce the environmental footprint, and ensure sustainable water supplies for their customers, employees, and communities (Rodriguez et al., 2020; McKinsey, 2020).

Water reuse has gained significant traction in the industrial sector as an essential factor in closing the water management loop. It is a resource that offers many opportunities to alleviate water stress, from agricultural to industrial reuse, as well as urban applications and direct potable reuse (Rudolph et al., 2020). Agricultural water reuse for crop irrigation is currently the most common application of wastewater to mitigate water shortages, with a market share of around 30% (Helmecke et al., 2020). Water reuse in industrial settings is a less common practice, as it hinges on cooperation and approval from policymakers, regulators, consumers, and industry leaders, alongside the need for advanced technological capacity to implement solutions on a wider spectrum (Morris et al., 2021). Water reuse schemes offer the option of tapping into existing wastewater from an external source or applying water reuse internally, which has become the most widely adopted approach due to its remunerative value (Georgiou et al., 2022).

Partnerships and cooperative arrangements are key to addressing the multilayered challenges associated with water resource management. Partnerships in which the private sector plays a substantial role- often recognised as public-private partnerships (PPPs)- could be a game changer for the upscale of industrial water reuse, with the potential to optimise urban water management by mobilising finance, providing technical expertise, installing knowledge continuity, and taking the risk (Morris et al., 2021; UNESCO, 2023).

Nevertheless, challenges will inevitably arise as companies incorporate more and more water circularity into their business models to create closed material flows and energy cycles, thus better structuring the management of natural resources in their business as usual (WEF, 2023). At present, the pharmaceutical industry is leading efforts to improve water efficiency across its value chain while maximising opportunities for the safe re-use of water at multiple water quality standards by incorporating conventional treatment plans in conjunction with biological and advanced post-treatment methods (Gadipelly et al., 2014; Guo et al., 2017). Indeed, the pharma sector is a water-intensive industry due to its requirement for a stable water supply of sufficient quantity and quality (Strade et al., 2020), whereas the internal reuse of water is not sufficient for sustainable value chain production. Public-private partnerships could, however, assist in the achievement of such a goal (Jomo et al., 2016).

Additionally, water reuse systems enable the strategic reduction of an industry’s reliance on freshwater sources while mitigating freshwater pollution risks given by the emissions of wastewater into the environment (Voulvoulis, 2018; UNESCO, 2020). **Although the associated opportunities are numerous, barriers stand in the way of effective water reuse, particularly in industrial settings.** These barriers are compounded by the inadequate response to the market in the face of advancements in water reuse, while industries have exhibited limited proficiency in integrating water reuse into their value chains as a core component of a smart and circular water management strategy.

The Obstacles to a Widespread Adoption of Industrial Water Reuse

For industries to stay afloat, they must fully comprehend the current trends and potential risks caused by water stress and changes to climate and adapt accordingly (Cole et al., 2023). However, if water reuse becomes an appealing option for companies looking to fulfil sustainable production standards, risks lie in the ability of organisational management to keep up with operational standards.

The linear ‘low-cost,” end-of-pipe treatment approach has become increasingly costly for industries as discharge standards become stricter and subject to legal complications. As the technological advancements associated with water reuse do not pose barriers, nor does the availability of industrial water reuse technologies (Reike et al., 2018), transforming conventional wastewater management into a fit-for-purpose scheme where feasible and viable wastewater technologies could leverage industrial water reuse.

Challenges might be shaped by the geopolitical and socio-economic fabric of each region or country where water reuse should be adopted (WWAP, 2017). It should be recognised that the context of applying industrial water reuse is not solely technical, but rather, that the creation of a sustainable implementation scheme should encompass technical, social, political, economic, and environmental aspects and an analysis of their potential interconnections (Lee & Jepson, 2020; Morris et al., 2021). Understanding the key barriers and drivers that influence the uptake of water reuse in industrial settings could help accelerate the progress towards the global goals of reducing freshwater demands, bolstering environmental resilience, and transitioning towards a circular economy.

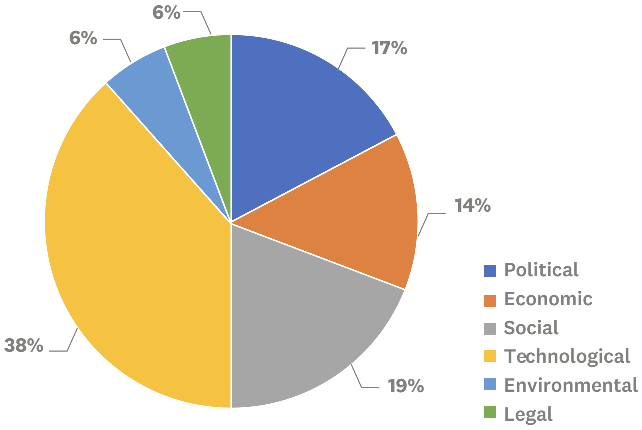


Figure 1: Distribution of Barriers to Water Reuse according to the Political, Economic, Social, Technological, Environmental, and Legal factors (Morris et al., 2021)

Not just a matter of technology: Policy and Regulation Barriers to Water Reuse

The absence of comprehensive policy frameworks and guidelines, as well as locks in regulatory pathways and absent or contradicting legal mechanisms, might hinder the ability to effectively address different industrial sectors' specific needs and challenges (Lee & Jepson, 2020). The complexity of industrial water reuse primarily stems from the heterogeneity of industrial water uses and the diverse water-quality requirements linked to each application (Caucci & Hettiarachchi, 2018; Meese et al., 2021). Such diverse requirements limit the applicability of overarching, one-size-fits-all approaches to industrial water reuse and undermine its effective implementation.

Government agencies and their assigned political actors are responsible for creating the policy environment that enables the implementation and maintenance of water reuse schemes at the industrial scale (Breitenmoser et al., 2022; Morris et al., 2021). In the absence of strong political will and government support to control and execute regulations, there remains a risk of using untreated or poorly treated wastewater in practices that demand restricted application (Hettiarachchi & Ardakanian, 2018; Domenech & Bahn-Walkowiak, 2019).

The success of water reuse initiatives is highly dependent on aligning the interests of various stakeholders, such as industries, regulatory bodies, and environmental groups. When these interests are not in sync, barriers arise that undermine the effectiveness of implementation (Khan & Gerrard, 2006). A lack of robust communication could amplify these barriers, hindering the identification of standard solutions and slowing down progress toward implementing sustainable water reuse practices (Georgiou et al., 2022).

Furthermore, regulations are frequently developed without accounting for their implementation's financial ramifications, particularly regarding operational expenses (UNESCO, 2020). Introducing flexible standards that are tailored to the objective of the specific wastewater investment will foster the development of innovative solutions required to provide wastewater services and create value from water reuse and resource recovery (Rodriguez et al., 2020).

Action Points

- A paradigm shift is needed to adopt industrial water reuse, which relies on robust policy, institutional, and regulatory frameworks to ensure and scale up safe wastewater-related action.
- Existing regulations and policies often fail to address fundamental aspects, such as targeting optimal water resource pricing and specifying water requirements based on the type of use, compromising the feasibility of water reuse initiatives (Georgiou et al., 2022; Jeuland, 2015).
- Fit-for-purpose water regulations that allow water reuse based on the specific quality requirements of the intended use are necessary to encourage sustainable wastewater investments. Regulations and standards must be tailored to the needs of specific regions and industrial sectors to foster reuse and resource recovery (Morris et al., 2021).
- Financial incentives, such as reduced tariffs for reclaimed water use or subsidies to companies, should complement these regulations to prevent potential uncertainties regarding the return on their investment (UNESCO, 2020).
- Water reuse is not yet safeguarded by changes to freshwater pricing for industrial and agricultural use. Too often, freshwater tariffs are cheaper than the wastewater treatment required for fit-for-purpose reuse. Increasing freshwater tariffs or providing incentives for water reuse applications in industrial settings could be key factors for the successful implementation of water circularity in the economy.
- To achieve these objectives—namely global water quality and the installation of circular economy principles—all parties must act in the collective interest (UNESCO, 2023).
- Establishing a structured communication strategy that involves all stakeholders, including public agencies, industry and commerce, special interest groups, customers, community leaders, and the general public, ensures the active involvement of all relevant parties from the outset, enhancing project transparency and accountability (Khan & Gerrard, 2006).
- Involving stakeholder groups with vested interests can provide multidimensional insights into drivers and barriers, thereby informing policy development that can address the specific needs of key users.

- Involving stakeholder groups with vested interests can provide multidimensional insights into drivers and barriers, thereby informing policy development that can address the specific needs of key users.

Skyline of Cartagena, Colombia, South America by redtea from Getty Images Signature

Social Aspects of Water Reuse Implementation

The social barriers to the widespread adoption of water reuse practices are primarily linked to public opinion and reservations towards the impact of the practice on public health, safety, and environmental quality, as well as the benefits and risks of reuse (Saliba et al., 2018).

Despite significant advancements in wastewater treatment technologies and an increased focus on health risk assessments, public opinion and social acceptance remain the decisive factors in the success or failure of any water reuse scheme (Rodriguez et al., 2020; UNESCO, 2020).

The lack of public confidence in the competency of governmental authorities regarding safe water reuse remains a key factor affecting its implementation (Massoud et al., 2018; Morris et al., 2021). is still one of the decisional factors in its implementation. Even when water reuse practices are technically well-designed and financially realisable, the limited trust and communication between policymakers, implementers, and the public contribute to a skewed perception of the value of wastewater, particularly if there is a well-structured information campaign in place (WWAP, 2017; Saliba et al., 2018).

Utilising existing water reuse technologies requires technical capacity, continuous knowledge transfer and dissemination, and capacity-building, all of which are particularly critical for developing countries (WWAP, 2017). A critical issue to be tackled is limited collaboration between industries and universities, along with the shortage of technical expertise from engineers and planners proficient in different wastewater treatment and resource recovery technologies (UNESCO, 2023).

Moreover, the absence of cooperation between science and practice and a lack of scientific data could further obstruct the effective development and implementation of innovative technologies for sustainable water reuse practices.

> Water sustainability approaches have often attempted to balance freshwater consumption with economic growth and societal development.

Action Points

- A participatory approach involving stakeholders throughout the entire project cycle—from planning and design to implementation and decision-making—is necessary to enhance public acceptance of innovative water reuse practices and to achieve more efficient and sustainable outcomes (Jimenez et al., 2018; Saad et al., 2017).

- Public acceptance requires clear communication regarding the quality standards and potential impacts of water reuse on human and environmental health.

- By demonstrating competency, building trust with the public, and showing a genuine commitment to properly and safely implementing water reuse, governments can enhance the acceptability of water reuse practices. Authorities and decision-makers must prioritise transparent communication, creating accessible information channels to promote a positive attitude (and thereby greater acceptance) towards water reuse (Massoud et al., 2018; Morris et al., 2021).

- Collaborative efforts facilitating knowledge exchange, research partnerships, and the development of tailored technologies are increasingly critical to bridging the gap between academia, industry, and the public to make societies more sustainable and circular.

- Closing the gap between academia and industry and strengthening professional networks are necessary to tackle the challenge of limited technical expertise for industrial water reuse (Morris et al., 2021; Khalid et al., 2018). Therefore, facilitating training and educational programs for water technicians and professionals can help accommodate the demands and rapid development of the labour market, particularly in the water and wastewater industry (UNESCO, 2021).

- To keep up with today's fast-paced, competitive environment, multistakeholder, cooperative, and international initiatives should be developed to continuously build skills, knowledge, and competencies that boost the capacity of young professionals to innovate in the water sector (Bikfalvi et al., 2018).

Created by AI on Canva by Zeynep Ozkul

Economic Aspects of Upscaling the Viability of Water Reuse

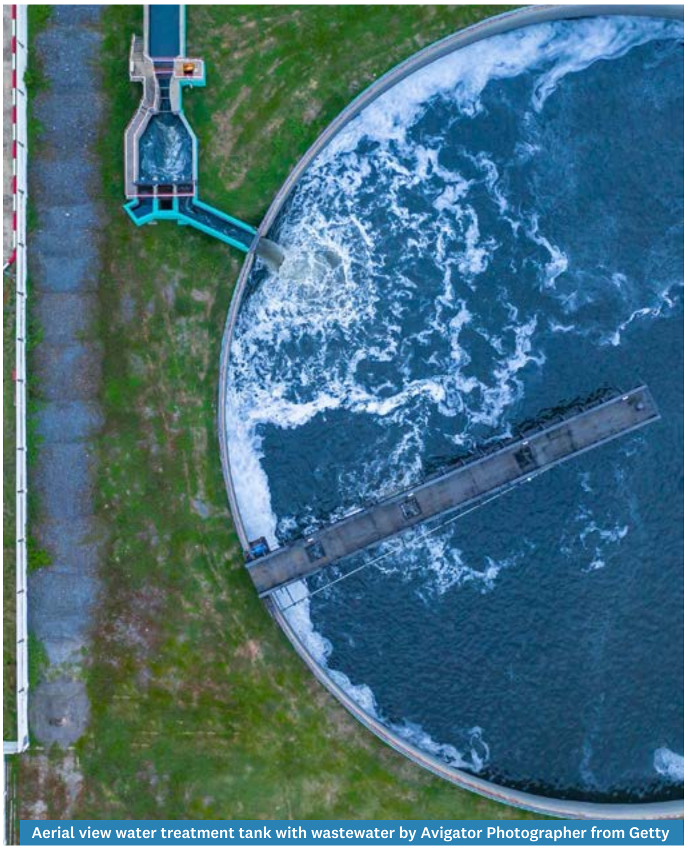
Economic feasibility through profit maximisation and cost minimisation are standpoints for (water-intensive) industries, especially those that rely on the availability and cost of water resources for their processes and operations (Shankar et al., 2021). It is known that implementing water reuse strategies brings about a range of economic benefits, such as lowering the costs of freshwater supply and wastewater disposal, which leads to substantial cost savings for industries and municipalities, as well as mitigates pollution charges by minimising the impact of effluent on the environment and leverages environmental and health benefits (WWAP, 2017).

However, the cost of high-performance wastewater treatment technologies is still substantially high and creates a fundamental disincentive, particularly for small and medium-sized enterprises that may not be able to afford the pricing of freshwater tariffs (Pryce et al., 2022; Feng & Chu, 2004; Obaideen et al., 2022). In some instances, the financial ramifications associated with installing and maintaining new or upgraded systems can result in industries opting to incur fines rather than investing in the treatments needed to meet regulations (WWAP, 2017). This financial burden is particularly hefty for the industrial zones that may not have direct connections to the wastewater provider (Georgiou et al., 2022).

The proper valuation of water resources and sustainable water pricing is a key aspect of promoting resource recovery initiatives and achieving diverse objectives, including cost recovery, efficient and optimal water use, and strategic water reallocation (Rodriguez et al., 2020; UNESCO, 2021). However, abundant and low-cost conventional water resources, combined with their easy accessibility, could adversely impact water reuse schemes (Meese et al., 2021). It is often the case that treated wastewater carries a higher price tag than conventional water sources due to the costs of collection and treatment, energy requirements or infrastructure maintenance (HernándezSancho et al., 2015). When charged minimal fees to extract freshwater, industries have limited financial incentives to invest in treated wastewater unless there is a significant short-term water shortage or prolonged water scarcity (UNESCO, 2020).

Action Points

- A key component in any strategy aimed at expanding industrial wastewater treatment should focus on the application of appropriate technologies that are effective, simple to operate, and low-cost in terms of both initial investment and ongoing operation and maintenance expenses (Morris et al., 2021; Kalbar et al., 2012).
- Given that not all water reuse practices require the same level of water quality, considering factors such as influent wastewater quality, climatic conditions, and socioeconomic factors is necessary to establish a cost-effective and sustainable water reuse scheme (Morris et al., 2021). Fit-for-purpose water reuse refers to the required treatment level defined by the water quality requirements of the intended use (WWAP, 2017). Incorporating fit-for-purpose solutions tailored to specific needs can be a viable approach to provide an affordable increase in the potential for cost recovery and to reduce the high costs of technological assets and operations (Morris et al., 2021; WWAP, 2017).
- Additionally, adjusting water pricing mechanisms to reflect the true value of water can be instrumental in encouraging the adoption of water reuse practices. A well-calibrated pricing system, combined with innovative financing mechanisms, can incentivise industries by providing a long-term, steady financial return that partially or fully covers operation and maintenance costs and reduces the financial risk of infrastructure projects (WWAP, 2017).
- At the governmental level, facilitating cost-sharing for wastewater treatment between the public (municipalities) and private (industries) sectors for fit-for-purpose water reuse might foster cooperative efforts between the parties. Additionally, urban planning should consider closing distances between municipal wastewater plants and industrial symbiosis parks, thus reducing costs for water piping and facilitating municipal water reuse in industry value chain production.



Aerial view water treatment tank with wastewater by Avigator Photographer from Getty

Environmental Factors

The efficient use of wastewater can be influenced by various environmental dynamics, such as the seasonal variation of effluent, which determines the composition and volume of wastewater (Morris et al., 2021). Fluctuations in climate conditions, including the durations of wet and dry seasons, can lead to higher or lower wastewater volumes, in turn imposing implications on the efficient utilisation of wastewater (Rashid & Liu, 2020).

The composition of municipal wastewater can vary considerably; it can include a large range of contaminants in the effluents released by wastewater treatment plants and industries. Effluent composition varies according to activities and products (Thomas & Thomas, 2022; WWAP, 2017), while the composition of industrial effluent could cause increased concentrations of nutrients, pathogens, endocrine disruptors, heavy metals, and pharmaceuticals in natural ecosystems. The result of these released concentrations can detrimentally affect the ecological balance and overall health of the ecosystems, posing a threat to biodiversity and human health (Nasr, 2022) if not considered in the sustainable flow of wastewater treatment for reuse.

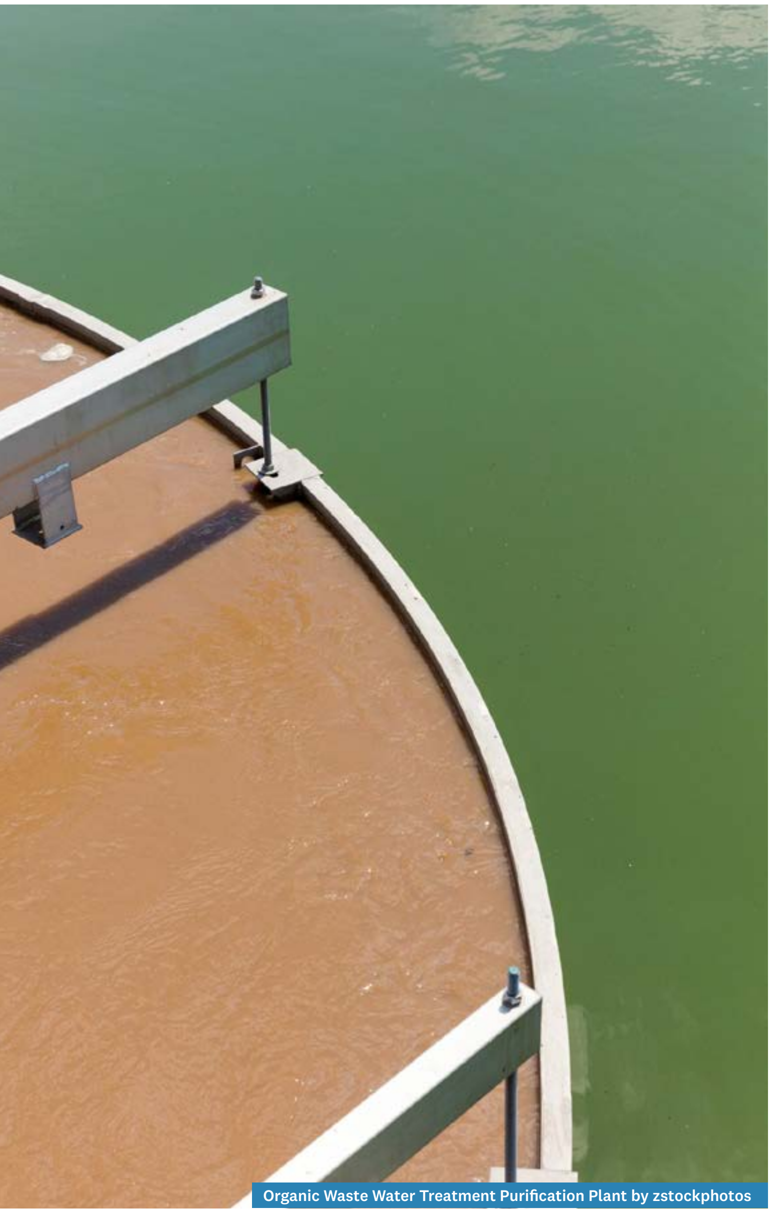
Action Points

- Operational systems, new infrastructure, and advanced wastewater technologies have been developed to remove pathogens and partially eliminate certain chemicals and pharmaceutically active compounds from wastewater (González et al., 2016). To prevent water pollution and ensure adequate control of industrial discharge, policies and regulations should guarantee that wastewater treatment is implemented according to international standards and is appropriate to the nature of the wastewater and its components, including substances, heavy metals, pathogens, etc. (UNESCO, 2020).

- The formulation of effective management strategies for the health risks posed by water reuse depends on various factors such as the water quality and type of wastewater—namely, whether it is untreated, partially treated, or treated—as well as social and behavioural factors that vary across diverse settings (Adegoke et al., 2018).In contemporary industrial settings, it is crucial to implement stringent quality requirements to mitigate chemical risks. These measures include reducing chemicals at the source, employing technical and natural water treatment processes to remove chemicals, and adopting preventive strategies such as knowledge transfer to relevant stakeholders (Helmecke et al., 2020).

- The higher cost and energy requirements of advanced water treatment can be mitigated by establishing fit-for-purpose solutions and setting water-quality benchmarks based on end users' unique needs and requirements (Helmecke et al., 2020; Morris et al., 2021).

- Another key issue currently acting as a barrier to advanced water reuse practices is the substantial amount of energy associated with membrane technologies that are highly effective in removing pollutants from contaminated wastewater (Adam et al., 2022). In the near future, researchers and policymakers will need to develop energy-efficient, cost-effective, and chemical-free alternatives for industrial wastewater treatment processes (Lee et al., 2023).



Organic Waste Water Treatment Purification Plant by zstockphotos

Unlocking Synergies between Circular Economy, SDGs, and Water Reuse for Resilient and Thriving Industries

Climate change, its ripple effects, and the need for resource conservation are among the greatest global challenges of our time and will continue to be over the long term. Global reasoning cannot continue to claim that natural resources are infinite, available, and cheap to eliminate. Urgent action is needed to avoid the depletion of our natural resources and stay within the safe operating space of the planetary boundaries.

The circular economy is an alternative model of production that breaks the "take-make-waste" model by focusing on material efficiency and optimising resource allocation. The concept of a circular economy simulates the behaviour of natural systems by providing a feedback loop that integrates "waste" back into the system as a "resource." The economic and corporate case for the circular economy has gained momentum in recent years due to an increased cost of raw materials and the negative environmental impacts linked to non-sustainable waste management. More and more industries around the globe are realising how their core operations could be affected by water scarcity, and that they must seek ways to increase the circularity of water to mitigate uncertain shocks and stressors.

Water sustainability approaches have often attempted to balance freshwater consumption with economic growth and societal development. However, often overlook the importance of adequately closing the loop in the operational water cycle, which is key to increased circularity and effectively tackling the ongoing water crisis.

However, innovative industrial water reuse schemes and promising technologies exist to save water resources, reduce the environmental impacts from the discharge of treated wastewater, and optimise economic benefits by reducing the cost and energy involved with water resource management. Despite the undeniability of the fundamental role of water reuse to mitigate water stress, increase water circularity, and subsequently add value to economic activities, industrial water reuse practices are still limited, with industries still falling short of adequately integrating water reuse into their value chains. To leverage industrial water reuse within a comprehensive smart water management strategy and increase the competitiveness of the industries, we need to devise potential pathways for water reuse implementation in accordance with the principles of the circular economy.

Uniting public water utilities and industrial users under a public-private partnership (PPP) could make headway in creating a promising alternative water reuse scheme to optimise urban water management and industrial and business processes. As a form of intersectoral cooperation, PPPs for water reuse projects are set to play a significant role in terms of current and future water scarcity adaptation by transferring technological knowledge and know-how and catalysing the capital. To boost the synergy between the public and private sectors, we must understand the barriers and pathways to industrial water reuse, which are often interrelated. These barriers bridge technology, science/

knowledge, finance, and policymaking; understanding these interlinkages is an important initial step to accepting wastewater as a positive action, rather than an unwanted output (Al-Saidi, 2021). The United Nations also prioritises scaling up the PPPs to achieve sustainability objectives by exploiting synergies in the joint innovative use of resources, financing key economic infrastructure, and improving management knowledge.

Industrial water reuse is highly relevant to the 2030 Agenda for Sustainable Development, which calls for a radical transformation of society and industry. The Sustainable Development Goals (SDGs) and their targets specifically emphasise improved water quality, implementing integrated management of water resources, achieving water use efficiency across sectors, mitigating the impact of water-related challenges on the communities, and restoring water-dependent ecosystems (UNEP, 2021). **Sustainable wastewater treatment and management is crucial to achieving SDG 6, specifically developed to 'ensure availability and sustainable management of water and sanitation for all.** The significance of sustainable wastewater treatment extends beyond SDG 6 and intersects with several other Sustainable Development Goals, including SDG 9, which focuses on "Industry, Innovation and Infrastructure," and SDG 12, which emphasises "Responsible Consumption and Production." Moreover, it indirectly contributes to the achievement of nearly all other SDGs, underscoring its intricate importance in advancing global sustainability efforts. As the world is, according to the UN Secretary General, 'tremendously off track' to meet the 2030 SDGs, we must fully realise the value of water in all its uses and foster the wide adoption of non-conventional water supplies (UN News, 2021).

The need for change extends beyond short-term perspectives and sectoral outlook. Rather than relying on traditional water management processes, we must embrace innovative and integrated solutions to tackle the growing challenge of wastewater reuse in a safe, sustainable, and cost-effective way. Establishing effective water reuse strategies requires holistic planning to incorporate key issues such as stakeholder engagement, public awareness, and policy integration. Future efforts should expand our understanding of sustainable solutions in urban systems by identifying different business strategies and co-participatory approaches that engage the public and private sectors in implementing smart water reuse practices and circular economy principles. Failing to act proactively and continuing 'business as usual' will inevitably lead to a significant increase in water demand and aggravate the already dire scarcity of valuable water resources.

Water treatment plant for a large city by henrikjonsson

Notes from the UNU-FLORES Director

Water is a common thread that unites us all. It is the key to peace and prosperity. We need to grasp this clearly and set high on the political agenda.

The Organisational Decision-Making in Water Reuse for Smart Cities (SMART-WaterDomain) https://flores.unu.edu/en/research/projects/organisational-decision-making-in-water-reuse-for-smart-cities-smart-waterdomain.html#outline project has been established in recognition of the complex water crisis we are currently facing – ***a crisis marked by a range of challenges*** *– from floods and droughts to a lack of clean drinking water and sanitation. By fostering potential collaborations between public and private entities within the private-public partnership framework, our efforts seek to optimise urban water management by enhancing the efficacy of public-private partnerships in utilising treated municipal wastewater within the industrial sector.*

As part of our approach, we are striving to develop collaborative methods for evaluating the sustainability of water reuse, and we are doing this by adopting a holistic perspective rooted in Resource Nexus thinking within the realm of urban water management. Additionally, our efforts are geared towards systematising business models aligned with circular economy principles, thereby promoting the expansion of water reuse practices within industrial contexts. Water underpins most of the Sustainable Development Goals (SDGs). However, as we have surpassed the midpoint of the 2030 Agenda timeline, we find ourselves significantly off-track. If we persist on our current trajectory, we risk falling short of achieving the SDG 6 targets, which call for comprehensive and integrated water resource management improvements. To ensure sustainable development, we must call upon governments and businesses to increase investments in resilient infrastructure and wastewater treatment systems.

Establishing effective partnerships is crucial in achieving Sustainable Development Goal 6 (SDG6) and realising the associated benefits across the 2030 Agenda. In the spirit of collaboration and shared aspirations, I extend a warm invitation for further collaborations, foreseeing a continuum of impactful engagements. I extend my deepest gratitude to the dedicated teams of researchers across Europe and Japan, whose commitment to creating an enabling environment for progress embodies the essence of our collective mission.

Edeltraud Guenther
Director of UNU-FLORES

Bibliography

Adam, M. R., Othman, M. H., Kurniawan, T. A., Puteh, M. H., Ismail, A. F., Khongnakorn, W., Rahman, M. A., & Jaafar, J. (2022). Advances in adsorptive membrane technology for water treatment and resource recovery applications: A critical review. Journal of Environmental Chemical Engineering, 10(3), 107633. https://doi.org/10.1016/j.jece.2022.107633

Adegoke, A. A., Amoah, I. D., Stenström, T. A., Verbyla, M. E., & Mihelcic, J. R. (2018). Epidemiological evidence and health risks associated with agricultural reuse of partially treated and untreated wastewater: A Review. Frontiers in Public Health, 6. https://doi.org/10.3389/fpubh.2018.00337

Al-Saidi, M. (2021). From Acceptance Snapshots to the Social Acceptability Process: Structuring Knowledge on Attitudes Towards Water Reuse. Frontiers in Environmental Science, 9. https://doi.org/10.3389/fenvs.2021.633841

Bikfalvi, A., Marques, P., Pérez-Cabaní, M.-L., Juandó Bosch, J., & Rodriguez-Roda, I. (2018). Bridging academia and waterrelated business through competence development: Evidence from a pan-European project. Journal of Cleaner Production, 171. https://doi.org/10.1016/j.jclepro.2016.12.135

Boretti, A., & Rosa, L. (2019). Reassessing the projections of the World Water Development Report. Npj Clean Water, 2(1). https://doi.org/10.1038/s41545-019-0039-9

Breitenmoser, L., Cuadrado Quesada, G., N, A., Bassi, N., Dkhar, N. B., Phukan, M., Kumar, S., Naga Babu, A., Kierstein, A., Campling, P., & Hooijmans, C. M. (2022). Perceived drivers and barriers in the governance of wastewater treatment and reuse in India: Insights from a two-round Delphi Study. Resources, Conservation and Recycling, 182, 106285. https://doi.org/10.1016/j.resconrec.2022.106285

Caucci, S.; Hettiarachchi, H. (2018). The Nexus Approach and Safe Use of Wastewater in Agriculture: A Workshop on Policy and Implementation for Tunisia. Proceedings, Tunis, 12–14 December 2017. Dresden: United Nations University Institute for Integrated Management of Material Fluxes and of Resources (UNU-FLORES). Retrieved from https://collections.unu.edu/eserv/UNU:6571/Proceedings_SUWA_Tunisia.pdf

CDP. 2018. Treading Water: Corporate Responses to Rising Water Challenges. CDP Global Water Report 2018. London, CDP Worldwide. www.cdp.net/en/research/global-reports/global-waterreport-2018.

Cole, D., Narayanan, S., Connors, E., Tewari, M., & Onda, K. (2023a). Water stress: Opportunities for supply chain research. Production and Operations Management. https://doi.org/10.1111/poms.13923

Domenech, T., & Bahn-Walkowiak, B. (2019). The transition towards a resource-efficient circular economy in Europe: Policy lessons from the EU and the Member States. Ecological Economics, 155, 7–19. https://doi.org/10.1016/j.ecolecon.2017.11.001

Feng, X., Chu, K. H. (2004). Cost optimization of industrial wastewater reuse systems. Process Safety and Environmental Protection, 82(3), 249–255. https://doi.org/10.1205/095758204323066019

Gadipelly, C., Pérez-González, A., Yadav, G. D., Ortiz, I., Ibáñez, R., Rathod, V. K., & Marathe, K. V. (2014). Pharmaceutical industry wastewater: Review of the technologies for water treatment and Reuse. Industrial & Engineering Chemistry Research, 53(29), 11571– 11592. https://doi.org/10.1021/ie501210j

Georgiou, I., Caucci, S., Morris, J. C., Guenther, E., & Krebs, P. (2022). Assessing the potential of water reuse uptake through a private–public partnership: A practitioner's perspective. Circular Economy and Sustainability, 3(1), 199– 220. https://doi.org/10.1007/s43615-022-00166-w

Guo, Y., Qi, P. S., & Liu, Y. Z. (2017). A review on advanced treatment of pharmaceutical wastewater. IOP Conference Series: Earth and Environmental Science, 63, 012025. https://doi.org/10.1088/1755-1315/63/1/012025

Heidebrecht, R. (2012). Skills Challenges in the Water and Wastewater Industry Contemporary Issues and Practical Approaches in TVET. UNESCO-UNEVOC International Centre. Retrieved from https://unevoc.unesco.org/fileadmin/user_upload/docs/WaterBooklet.pdf

Helmecke, M., Fries, E., & Schulte, C. (2020). Regulating water reuse for agricultural irrigation: Risks related to organic micro-contaminants. Environmental Sciences Europe, 32(1). https://doi.org/10.1186/s12302-019-0283-0

Hernández-Sancho, F., Molinos-Senante, M., & SalaGarrido, R. (2015). Pricing for reclaimed water in Valencia, Spain: Externalities and cost recovery. Water Pricing Experiences and Innovations, 431–442. https://doi.org/10.1007/978-3-319-16465-6_22

Hettiarachchi, H., & Ardakanian, R. (2018). Safe Use of Wastewater in Agriculture From Concept to Implementation. Springer Cham. https://doi.org/10.1007/978-3-319-74268-7

Hundertmark, T., Lueck, K.; Packer, B. (2020). Water: A human and business priority. McKinsey & Company. Retrieved from https://www.mckinsey.com/capabilities/sustainability/our-insights/water-a-human-and-business-priority

Interministerial Working Group on Adaptation to Climate Change. (2019). 2019 Monitoring Report on the German Strategy for Adaptation to Climate Change [Report]. Umweltbundesamt (German Environment Agency). Retrieved from https://www.umweltbundesamt.de/sites/default/files/medien/421/publikationen/das_2019_monitoring_report_bf.pdf

IPCC. (2022). Summary for policymakers. H.-O. Pörtner, D.C. Roberts, E.S. Poloczanska, K. Mintenbeck, M. Tignor, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, & A. Okem, Climate change 2022: Impacts, adaptation, and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 1-34). Cambridge University Press. Retrieved from https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_SummaryForPolicymakers.pdf

Jeuland, M. (2015). Challenges to wastewater reuse in the Middle East and North Africa. Middle East Development Journal, 7(1), 1–25. https://doi.org/10.1080/17938120.2015.1019293

Jimenez, N., Caucci, S., & Hettiarachchi, H. (2018). Safe use of wastewater in agriculture: Exchanging knowledge in Colombia. In Proceedings, Bogotá, Colombia, 27-28 November 2018. Dresden: United Nations University Institute for Integrated Management of Material Fluxes and of Resources (UNUFLORES). Retrieved from https://collections.unu.edu/eserv/UNU:7298/Proceedings_SafeUseOfWastewaterInAgriculture_Colombia.pdf

Jomo, K., Chowdhury, A., Sharma, K., & Platz1, D. (2016). Public-private partnerships and the 2030 Agenda for Sustainable Development. UN Department of Economic and Social Affairs (DESA) Working Papers, (N.148). https://doi.org/10.18356/f42bd4bb-en

Kalbar, P. P., Karmakar, S., & Asolekar, S. R. (2012). Selection of an appropriate wastewater treatment technology: A scenario-based multiple-attribute decision-making approach. Journal of Environmental Management, 113, 158–169. https://doi.org/10.1016/j.jenvman.2012.08.025

Khalid, S., Shahid, M., Natasha, Bibi, I., Sarwar, T., Shah, A., & Niazi, N. (2018). A review of environmental contamination and health risk assessment of wastewater use for crop irrigation with a focus on low and high-income countries. International Journal of Environmental Research and Public Health, 15(5), 895. https://doi.org/10.3390/ijerph15050895

Khan, S. J., & Gerrard, L. E. (2006). Stakeholder Communications for successful water reuse operations. Desalination, 187(1–3), 191–202. https://doi.org/10.1016/j.desal.2005.04.079

Lee, J., Shin, Y., Boo, C., & Hong, S. (2023). Performance, limitation, and opportunities of acid-resistant nanofiltration membranes for industrial wastewater treatment. Journal of Membrane Science, 666, 121142. https://doi.org/10.1016/j.memsci.2022.121142

Lee, K., &; Jepson, W. (2020). Drivers and barriers to urban water reuse: A systematic review. Water Security, 11, 100073. https://doi.org/10.1016/j.wasec.2020.100073

Massoud, M. A., Kazarian, A., Alameddine, I., & Al-Hindi, M. (2018). Factors influencing the reuse of reclaimed water as a management option to augment water supplies. Environmental Monitoring and Assessment, 190(9). https://doi.org/10.1007/s10661-018-6905-y

Meese, A. F., Kim, D. J., Wu, X., Le, L., Napier, C., Hernandez, M. T., Laroco, N., Linden, K. G., Cox, J., Kurup, P., McCall, J., Greene, D., Talmadge, M., Huang, Z., Macknick, J., Sitterley, K. A., Miara, A., Evans, A., Thirumaran, K., … Kim, J.-H. (2021). Opportunities and challenges for industrial water treatment and Reuse. ACS EST Engineering, 2(3), 465–488. https://doi.org/10.1021/acsestengg.1c00282

Morris, J. C., Georgiou, I., Guenther, E., & Caucci, S. (2021). Barriers in implementation of wastewater reuse: Identifying the way forward in closing the loop. Circular Economy and Sustainability, 1(1), 413–433. https://doi.org/10.1007/s43615-021-00018-z

Nasr, M. (2022). Aquatic pollution and wastewater treatment system. Algae and Aquatic Macrophytes in Cities, 23–37. https://doi.org/10.1016/B978-0-12-824270-4.00006-7

Obaideen, K., Shehata, N., Sayed, E. T., Abdelkareem, M. A., Mahmoud, M. S., & Olabi, A. G. (2022). The role of wastewater treatment in Achieving Sustainable Development Goals (SDGs) and sustainability guidelines. Energy Nexus, 7, 100112. https://doi.org/10.1016/j.nexus.2022.100112

Pryce, D., Kapelan, Z., & Memon, F. A. (2022). Economic evaluation of a small wastewater treatment plant under different design and operation scenarios by life cycle costing. Development Engineering, 7, 100103. https://doi.org/10.1016/j.deveng.2022.100103

Rashid, S. S., & Liu, Y.-Q. (2020). Assessing environmental impacts of large centralized wastewater treatment plants with combined or separate sewer systems in dry/wet seasons by using LCA. Environmental Science and Pollution Research, 27(13), 15674–15690. https://doi.org/10.1007/s11356-020-08038-2

Reike, D., Vermeulen, W. J. V., & Witjes, S. (2018). The Circular Economy: New or refurbished as CE 3.0? — exploring controversies in the conceptualization of the circular economy through a focus on history and resource value retention options. Resources, Conservation and Recycling, 135, 246–264. https://doi.org/10.1016/j.resconrec.2017.08.027

Ritchie, H., & Roser, M. (2017). Water Use and Stress. OurWorldInData.org. https://ourworldindata.org/water-usestress

Rodriguez, D. J., Serrano, H. A., Delgado, A., Nolasco, D., & Saltiel, G. (2020). From Waste to Resource: Shifting paradigms for smarter wastewater interventions in Latin America and the Caribbean. World Bank, Washington, DC. Retrieved from https://documents.worldbank.org/en/publication/documents-reports/documentdetail/161611584134018929/from-waste-to-resource-shifting-paradigms-for-smarter-wastewater-interventions-in-latin-america-and-the-caribbean.

Rudolph, K., Boysen, B., Hilbig, J., Shalizi, F., Stroemer, K., & Walenzik, G. (2020). Drivers, challenges and solutions—case studies for Water Reuse. Wastewater Treatment and Reuse – Present and Future Perspectives in Technological Developments and Management Issues, 189–225. https://doi.org/10.1016/bs.apmp.2020.07.009

Saad, D., Byrne, D.; Drechsel, P. (2017). Social Perspectives on the effective management of wastewater. Physico-Chemical Wastewater Treatment and Resource Recovery. https://doi.org/10.5772/67312

Saliba, R., Callieris, R., D'Agostino, D., Roma, R., & Scardigno, A. (2018). Stakeholders' attitude towards the reuse of treated wastewater for irrigation in Mediterranean Agriculture. Agricultural Water Management, 204, 60–68. https://doi.org/10.1016/j.agwat.2018.03.036

Shankar, R., Sanjay Kumar, Prasad, A. K., Khare, P., Varma, A. K., & Yadav, V. K. (2021). Biological wastewater treatment plants (WWTPS) for industrial wastewater. Microbial Ecology of Wastewater Treatment Plants, 193–216. https://doi.org/10.1016/b978-0-12-822503-5.00023-0

Strade, E., Kalnina, D., & Kulczycka, J. (2020). Water efficiency and safe re-use of different grades of water - topical issues for the pharmaceutical industry. Water Resources and Industry, 24, 100132. https://doi.org/10.1016/j.wri.2020.100132

Thomas, O., Thomas, M.-F. (2022). Urban wastewater. UVVisible Spectrophotometry of Waters and Soils, 347–383. https://doi.org/10.1016/b978-0-323-90994-5.00005-8

UN News. (2021, July). 'Tremendously off track' to meet 2030 SDGs: UN chief. UN News. https://news.un.org/en/story/2021/07/1095722

UNEP (2021). Progress on Integrated Water Resources Management. Tracking SDG 6 series: global indicator 6.5.1 updates and acceleration needs. Retrieved from https://www.unwater.org/publications/progress-integrated-water-resources-management-2021-update

UNESCO & UNESCO i-WSSM. (2020). Water Reuse within a Circular Economy Context (Series II). Global Water Security Issues (GWSI) Series – No.2, UNESCO Publishing, Paris. https://unesdoc.unesco.org/ark:/48223/pf0000374715

United Nations, The United Nations World Water Development Report 2023: Partnerships and Cooperation for Water. UNESCO, Paris United Nations. (2023). The United Nations World Water Development Report 2021: Valuing Water. UNESCO, Paris. Retrieved from https://www.unesco.org/reports/wwdr/2023/en

Voulvoulis, N. (2018). Water reuse from a circular economy perspective and potential risks from an unregulated approach. Current Opinion in Environmental Science &; Health, 2, 32–45. https://doi.org/10.1016/j.coesh.2018.01.005

Wada, Y., Flörke, M., Hanasaki, N., Eisner, S., Fischer, G., Tramberend, S., Satoh, Y., van Vliet, M. T. H., Yillia, P., Ringler, C., Burek, P., & Wiberg, D. (2016). Modeling global water use for the 21st century: The Water Futures and Solutions (WFaS) initiative and its approaches. Geoscientific Model Development, 9(1), 175–222. https://doi.org/10.5194/gmd-9-175-2016

World Bank Group. (2016). High and Dry: Climate Change, Water, and the Economy. © World Bank, Washington, DC. Retrieved from https://documents1.worldbank.org/curated/en/862571468196731247/pdf/105130-REVISED-K8517.pdf

World Economic Forum. (2023). WEF Global Risks Report 2023 [PDF]. Retrieved from https://www3.weforum.org/docs/WEF_Global_Risks_Report_2023.pdf

WWAP (United Nations World Water Assessment Programme). (2017). The United Nations World Water Development Report 2017: Wastewater: The Untapped Resource. Paris, UNESCO. Retrieved from https://www.unwater.org/publications/un-world-water-development-report-2017

Acknowledgements

SMART-WaterDomain Project funded by the Federal Ministry of Education and Research (BMBF) under EIG CONCERT-Japan (01DR20007A).

This policy brief is built upon the outcomes of the SMART-WaterDomain project led by UNU-FLORES and its scientific evidence “Barriers in implementation of wastewater reuse: Identifying the way forward in closing the loop. Morris, J. C., Georgiou, I., Guenther, E., & Caucci, S. (2021). Circular Economy and Sustainability, 1(1), 413–433. https://doi.org/10.1007/s43615-021-00018-z “.

The success of this project would not have been achievable without the outstanding collaboration of the project partners Prof. Dr Edeltraud Günther, Prof. Dr Kensuke Fukushi, Dr Takashi Hashimoto, Ms Isabella Georgiou, Dr Jonathan Clive Morris, Prof. T. Bartosz Kalinowski, Dr Piotr C. Sosnowski, Dr Agata Rudnicka – Reichel, Prof. Katarzyna Pawęska, Dr Wieslaw Fialkiewicz, Dr Aleksandra Bawiec, Mr Petr Skalák, Dr Petr Štěpánek, Prof. Tatiana Kluvánková, Dr Stanislava Brnkaľáková and Dr Danguolė Montvydienė for their efforts and contributions. Their shared vision and collective effort have been essential in shaping the policy recommendations presented here.

United Nations University Institute for Integrated Management of Material Fluxes and of Resources (UNU-FLORES)
Ammonstrasse 74, 01067 Dresden, Germany
Tel.: + 49-351 8921 9370
Fax: + 49-351 8921 9389
Email: flores@unu.edu

Authors: Serena Caucci, Zeynep Ozkul
Language editor: Louisa Andrews
Editor: Serena Caucci

This publication should be cited as: “Caucci S. and Ozkul Z., 2024. Revitalizing Resource Efficiency for Industrial Water Reuse in the Circular Economy”. United Nations University Institute for Integrated Management of Material Fluxes and of Resources (UNU-FLORES).
ISBN 978-3-944863-43-6