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Wastewater as a resource

May 2022

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Environment and Natural Resources Department

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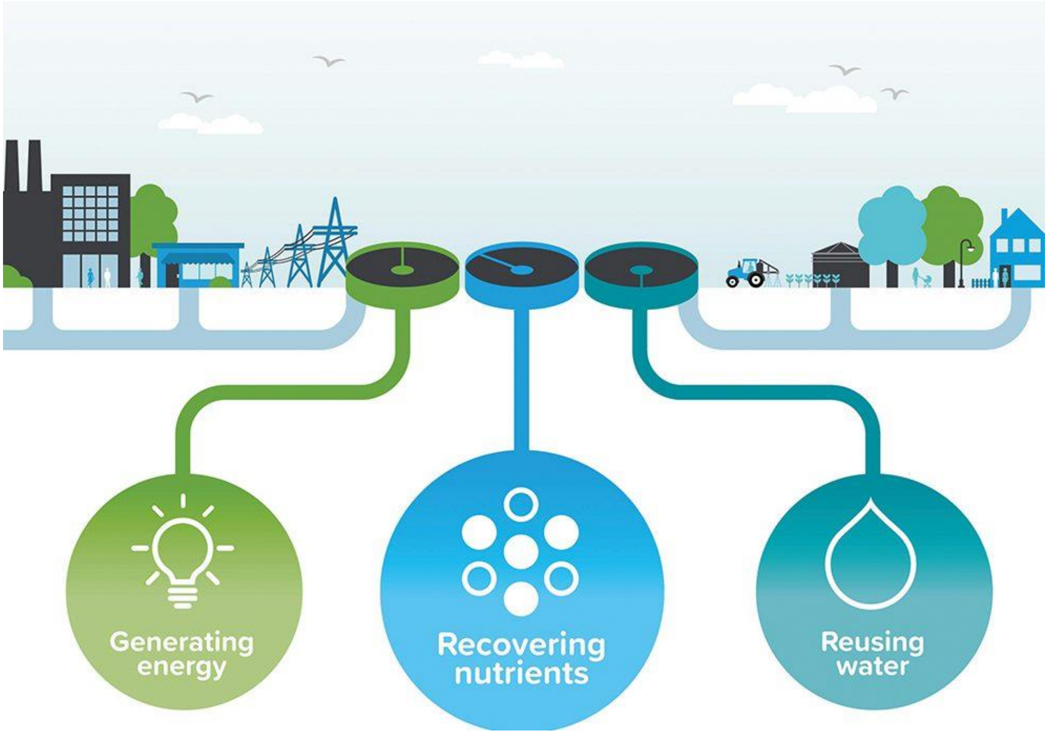
WASTEWATER AS A RESOURCE



[1] *Illustration created by Southern Water Services Ltd for the NEREUS (New Energy and Resources from Urban Sanitation) Project — https://www.nereus-project.eu/.*

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ACRONYMS and UNITS	
AQUASTAT	Food and Agriculture Organization's Global Information System on Water and Agriculture
CH_4	Methane
COD	Chemical Oxygen Demand
GWh	Gigawatt hour
H_2	Hydrogen
IPR	Indirect Potable Reuse
km	Kilometre
KWh	Kilowatt-hour
m^3	Cubic metre
N_2	Nitrogen
NH_4^+	Ammonium
P	Phosphorus
p.e.	population equivalent
SDG	Sustainable Development Goal
UN	United Nations
UWWTD	Urban Wastewater Treatment Directive

INTRODUCTION AND BACKGROUND

Introduction

This paper discusses the potential of wastewater as a resource and the associated challenges and opportunities. The paper starts with a brief explanation of the current global situation regarding wastewater and a simple overview of wastewater treatment, before going into more detail about the resources that can be recovered from it and how. To conclude, a summary of the challenges and opportunities involved in using wastewater as a resource is provided along with an overview of recent developments in the European Union.

Background

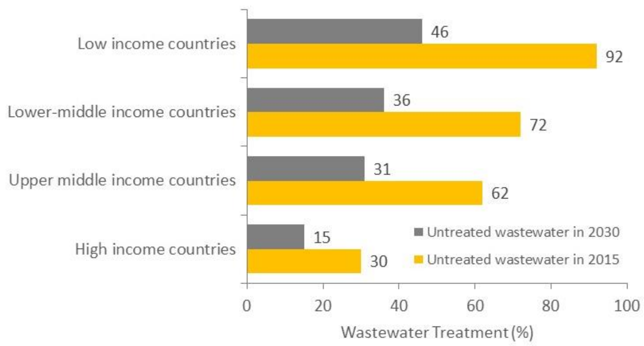
Volumes of wastewater have been steadily increasing over time with the growing population, improvements in water supply, enhanced living standards and economic growth. Each year, 380 billion m^3 of municipal wastewater are generated globally. Wastewater production is expected to increase by 24% by 2030 and 51% by 2050[2]. However, as the common perception remains that wastewater is a source of pollution that needs to be treated and disposed of, wastewater is perceived as a growing problem rather than a valuable and sustainable source of water, energy and nutrients.

A paradigm shift is currently underway, with developed countries taking a proactive interest in improved wastewater management. The goal is to go beyond pollution abatement and to seek to obtain value from wastewater. As a result, the wastewater sector in developed countries has started moving away from simply treating wastewater in wastewater treatment plants and has instead started seeing the potential of these plants as water resource recovery facilities. These recovery facilities can produce clean water, recover nutrients and reduce fossil fuel consumption through the production and use of renewable energy.

Despite the opportunities that wastewater presents, the global reality is that only a very small portion of the total wastewater produced is collected and treated, let alone exploited for the recovery of resources. It is estimated that, globally, over 80% of all wastewater produced is discharged into the environment without adequate treatment although the level varies across different regions.

According to UN Water[3], high-income countries treat on average about 70% of the wastewater they generate. This ratio drops to 38% in upper middle-income countries and to 28% in lower middle-income countries. In low-income countries, only 8% of wastewater generated undergoes treatment of any kind.

Figure 1: Percentage of untreated wastewater in 2015 in countries with different income levels and aspirations for 2030 (50% reduction vs. 2015 baseline).



2 Qadir M, Drechsel P, Jiménez Cisneros B, et al., Global and regional potential of wastewater as a water, nutrient and energy source, Natural Resources Forum. 2020;44:40–51. https://doi.org/10. 1111/1477-8947.12187, (2020).

3 United Nations World Water Development Report (2017), Wastewater The Untapped Resource.

Wastewater components and the wastewater treatment process

Wastewater consists of up to 99% water with the rest being solids, dissolved and particulate matter, microorganisms, nutrients, heavy metals and micropollutants, although the exact composition obviously differs depending on the source. Domestic and municipal wastewater is likely to contain high bacterial loads, whereas industrial activities can produce wastewater that is characterised by a broad spectrum of pollutants.

The treatment of wastewater is not a single-step process and consists of several separate and sequential stages that rely on a combination of physical, chemical and biological processes to remove contaminants. There are several levels of wastewater treatment, the choice of which depends on the type of contaminants, the pollution load and the discharge requirements, as well as the anticipated end use of the effluent. Treatment that is tailored to produce effluent of a quality that meets the needs of the intended end-uses is known as “fit-for-purpose” treatment. The number of treatment technologies is vast and includes physical, chemical and natural processes. The aim of wastewater treatment is that the treated water or effluent is clean enough either to be safely used again or to be returned to the water cycle with minimal environmental impact.

A brief description of the typical steps involved in the wastewater treatment process is provided below for reference.

Preliminary treatment: The physical process of wastewater treatment begins with screening out large items that have found their way into the sewer system (such as plastic waste, rags, sticks, floating objects, etc.). Fine grit is also removed during preliminary treatment as it can cause maintenance and operational problems. Often fats, oils and grease are also removed as early in the treatment process as possible to avoid build-up and blockages downstream.

Primary treatment involves the physical process used for the initial separation of large suspended solids and solid organic matter from the wastewater.

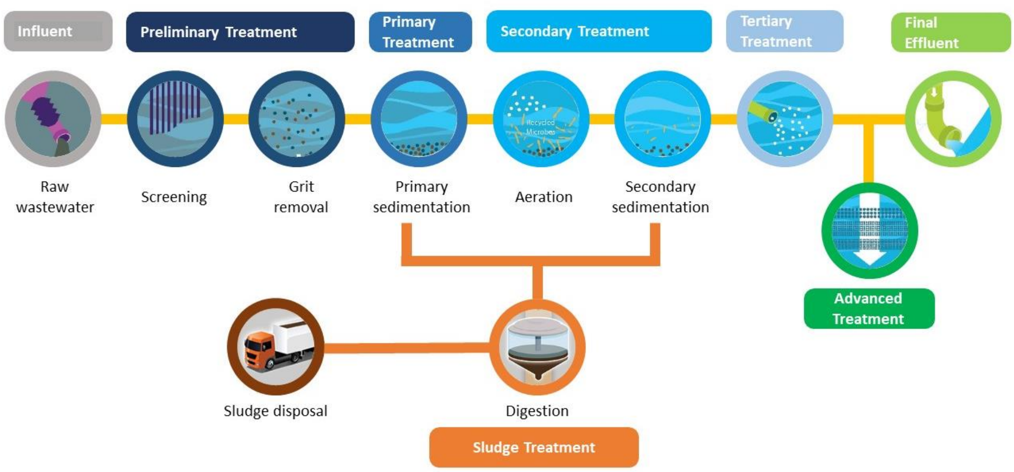
Secondary treatment uses physical and biological processes (microorganisms) to remove mainly organic matter. At the end of secondary treatment, up to 95% of the organic matter has been removed.

Tertiary treatment raises the quality of the water to meet specific requirements, mainly through chemical processes. It involves removing any residual suspended solids and additional nutrients (nitrogen and phosphorus) and disinfection. In current practices worldwide, tertiary treatment is mainly used for nutrient removal when the effluent is expected to be discharged in areas sensitive to eutrophication.

Advanced treatment (or fourth-stage treatment), eliminates micropollutants, such as pharmaceutical residues, that may not have been removed by primary, secondary or tertiary treatment processes.

Sludge treatment reduces the weight and volume of the nutrient-rich organic residue or sludge resulting from the wastewater treatment process.

Figure 2: A typical wastewater treatment process

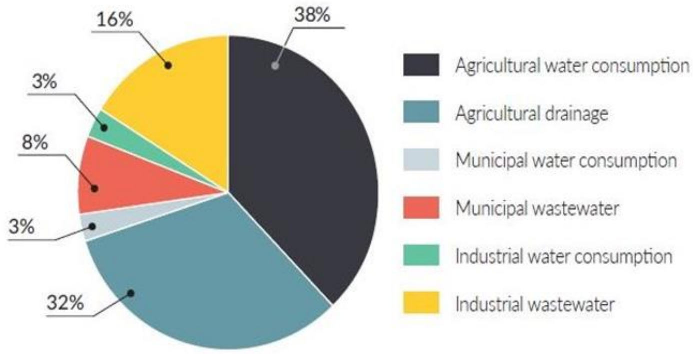


WATER REUSE

Using wastewater as an alternative water resource

Although water covers 70% of the Earth, less than 3% of the planet's water resources is fresh water and only around 1% of that is easily accessible. As a result, fresh water resources are limited and it is essential that they are protected for use as drinking water now and for future generations. However, while fresh water is not abundant, only 3% is used to produce drinking water. The rest is used for other purposes, mainly agriculture, which accounts for almost two-thirds of fresh water use, according to data from AQUASTAT presented in the figure below.

Figure 3: Fate of freshwater withdrawals — Global consumption and wastewater production by major water use sector (circa 2010)[4]



In areas with more limited freshwater resources and increasing demand, water reuse can provide a sustainable and efficient solution.

Water can be reused in many different ways and for a variety of purposes. Depending on the purpose, water reuse may be not only economically feasible but also attractive, particularly when there is potential for cost recovery by treating wastewater to transform it into water of a quality standard that is acceptable to users.

The terminology used to describe the various types of water reuse can be confusing as the terms can differ. This has led to the creation of standard terminology[5] for water reuse. The basic terms are presented in the table below.

4 United Nations World Water Development Report (2017), Wastewater The Untapped Resource.
5 BS ISO 20670:2018 Water reuse – Vocabulary.

DEFINITIONS	
Reclaimed water / water reuse	Wastewater that has been treated to meet a specific water quality standard corresponding to its intended use.
Non-potable reuse	Use of reclaimed water not meeting drinking water standards for non-potable purposes.
Potable reuse	Use of reclaimed water for drinking water supply.
Indirect potable reuse (IPR)	Augmenting natural sources of drinking water with recycled water.
Planned IPR	Using reclaimed water to augment a natural water source (river, groundwater basin or reservoir) so that the blended water can be used for drinking water supply.
Unplanned IPR	Unintentionally adding reclaimed water to a water resource that is subsequently used for the production of drinking water. Generally, in these cases the reclaimed water is treated to a lower standard than reclaimed water intended for planned indirect potable reuse.
Direct potable reuse (DPR)	The injection of reclaimed water directly into the potable water supply distribution system, either upstream or downstream of the water treatment plant.

Types of water reuse

Reclaimed water can be used in many different ways and for a variety of purposes. However, each potential use has different implications for human health and regulations. These are briefly discussed below.

Non-potable reuse

Non-potable reuse is widely practised and involves using reclaimed water that does not necessarily need to comply with strict water quality standards, for a variety of beneficial uses as outlined below.

Agricultural irrigation

Agriculture has a long history of using reclaimed water to irrigate crops, with the level and type of treatment and application methods varying around the world. In developed countries, the quality of treated wastewater used for irrigation has increased as treatment has improved. However, in developing countries, water of lower quality is often used. Water reused in agriculture can be reclaimed indirectly by abstracting water from a river that contains effluent from a wastewater treatment plant or directly, usually locally, from the (non-potable) effluent of a wastewater treatment plant.

Water reuse is increasingly common in agriculture as it offers a reliable alternative in the face of increasing water scarcity and the impact of extreme climate events. The main challenge in using wastewater for irrigation is, in certain contexts, shifting from informal, unplanned use of untreated or partially treated wastewater to planned, safe use.

Industrial use

Industrial activities are diverse and water requirements can vary greatly in quantity and quality. Recycled industrial water has been used as process water in power stations, textile manufacturing, paper production, oil refineries, heating and cooling, and steelworks for a long time.

Overall, industry is in a good position to use or recycle its wastewater internally via a closed loop. Using wastewater not only reduces demand for, and therefore the cost of, fresh water — particularly in areas or times of scarcity. It also has the added benefit of reducing discharges. This helps companies meet regulatory standards and reduces their risk of fines. Furthermore, the practice benefits the environment and adds weight to any industry's "social licence" to operate.

Landscape irrigation

Reclaimed water is used extensively, particularly in arid and semi-arid regions, for the irrigation of urban landscaped areas such as parks, gardens and sports fields, as well as for street cleaning.

Environmental enhancements

Reclaimed water can be used, particularly during hot periods or droughts, to restore or maintain river flows and to supplement water in lakes and wetlands and preserve biodiversity. The advantage of using reclaimed water for environmental purposes is that the supply is reliable and largely independent of seasonal drought and weather events, making it particularly useful during periods of peak water demand.

A form of environmental enhancement that is increasingly gaining momentum is managed aquifer recharge. This approach involves the intentional injection of treated wastewater into groundwater aquifers for subsequent recovery, to enhance ecosystems and to form barriers against seawater intrusion in coastal regions.

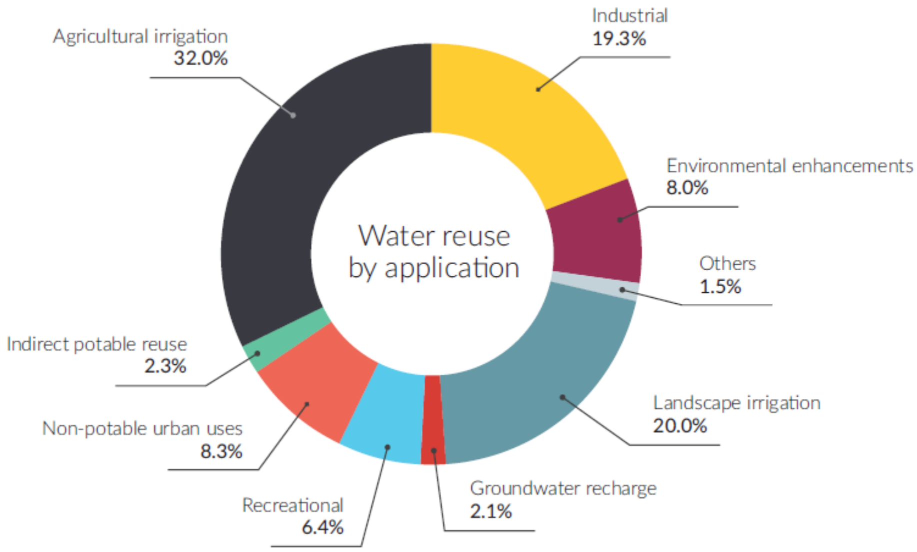
Potable reuse

Planned indirect potable reuse, where treated wastewater is intentionally added to ground or surface sources and eventually ends up as drinking water, has become increasingly common. Australia and the United States have been reusing water to increase potable supply for a number of years. In the European Union, only one full-time potable water reuse system is currently in operation, the Torreele facility in Flanders in northern Belgium. The facility produces infiltration water for indirect potable reuse through artificial recharge of the dune aquifer of St-André, which has been supplying water to around 60 000 people daily since 2003.

In reality, a large proportion of treated, and even untreated, wastewater worldwide ends up being discharged into a watercourse and used downstream for water supply as unplanned indirect potable reuse.

The use of reclaimed water for drinking through direct potable reuse, however, is not as common, although there are some well-established schemes around the world. In Namibia, the city of Windhoek has been successfully using direct potable reuse from secondary treatment effluent for over 50 years. Drinking water currently supplied to the approximately 400 000 inhabitants of the City of Windhoek consists of 25% to 30% of reclaimed water. Singapore covers up to 40% of its water by direct potable reuse schemes called NEWater. The NEWater process recycles treated used water into ultraclean, high-grade reclaimed water, cushioning the country's water supply against dry weather and moving Singapore towards water sustainability. By 2060, NEWater is expected to meet up to 55% of Singapore's water demand.

Figure 4: Global water reuse after tertiary treatment: market share by application



Note: Direct potable reuse included under "Others"

Water reuse considerations

Risk to human health

Even wastewater that has been through some treatment contains pathogens and pollutants, which may pose health risks. The type and extent of such risks depend on many factors, such as the treatment level, how the wastewater is used, the types and concentrations of contaminants in the wastewater, the level of human exposure as well as the regional risk relevance. In middle and high-income countries, for example, where sewer systems serve domestic and industrial areas, pathogenic hazards are largely controlled, and the discussion focuses on heavy metals or other chemical contaminants, like those deriving from pharmaceutical and personal care products.

To protect public health without unnecessarily discouraging wastewater use, fit-for-purpose water quality standards need to be developed to safeguard public health, and those standards need to be an integral pillar of any reuse system. Overall, though, for many countries around the world, the main challenge is still how to shift from the unplanned use of untreated, or partially treated, wastewater to safe water reuse. So, while Namibia or Singapore may be concerned about the increased antibiotic resistance caused by contaminants in the water, the majority of countries are worried about pathogens such as bacteria or viruses in wastewater — something that has been highlighted during the coronavirus pandemic.

Risk management is an important component of wastewater use. This is particularly true for agriculture, which represents the largest use of wastewater globally. The *WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater in Agriculture (WHO, 2006 a)* recommend a multiple-barrier approach to protecting public health.

Public perception

Despite the increasing need, the use of reclaimed water remains a controversial topic, particularly when it comes to potable reuse. The instinctive disgust associated with the idea of recycling sewage combined with the fear that reclaimed water is unsafe is known as the "yuck factor"[6].

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.

Although the factors that influence public perception are not directly related to the actual hazards and levels of risk associated with water reuse, they create genuine challenges for schemes seeking to integrate recycled water into the water supply.

Israel — From water scarcity to water security

Israel is classified as one of the most water-scarce countries in the world with a total renewable annual volume of water per capita of 86 m^3, significantly below the 500 m^3 limit that defines absolute scarcity*. The country has managed, however, not only to secure the supply of drinking water for its population, but to produce surplus water that can be exported to its neighbours, like Jordan, which also suffers from water scarcity. Israel has managed to achieve this by relying on unconventional water resources — reclaimed water and desalination — to complement natural sources.

Reusing treated wastewater for irrigation enables scarce fresh water to be dedicated to domestic use. Almost **90% of the country's wastewater effluent is currently reused for agriculture**, representing approximately half of the total water that farmers use nationwide[7]. In addition, recharging aquifers with treated wastewater during low-demand months (managed aquifer recharge) means that aquifers can be used as reservoirs (in the absence of surface reservoirs and dams) to store water for periods of high demand and/or drought.

Israel's large-scale desalination of seawater and brackish water provides 85% of all potable water that municipal and regional utilities distribute in the country. The EIB-financed Sorek II desalination plant will be the sixth desalination plant in the country and one of the largest in the world to use reverse osmosis.

* *Typically scarcity is assessed by looking at the population-water equation. An area is experiencing water stress when annual water supplies drop below 1 700 m^3 per person. When annual water supplies drop below 1 000 m^3 per person, the population faces water scarcity, and below 500 m^3 "absolute scarcity" (UNWater).*

[6] *Garcia-Cuerva L., et al., Public perceptions of water shortages, conservation behaviors, and support for water reuse in the US, Resources, Conservation and Recycling, 2016.*

NUTRIENT RECOVERY

Recovering nitrogen and phosphorus from wastewater

Wastewater treatment separates solids contained in sewage from the water. Sewage sludge, or simply sludge, is the residual, semi-solid material that is produced as a by-product during the biological treatment of industrial or municipal wastewater. Sludge production cannot be avoided. Sludge production will inevitably increase as the number of people with access to wastewater services grows and effluent quality standards tighten.

Due to the physical-chemical processes involved in wastewater treatment, sludge tends to concentrate heavy metals, microplastics[8] and poorly biodegradable trace organic compounds as well as potentially pathogenic organisms (viruses, bacteria etc.) present in wastewater. Sludge is, however, also rich in nutrients such as nitrogen and phosphorus originating from human waste, food and certain soaps and detergents. These nutrients are useful when soils are depleted or subject to erosion, making them valuable in agriculture as components of fertilisers.

At the levels found in wastewater, nitrogen and phosphorus are considered contaminants and can cause eutrophication in water bodies. With increasing urbanisation, nutrients accumulate in populated areas and contribute to pollution wherever the coverage of wastewater collection and treatment is insufficient. Even in Europe, decades after the Urban Wastewater Treatment Directive was passed, nutrient pollution resulting from excess nitrogen and phosphorus is still a leading cause of water degradation.

Phosphorus recovery

Another reason why nutrient recovery is so important is that non-renewable resources, including phosphorus, are diminishing. Phosphorus is a finite resource that is being used at alarming rates for fertiliser production to maintain agricultural productivity and the food supply. However, forecasts indicate that extractable phosphorus mineral resources will become scarce, or even exhausted, in the next 50 to 100 years. Though costly, recovering phosphorous from wastewater is becoming an increasingly viable alternative. An estimated 22% of global phosphorus demand could be satisfied by recycling domestic wastewater worldwide[9].

Expected future shortages are driving the research and development of phosphorus removal from wastewater. Phosphorus recovery technologies are operating at full scale at several locations. In some EU countries such as Germany, legislation published in 2017[10] already obliges wastewater treatment plants of a certain size to recover a minimum amount of the incoming phosphorus load.

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[7] *Marin, P., Shimon T., Joshua Y., and Klas R., "Water Management in Israel: Key Innovations and Lessons Learned for Water-Scarce Countries." World Bank, Washington, DC. (2017).*

8 See sector paper: "Microplastics and Micropollutants in Water. Contaminants of Emerging Concern."

[9] *Qadir M, Drechsel P, Jiménez Cisneros B, et al., "Global and regional potential of wastewater as a water, nutrient and energy source." Natural Resources Forum. 2020;44:40–51. https://doi.org/10. 1111/1477-8947.12187, (2020).*

[10] *Bundesgesetzblatt Jahrgang 2017 Teil I Nr. 65, ausgegeben am 02.10.2017, Seite 3465: Verordnung zur Neuordnung der Klärschlammverwertung vom 27.09.2017.*

Nitrogen recovery

Unlike phosphorus, which is a limited and non-renewable resource, nitrogen is abundantly present in the atmosphere in a highly stable and non-reactive form: nitrogen gas (N_2). Ever since the invention of the Haber-Bosch process in 1909, which managed to convert atmospheric nitrogen to ammonia, nitrogen-based fertilisers have supported the largest increase of food production capacity in history.

The increased food production achieved by the use of nitrogen-based fertilisers has resulted in nitrogen being excreted (mainly as urea and ammonium) by human beings into wastewater. As a result, wastewater treatment plants currently have to employ energy-intensive methods to remove nitrogen to avoid the eutrophication of effluent-receiving waters and comply with effluent concentration limits. In addition to the high energy consumption, the biological removal of nitrogen from wastewater results in emissions of nitrous oxide (N_2O), a potent greenhouse gas. Nitrogen recovery from wastewater instead allows the simultaneous treatment of wastewater and collection of a concentrated ammonia product, which not only helps the environment but also contributes to the circular economy.

Considerations about nutrient recovery

Although rapid technological advances provide increasing opportunities for nutrient recovery from wastewater and sludge, making these processes economically feasible is still a significant challenge. Business opportunities remain limited, mainly due to a lack of markets, and in the case of nitrogen, the abundance of the source. The low nutrient content in biosolids, particularly for nitrogen, limits the scope for profitable sales on the market. Only 5-15% of the nitrogen available in wastewater can be recovered, while it is possible to capture 45-90% of the phosphorus[11].

Moving forward, scientists and engineers are also considering other as yet under-exploited resources in wastewater, including bioplastics, enzymes, metals and minerals, but more work is needed to make their recovery economically viable.

[11] *Drechsel, P., Qadir, M. and D. Wichelns, Wastewater: An Economic Asset in an Urbanizing World (2015).*

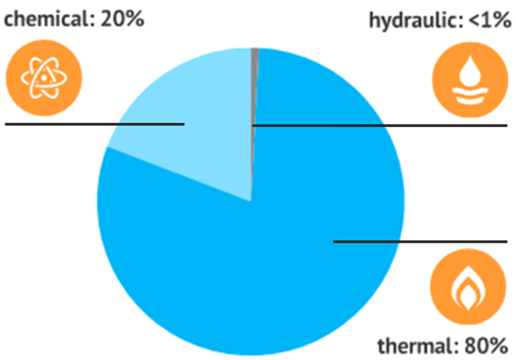
ENERGY RECOVERY

The potential of the chemical, thermal and hydraulic energy contained in wastewater

Wastewater treatment plants are major consumers of energy. A detailed analysis of the energy consumption of the plants in the European Union estimates their overall energy use at 24 747 GWh per year, which is equal to approximately 0.8% of total EU electricity generation[12]. Studies have, however, demonstrated that wastewater contains nearly five times the amount of energy that is needed for the process of treating it[13]. Wastewater treatment facilities therefore have the potential not only to produce the energy needed to treat the wastewater, but to help heat and power the cities that produce it while at the same time contributing to the economy's decarbonisation.

Energy embedded in wastewater

Figure 5: Energy embedded in wastewater



Source: Energy from Wastewater ENER6C13-Factsheet

Wastewater contains energy in a number of forms (namely chemical, thermal and hydraulic) yet energy recovery from wastewater typically only considers chemical energy in the form of biogas produced from the anaerobic digestion of wastewater sludge.

However, estimates of the recoverable energy embedded in municipal wastewater suggests that the potential for thermal energy (80% of energy recovered) is much higher than for chemical energy (20%) while only a very small amount (less than 1%) of the embedded energy is in the form of hydraulic energy[14]. This indicates that a significant portion of recoverable energy in wastewater is currently unexploited.

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[12] *Magagna, D., Hidalgo González, I., Bidoglio, G., Peteves, S., Water — Energy Nexus in Europe (2019).*

[13] *Tarallo, Shaw, Kohl, & Eschborn, A Guide to Net-Zero Energy Solutions for Water Resource Recovery Facilities. IWA Publishing (2015).*

[14] *Tarallo S., Utilities of the Future Energy Findings, IWA Publishing (2014).*

Chemical energy

Wastewater contains organic and inorganic molecules, and exothermic reactions of these constituents will result in a release of chemical energy contained in the molecules. The majority of the chemical energy in wastewater is contained in organic compounds measured as chemical oxygen demand (COD) and/or biochemical oxygen demand. Some inorganic constituents such as ammonia also contain chemical energy that could be extracted. Chemical energy from organic matter is converted into biomass energy during biochemical treatment. The recovery of chemical energy involves transforming wastewater constituents into gaseous, liquid or solid fuels. Biogas is one of the most important renewable energy sources and it can be produced in wastewater treatment plants.

Organic matter from sewage sludge is converted by anaerobic digestion into biogas that usually contains more than 60% methane. Biogas is then used for combined heat and power production in cogeneration units. The calorific energy of wastewater is the energy content stored mainly in the various organic chemicals. The energy content in untreated wastewater was estimated to be about 1.5 kWh/m^3 for wastewater with chemical oxygen demand in the range of 250 mg COD/l to more than 1 000 mg COD/l (which is common for domestic wastewater)[15].

As anaerobic digestion is a well-known and widely applied technology, the process has been subjected to extensive research to make the degradation of organic matter more efficient and achieve higher biogas yields. As a result, several methods, known as enhanced anaerobic digestion processes, have been developed to improve the performance of anaerobic digestion. These methods either involve applying pre-treatments such as thermal hydrolysis and pyrolysis to facilitate the breakdown of the organic material, or increasing the treatment efficiency by adding a co-substrate or chemicals. The co-digestion of sludge with other organic waste (such as food waste) is another method used for both waste treatment and enhanced biogas production.

Biogas produced from wastewater is a clean energy source that has several advantages, even when compared to other renewable energy sources. Biogas is dispatchable[16] and, once upgraded, can be stored and distributed using the existing gas infrastructure network. In addition, it does not rely on critical raw materials and does not disrupt wildlife.

[15] *Maktabifard M., Zaborowska E., Makinia J., Achieving energy neutrality in wastewater treatment plants through energy savings and enhancing renewable energy production, Reviews in Environmental Science and Biotechnology (2018).*

[16] *Dispatchable energy refers to sources of electricity that can be dispatched on demand at the request of power grid operators, according to market needs.*

Thermal energy

Thermal energy in the form of heat can be recovered from wastewater using various technologies (such as heat exchangers and heat pumps) that are simple, proven and environmentally friendly. Thermal energy from wastewater can be used for district heating/cooling, agricultural greenhouses and even for drying sludge. Compared with other traditional sources for heat pumps (groundwater, geothermal heat or outdoor air), wastewater usually has a higher temperature because it originates from warm sources such as showers, dishwashers, washing machines etc. Domestic wastewater maintains a fairly constant temperature as it travels through sewers to the treatment plant, with temperatures generally between 10 ºC and 25 ºC, although this can vary by geography and season. Thermal energy could yield about 5.8 kWh/m^3 for a drop of 5 ºC in wastewater temperature[17].

The limitations in the recovery and utilisation of thermal energy from wastewater are not based on technical difficulties but rather are associated with the supply distances from wastewater treatment plants and governmental policies. To be able to utilise the thermal energy, governmental and municipal authorities would need to consider and include it in municipal planning. They would also need to coordinate their approach with different authorities.

EIB Case Study — Hamburg Wastewater Climate Adaptation Project

In 2020 the European Investment Bank financed investments to enhance energy recovery at Hamburg's wastewater treatment plant. Although the plant already produces 107% of its electricity needs and 113% of its heat needs, the amount of energy produced will improve thanks to the investment. Hamburg's wastewater treatment plant is not just energy self-sufficient. It also provides electricity to around 5 700 households.

Hydraulic energy

Although the vast majority of energy contained in wastewater is in the form of chemical and thermal energy, wastewater can also contain hydraulic potential energy. Hydraulic energy can take the form of elevation head (the relative position of the influent to effluent free water surface), pressure head (in certain pressurised processes such as reverse osmosis) and velocity head (associated with the kinetic energy of the moving fluid).

Generally, hydraulic turbines for electrical power generation are used for the recovery of hydraulic potential energy from wastewater. Despite the straightforward technology used for the recovery of hydraulic potential energy at wastewater treatment plants, a number of potential barriers prevent the exploitation of this energy. These barriers include the lack of excess head, seasonal flow rate variations and turbine failure due to blockages or damage from particulates present in wastewater, particularly in raw sewage at the plant inlet. However, under certain conditions, for example for wastewater treatment plants with a high flow rate and an acceptable elevation difference, hydropower can be a significant renewable energy generation source.

Electricity pricing has a major impact on the economic viability of hydropower energy recovery. Installing a hydropower turbine is not economically viable unless the plant has a high flow rate.

[17] *Capodaglio A., Olsson G., Energy Issues in Sustainable Urban Wastewater Management: Use, Demand Reduction and Recovery in the Urban Water Cycle, Sustainability (2019).*

Considerations when recovering energy from wastewater

In current practices, the energy potential of wastewater is not fully exploited and, although several energy-neutral or energy-positive plants exist and operate fully, they are not yet the norm. Wastewater treatment plants can become 100% self-sufficient in energy terms if they effectively employ energy efficiency and energy harvesting from wastewater. Additional steps, such as the co-digestion of organic waste, using thermal energy harboured by wastewater for space heating along with alternative processes for wastewater and waste options, could even make municipal wastewater treatment plants ''energy positive."

A large-scale transition in this direction requires significant investments, and is usually only possible for new plants or for major overhauls (and primarily for plants larger than 50 000 population equivalent[18].

Energy often represents the second largest operational cost (after labour) in providing wastewater services to the public. Therefore, increasing energy efficiency is one of the most effective ways for wastewater treatment plants to manage costs and help ensure long-term operational sustainability.

Energy costs can constitute 25% to 56% of a wastewater treatment plant's operation and maintenance costs. These costs can make up 20% of the municipality's bill, and are estimated to cost the EU public €2 billion per year[19]. Improving energy efficiency at the least efficient plants would enable EU-wide savings of 5 500 GWh annually, while if less efficient plants complied with the standards of the most efficient plants, energy savings could amount to 13 000 GWh/year[20]. Very little information is available to assess energy use in wastewater collection systems and the potential to reduce it.

To fulfil this potential for boosting energy efficiency, operators of wastewater treatment plants need to make (possibly high) initial investments such as carrying out energy audits and replacing inefficient technologies. The potential for savings varies between bigger and smaller plants, with the bigger ones likely to achieve more savings with less effort. As wastewater service provision yields low margins, if any at all, owners have difficulties getting the funding they need to carry out investments, including for energy recovery schemes and other projects going beyond their core mission of treating wastewater. Additionally, if wastewater treatment plants were to become clean energy producers, they would need to be able to feed the energy into existing networks.

[18] *For wastewater treatment plants treating both domestic and commercial/industrial wastewater, rather than population served, population equivalent is used instead. Population equivalent is the number expressing the ratio of the sum of the pollution load produced by industrial facilities and services during 24 hours to the individual pollution load in household sewage produced by one person in the same period.*

[19] *Evaluation of the Urban Wastewater Treatment Directive, EC Working Document (2019).*

[20] *Ganora D., et al., Opportunities to improve energy use in urban wastewater treatment: a European-scale analysis, Environmental Research Letters (2019).*

CONTRIBUTING TO GLOBAL OBJECTIVES

HOW WASTEWATER CAN HELP SUSTAINABLE DEVELOPMENT

Sustainable development is defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Depleting natural resources and the declining quality of fresh water make the recovery of resources from wastewater a perfect fit for sustainable development. As a result, wastewater management and resource recovery dovetail with a number of initiatives and global objectives for sustainability, as indicated in the following sections.

2030 Agenda for Sustainable Development

Wastewater management and resource recovery from wastewater will be critical for the United Nation's 2030 Agenda for Sustainable Development. The achievement of Sustainable Development Goal (SDG) 6 (clean water and sanitation for all) is not only highly relevant to achieving several other SDGs, but it is also a precondition for achieving the overarching goal of eradicating poverty. Although target 6.3 explicitly focuses on reducing pollution and improving the disposal, management and treatment of wastewater and its impact on ambient water quality, wastewater treatment and resource recovery also fit in with a number of other SDGs.

For example, energy recovery by wastewater treatment plants can contribute to SDG 7 (affordable and clean energy) and SDG 13 (climate action). Treating wastewater and restoring watersheds contribute to SDG 3 (good health and well-being), SDG 11 (sustainable cities and communities), and SDG 14 (life below water) among others. Finally, nutrient recovery and water reuse will be key to achieving SDG 2 (zero hunger), which addresses food security, improved nutrition and sustainable agriculture.The latest UN report on the progress of the SDG agenda[21] found that the world is not on track to achieve the global Goals by 2030, even though one-third of the time period has passed. The report pointed out that SDG 6, in particular, will not be met unless progress increases substantially.

[21] *https://unstats.un.org/sdgs/report/2020/The-Sustainable-Development-Goals-Report-2020.pdf.*

Climate neutrality

Improving approaches to the treatment of wastewater also offers a range of opportunities for climate change mitigation. Water and wastewater utilities are responsible for 3% to 7% of greenhouse gas emissions[22], but these estimates do not include emissions associated with discharging untreated sewage. Untreated wastewater is itself a major source of greenhouse gas emissions. Given that in developing countries, 80% of the wastewater is neither collected nor treated, emissions related to sanitation and the sector's potential to contribute significantly to climate change mitigation represent a significant opportunity.

Water reuse can also reduce the amount of energy associated with water extraction, advanced treatment and, if the water is reused at or near the release site, transport. These combined opportunities reduce the need for energy. Since much of the energy used still derives from fossil fuels, resource recovery from wastewater can substantially reduce greenhouse gas emissions and contribute to climate change mitigation.

Water-energy-food nexus

The interaction of water, energy and food systems with each other and the environment, also known as the water-energy-food nexus, has gained prominence in discussions of international resource policies. In this context, wastewater is of increasing interest given that it allows the recovery of all three resources — water, energy and nutrients for crop production.

Resources like freshwater, energy and food are under pressure from population growth, economic development and climate change. At the same time, natural resources are being depleted, which makes resource recovery and a combined approach to water, energy and food crucial for sustainable development. However, to effectively implement a nexus approach, investment in infrastructure for the collection and treatment of wastewater needs to be done in a way that makes the recovery of water, nutrients and energy a top priority.

Climate change, globalisation and the uncertain future of fossil fuels have expanded the concept of energy security by adding new dimensions, such as sustainability, energy efficiency, mitigation of greenhouse gas emissions, accessibility of energy services (energy poverty) and others. Turning wastewater treatment plants into efficient generators of renewable energy will cut energy consumption and boost (green) energy production, enabling wastewater to contribute to energy security.

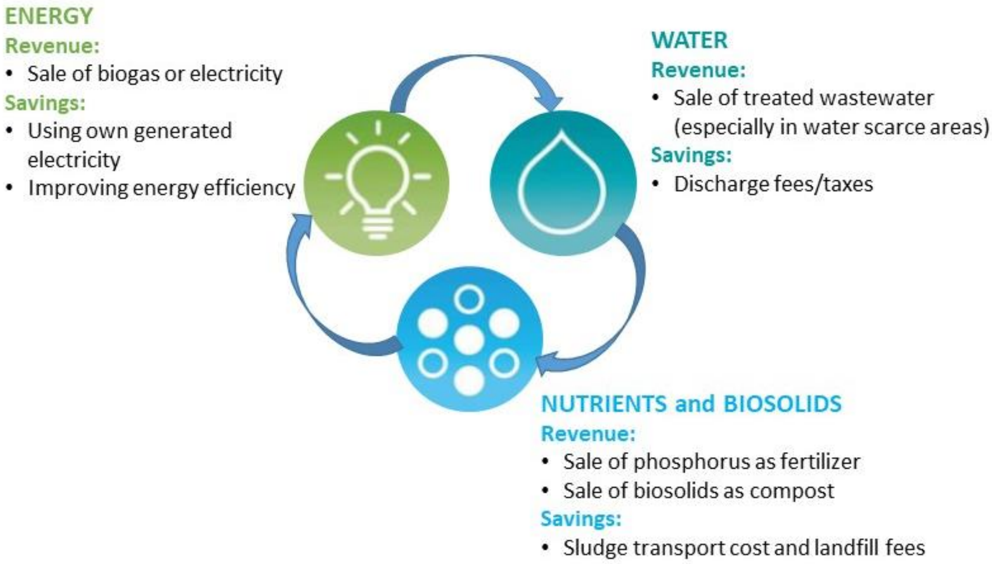
[22] *https://iwa-network.org/can-the-water-sector-deliver-on-carbon-reduction/.*

Cost recovery and utility sustainability

Resource recovery can provide an extra revenue stream or help reduce and/or cover the operation and maintenance costs of wastewater utilities. This could potentially transform the sanitation sector from a heavily subsidised sector to one that generates revenue and is self-sufficient.

In addition, resource recovery can help overcome some of the challenges involved in financing wastewater infrastructure. It reduces the financial risk of wastewater infrastructure projects, improves the rate of return and creates a more attractive environment for the private sector, with revenues not solely reliant on public sector tariffs, but also on the market for the by-products generated during the wastewater treatment process. Finally, given the long-term benefits and potential positive social impact of resource recovery projects, analysing costs over the life of a project could improve how investors evaluate and justify the financing of treatment plants and sanitation initiatives.

Figure 6: Potential revenue streams and savings from resource recovery for wastewater treatment plants



Source: EIB

WASTEWATER RESOURCE RECOVERY IN THE EUROPEAN UNION

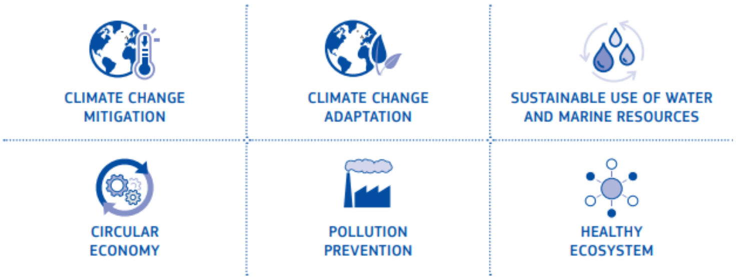
Current status and recent developments in EU regulation

In Europe, the wastewater sector offers significant opportunities for economic development, growth and jobs. Estimates indicate that 60-70% of the potential value of wastewater across the European Union is currently unexploited (heat, energy, nutrients, minerals, metals, chemicals, etc.)[23]. This means that Europe is already missing out on an opportunity for development, competitiveness and jobs, not only in wastewater, but also in other related sectors of the economy. Changes in policy, regulations and norms are essential to promote wastewater resource recovery so that the full potential of wastewater is realised. A summary of EU regulations and developments concerning wastewater resource recovery and recent developments are outlined below.

The European Green Deal and sustainable investment framework

On 11 December 2019, the European Commission presented the European Green Deal, outlining the European Union's ambition to become climate-neutral by 2050. Subsequently, on 15 April 2020, the EU Parliament adopted new legislation to establish a framework for sustainable investments, also known as the EU Taxonomy Regulation[24], which entered into force on 12 July 2020.

Figure 7: The six environmental objectives of the EU Taxonomy Regulation



Source: European Commission

The legislation lays down six environmental objectives, as shown in the figure below, and allows economic activity to be labelled as environmentally sustainable if it substantially contributes to at least one of the objectives without significantly harming any of the others.

Wastewater/sewerage management activities and particularly resource recovery activities, either directly or indirectly, have the potential to contribute to all six of the objectives.

[23] *Water Europe, Water Europe Strategic Innovation and Research Agenda (Water Europe SIRA) 2030, Water Europe, Brussels.*

[24] *https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32020R0852.*

Water reuse for agricultural irrigation regulation

A new EU regulation on water reuse in agriculture[25], which introduces minimum water reuse requirements for agricultural irrigation, entered into force on 25 May 2020. The new rules will apply from 26 June 2023 and are expected to stimulate and facilitate agricultural water reuse in the European Union. According to the European Commission, the new regulation could increase water reuse six-fold from 1.7 billion m³ to 6.6 billion m³ per year and reduce water stress by 5%. Water reuse contributes to the broader water sector, which is a key component of EU eco-industrial policy. The world water market is growing rapidly, and it was estimated to reach €1 trillion in 2020[26]. For this reason, water reuse also has significant potential to create "green jobs" in the water-related industry. A 1% increase in the growth rate of the water industry in Europe could create up to 20 000 new jobs.

The regulation identifies the high level of investment needed to upgrade urban wastewater treatment plants and the lack of financial incentives for practising water reuse in agriculture as reasons for the low uptake of water reuse in the European Union. It also indicates that these issues could be addressed by promoting innovative schemes and economic incentives.

Fertilising products regulation

In May 2020, the European Commission adopted a delegated act to include sewage sludge in the materials authorised for use as fertiliser sold across the European Union, paving the way for increased investment in phosphorus recovery from sludge. The move expands the new EU Fertilising Products Regulation[27] that entered into force on 15 July 2019. Although the new regulation mentioned the use of sewage sludge, the details of sludge-based nutrients were left open. In addition to that, in the new Circular Economy Action Plan[28] adopted on 11 March 2020, the European Commission stated that it intends to develop an Integrated Nutrient Management Plan, with a view to ensuring more sustainable application of nutrients and stimulating the markets for recovered nutrients.

Revision of the Urban Wastewater Treatment Directive

In December 2019, the European Commission published the results of its evaluation of the Urban Wastewater Treatment Directive[29]. Although the directive was found to be successful in reducing loads of the targeted pollutants from urban point sources[30], the evaluation highlighted the fact that the wastewater sector could do more to help meet EU-wide climate and energy targets. The directive does not include requirements on energy consumption and/or production. Estimates show that EU wastewater treatment plants (those falling under the directive) use 0.8% of all energy consumed in the European Union. Small plants use 42% of the total energy consumed for waste water treatment and large plants 58%.

The evaluation also found that, although the directive contains some provisions for wastewater and sludge reuse or the recovery of valuable components, the requirements are unclear and left room for interpretation of the meaning of "whenever appropriate." These provisions have never been strictly enforced partly because of a lack of strong harmonised standards at the EU level and the potential risks to human health.

Water reuse standards have now been addressed in the new water reuse legislation, and sludge use is currently proposed for review as part of the update of the Sewage Sludge Directive.

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[25] *https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32020R0741&from=EN.*

[26] *The sum of both operating and capital expenditures by utilities and industrial water users on water and wastewater.*

[27] *https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32019R1009.*

[28] *https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN.*

[29] *https://ec.europa.eu/environment/water/water-urbanwaste/pdf/UWWTD%20Evaluation%20SWD%20448-701%20web.pdf.*

[30] *The directive requires the collection and treatment of wastewater in all agglomerations of >2000 p.e.*

Following a stakeholder consultation concerning the different options and criteria to be improved as a result of the evaluation, the European Commission is preparing a proposal for a Revision of the Urban Wastewater Treatment Directive that will be published during 2022. The directive revision could include more stringent nutrient removal standards and minimum levels of phosphorus recovery in large wastewater facilities.

Sewage Sludge Directive

The Sewage Sludge Directive[31] was adopted in 1986 to encourage the correct use of sewage sludge in agriculture and to regulate its use to prevent harmful effects on soil, vegetation, animals and humans. The use of sludge in agriculture is an effective alternative for chemical fertilisers, especially phosphorus fertilisers. The European Commission evaluated the sludge directive in 2014, highlighting a number of points which do not fully match the present-day needs and realities. Because recycling materials in line with circular economy principles is a priority under the European Green Deal, the European Commission launched a further evaluation[32] of the sludge directive on 16 June 2020. No results have been published so far.

Fitness Check of the Water Framework Directive, Groundwater Directive, Environmental Quality Standards Directive and the Floods Directive

In October 2017, the European Commission announced that it would perform a fitness check of the EU Water Legislation, which covers four different directives: the Water Framework Directive, the Groundwater Directive, the Environmental Quality Standards Directive, and the Floods Directive. The fitness check was concluded and the findings were published in December 2019[33].

The check concluded that the directives are still relevant and overall fit for purpose, with some room for improvement, such as increasing investments in water management and tackling chemical pollution. Based on the findings, the European Commission in June 2020 confirmed that it does not intend to revise the Water Framework Directive and the focus will be instead on implementing and enforcing it.

As the Water Framework Directive is closely linked to the Urban Wastewater Treatment Directive, the fitness checks for both were carried out in parallel. Despite the overall fitness for purpose of the Water Framework Directive, the European Commission assessed that water reuse was insufficiently promoted by the directive. In addition, the European Commission highlighted a need for harmonising and improving the coherence between the various directives.

[31] *https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31986L0278.*

[32] *https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=PI_COM:Ares(2020)3116544.*

[33] *https://ec.europa.eu/environment/water/fitness_check_of_the_eu_water_legislation/index_en.htm.*

EU Taxonomy for sustainable finance

The EU Taxonomy[34] is a classification system created under the EU Taxonomy Regulation, which establishes a list of environmentally sustainable economic activities. This classification system includes appropriate definitions for economic activities that can be considered environmentally sustainable because they make a substantial contribution to environmental objectives. The taxonomy is prepared by the European Commission, which is advised by the Platform on Sustainable Finance, a permanent expert group that was established to assist the development of sustainable finance policies.

In the first delegated act published in December 2021, the “Anaerobic digestion of sewage sludge” activity is recognised as an activity that may make a substantial contribution to the climate change mitigation objective, since generated biogas is a source of renewable energy. In addition, the report prepared and published[35] in March 2022 includes “Phosphorus recovery from wastewater” and “Production of alternative water resources (wastewater reuse)” as activities that can make a substantial contribution to the circular economy. This eligibility criterion will probably be included in a second delegated act to be completed by the European Commission in late 2022 or early 2023.

EU action plan for zero pollution

On May 2021, the European Commission adopted the EU action plan36: “Towards Zero Pollution for Air, Water and Soil.” The action plan sets out the “zero pollution vision for 2050,” which aims for air, water and soil pollution to be reduced to levels no longer considered harmful to health and natural ecosystems.

The removal of nutrients from wastewater including for reuse is one of the cornerstones of the action plan’s water and soil targets for 2030: (i) improving water quality by reducing waste, plastic litter at sea (by 50%) and microplastics released into the environment (by 30%); and (ii) improving soil quality by reducing nutrient losses and the use of chemical pesticides by 50%.

34 EU taxonomy for sustainable activities | European Commission (europa.eu).

35 Annex to the Platform on Sustainable Finance’s report with recommendations on technical screening criteria for the four remaining environmental objectives of the EU taxonomy | European Commission (europa.eu).

[36] *Zero pollution action plan (europa.eu).*

CHALLENGES AND CONCLUSION

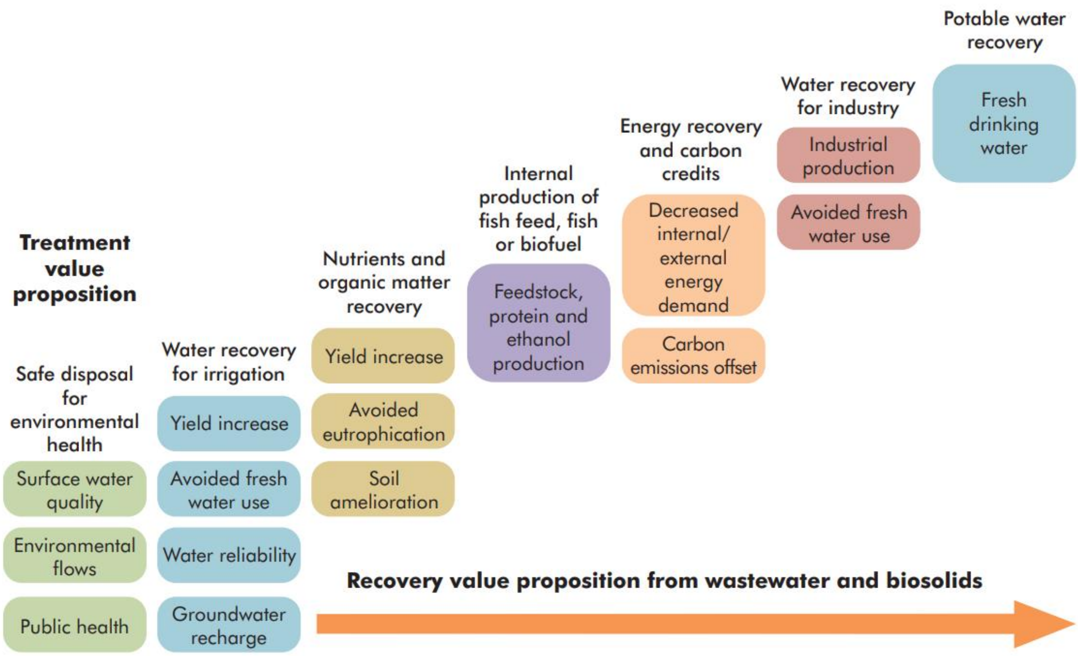
Wastewater value, resource recovery bottlenecks, investment needs

Along with the opportunities, significant barriers stand in the way of an enabling environment for recovering resources from wastewater. These are presented below along with estimates of investment requirements in the water and sanitation sector, in the European Union and globally. Although the investment figures indicated refer to the water sector as a whole, there are significant links between water and wastewater for infrastructure needs and operation.

Wastewater's value

The potential for wastewater exploitation increases with higher levels of treatment, which in turn translates into improvements in water quality and/or the potential to recover additional resources and materials. Recovering products from wastewater provides new opportunities, enhances revenue and moves the business up the economic value proposition ladder as outlined in the figure below. It is important to note, however, that increased value comes with an increased cost of treatment. It is also possible that in the future, stricter regulations on effluent quality will require the elimination of emerging pollutants, making advanced energy-intensive treatment steps necessary anyway.

Figure 8: Ladder of value propositions related to wastewater treatment, based on increasing investments in water quality and/or the reuse value chain[37].



As the figure above illustrates, the most precious resource contained in wastewater is the water itself. Wastewater reuse can provide an important alternative source of fresh water in regions that expect lasting shortages in the future.

[37] *Drechsel, P., Qadir, M. and D. Wichelns, Wastewater: An Economic Asset in an Urbanizing World (2015).*

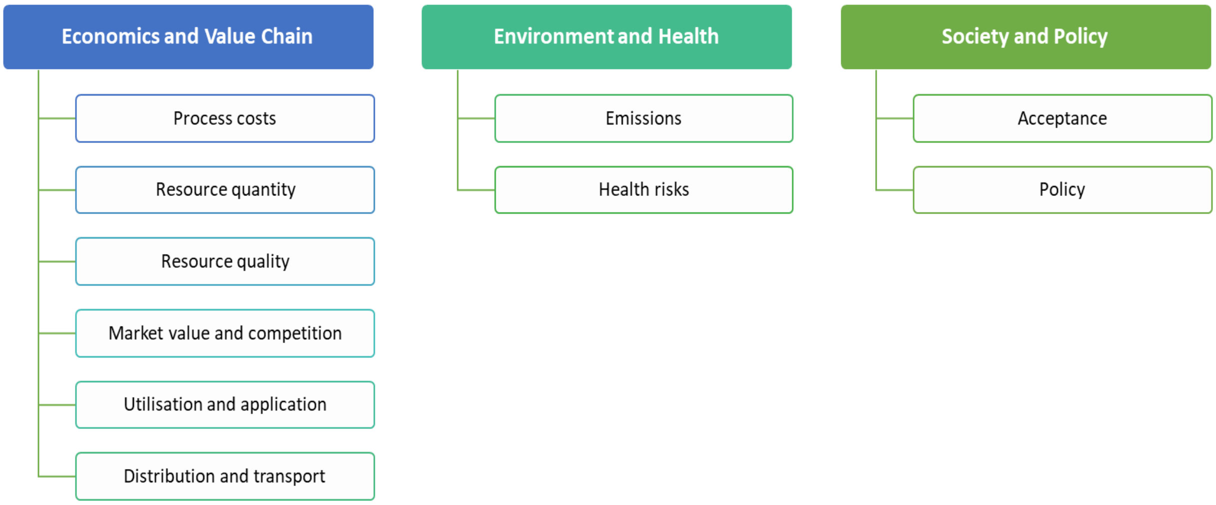
Nevertheless, valuing wastewater means recognising and considering all the diverse benefits and risks associated with it, including economic, social, ecological and security factors as well as cultural and religious dimensions. Defining a price that reflects the true value of resources recovered from wastewater is critical for the long-term sustainable management of water resources. However, calculating the right price is not a simple task.

In the European Union, Article 9 of the Water Framework Directive introduces the principle of cost recovery for water services and obliges EU members to provide adequate incentives for the sustainable use of water resources. In addition, the directive promotes the internalisation of environmental and resource costs that result from existing uses of water resources and aquatic ecosystems.

Bottlenecks to wastewater resource recovery

Although numerous technologies for the recovery of water, energy, fertiliser and other products from wastewater have been explored in the academic arena, few of these have ever been applied on a large scale due to their technical immaturity and/or non-technical bottlenecks. A recent study[38] that involved an extensive review of the scientific literature identified nine bottlenecks that can be grouped into three categories, as shown in the figure below.

Figure 9: Bottlenecks to the successful resource recovery from wastewater



Most of the identified bottlenecks (a detailed list of which is provided in the annex) relate to economics and value chain development. In particular, market potential and competition are the main uncertainties surrounding the successful model for recovering resources from wastewater.

Technological solutions and management models need to be supported by full demonstration, market validation and changes in policy for stakeholders to start perceiving wastewater as a resource that requires management at different levels. However, rather than interpreting bottlenecks as barriers to resource recovery models, they should be seen as starting points for the design of wastewater process and management strategies. Considering bottlenecks in the early planning phase of resource-oriented wastewater treatment processes increases the chance of developing successful recovery strategies. For example, early public involvement and education about a water reuse project is more likely to lead to social acceptance.

[38] *Kehrein P. et al., A critical review of resource recovery from municipal wastewater treatment plants – market supply potentials, technologies and bottlenecks: Environ. Sci.: Water Res. Technol. (2020).*

Investment needs

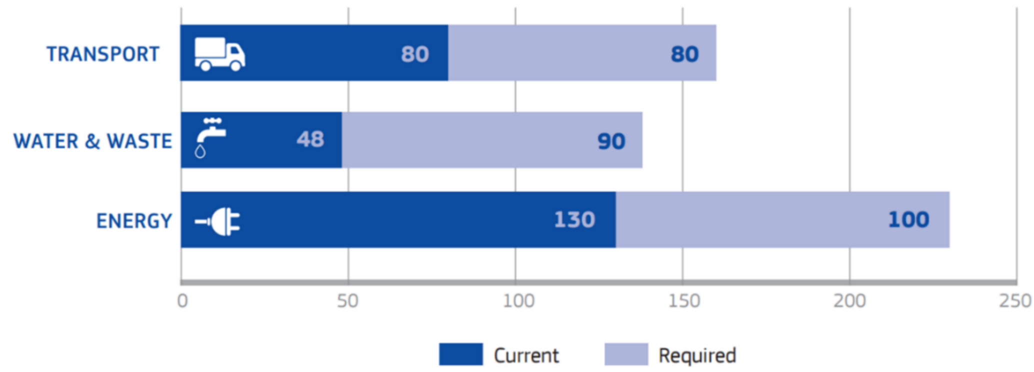
Europe

In the past, investments in wastewater in the European Union were driven mainly by the requirement for compliance with the Urban Wastewater Treatment Directive, although several EU Member States are still failing to comply fully. According to the OECD report on Financing Water Supply, Sanitation and Flood Protection[39], investments across the European Union amounted to an average of €100 billion annually across 28[40] EU members, although there were significant variations among countries, with the lion's share attributable to the EU15 (and Germany, France, the United Kingdom and Italy in particular).

However, the OECD estimates that by 2030, investments will need to increase significantly. Total additional spending of €289 billion is needed for the 28 Member States to comply with the Urban Wastewater Treatment Directive and the drinking water directive. Investment in wastewater represents the lion's share of the additional expenditure, particularly in Italy, Romania and Spain and, at lower levels, in Bulgaria, Croatia, Portugal and Slovakia. The conclusion of the 10th report on the implementation of the Urban Wastewater Treatment Directive, published by the European Commission in September 2020[41], concluded that investments in many EU Member States are too low to achieve and maintain compliance with the Urban Wastewater Treatment Directive, which in the long term will make additional investments necessary. This comes in addition to the warning from the European Environment Agency in 2019 [42] that new pressures — such as adapting to climate change, providing facilities in urban and rural areas, and tackling newly identified pollutants — will all require substantial investment in addition to maintaining existing infrastructure.

The above figures do not, however, take into account Europe's transition to a sustainable economy, which means significant investment across all sectors, including water and sanitation. Reaching the current 2030 climate and energy targets will require additional investments of €260 billion a year by 2030, €90 billion of which should be in the water and waste sectors (Figure 10). The legislation relating to the transition is particularly important, as it can be a key driver in accelerating the recycling and recovery of resources, particularly where additional costs pose a challenge.

Figure 10: Annual investment needs for sustainable development in the European Union (€ billion)



Source: European Commission[43]

39 OECD Studies on Water, Financing Water Supply, Sanitation and Flood Protection: Challenges in EU Member States and Policy Options (2020).

40 At the time of the assessment the United Kingdom was still part of the European Union.

41 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0492.

42 https://www.eea.europa.eu/themes/water/european-waters/water-use-and-environmental-pressures/uwwtd/urban-waste-water-treatment#tab-based-on-indicators.

43 https://ec.europa.eu/info/files/180308-action-plan-sustainable-growth-factsheet_en).

Worldwide

Investments in water and sanitation services and water resource management have historically been financed by the public sector, with concessional finance playing an important role in developing countries. According to the World Bank[44], an estimated $74 billion to $166 billion per year of spending on water, sanitation and hygiene services will be needed over 2015-2030 (0.26 – 0.55% of global GDP) to meet targets 6.1 and 6.2 of SDG 6 on clean water and sanitation[45]. Additional spending will be required to reach the remaining targets under SDG 6, such as wastewater treatment and environmental water quality (SDG 6.3). On the other hand, the annual economic losses due to inadequate water supply and sanitation are estimated at $260 billion.

Projections of global financing needs for water infrastructure range from $6.7 trillion by 2030 to $22.6 trillion by 2050 according to the OECD[46].

The above values, although they do not include the additional investment required to enable resource recovery from wastewater, are an indicator of the potential of the sector. Yet, despite a strong economic case for governments and private stakeholders, financing persistently falls well short of needs.

The COVID-19 impact

The coronavirus pandemic, which exacerbated poverty and food security, has increased the focus on the critical importance of water, sanitation and hygiene in protecting human health. The recovery from the crisis needs to focus on improving the sustainability of these key parameters. Investing in infrastructure that enables the recovery of resources from wastewater can safeguard against future crises and aid long-term sustainable development. According to the United Nation's latest report on progress towards the SDG 6[47], a funding gap of 61% exists between the identified needs to achieve national water, sanitation and hygiene targets, and the available funding. Increasing donor commitments to the water sector remains crucial in sustaining progress towards SDG 6.

Despite the funding gap, however, capital expenditure in the water sector is expected to decline in the short to medium term, according to Global Water Intelligence. New capital projects are likely to be delayed as municipalities prioritise operational spending and the emergency response. However, because automated and remote-control processes useful during the pandemic, their future use may be boosted. Taking the COVID-19 effect into account, Global Water Intelligence estimates global spending on digital solutions to grow 8% annually, on average, from $32 billion in 2019 to $47 billion by 2024.

44 Vorisek, D., and Yu S., Understanding the Cost of Achieving the Sustainable Development Goals, Policy Research Working Paper 9146, World Bank (February 2020).

45 Hutton, G., and M. Varughese., The Costs of Meeting the 2030 Sustainable Development Goal Targets on Drinking Water, Sanitation, and Hygiene. Water and Sanitation Program: Technical Paper, World Bank (2016).

46 OECD Studies on Water, Making Blended Finance Work for Water and Sanitation: Unlocking Commercial Finance for SDG 6 (2019).

47 *https://unstats.un.org/sdgs/report/2020/goal-06/.*

Conclusion

Wastewater treatment plants have the potential to produce valuable water resources, energy and new secondary raw materials, and to exploit the economic value of these for a variety of sectors (municipal, industrial, agriculture).

In a world where demand for fresh water is continuously growing and where the limited water resources available are becoming increasingly stressed by over-abstraction, pollution and climate change, it would be absurd to neglect the opportunities that arise from improved wastewater management. Successfully recovering resources from wastewater contributes to the circular economy and long-term sustainable development.

However, transitioning from removing pollutants to recovering resources requires a paradigm shift. Resource recovery needs to be a strategic goal from the earliest planning stages of new investments wherever possible. Recent developments in EU regulation reflect an increase in support for resource recovery and momentum for change, but a comprehensive approach has yet to be adopted.

ANNEX

Detailed overview of bottlenecks in wastewater resource recovery

A detailed overview of bottlenecks that may hinder the successful implementation of resource recovery in municipal wastewater treatments plants[48] is presented below. Rather than seeing bottlenecks as barriers to water resource recovery, these bottlenecks are merely issues that need to be taken into account during the design of wastewater treatment plant processes and management strategies. Considering these obstacles early in the planning phase increases the chance of developing successful resource recovery strategies.

Category A. Economics and value chain			
Bottleneck	**Description**	**Resource**	**Consideration**
Process costs	A resource recovery process is not cost-effective due to excessive operational or investment costs	Water	High energy demand of membrane technologies. Per m^3 water reclaimed by secondary effluent treatment with ultrafiltration and reverse osmosis, a cost of 46 euro cents and a benefit of 25 euro cents have been calculated. Very location-specific however.
			Fouling is an additional cost factor for membrane technologies. Costs vary greatly and depend on membrane characteristics, operating conditions, feed water quality and applied cleaning techniques.
			Disposal costs of membrane retentate depend on the level of treatment, retentate characteristics and the disposal method.
			Advanced oxidation processes are energy intensive and require expensive reagents.
		Energy	Microbial fuel cells: expensive equipment and operation.
			Ammonia recovery for fuel is not cost-effective because energy costs of removing ammonia often exceed the energy and value of the recovered gas.
		Fertiliser	Phosphorus recovery costs exceed conventional phosphorus ore costs. Assuming a load of 660 g of phosphorus per capita per year, recovery costs would be €3 600 to €8 800 per tonne of recovered phosphorus under German market conditions.
			Struvite[49] recovery processes may not be cost-effective which depends strongly on profits from struvite sales. Market prices vary greatly and have been estimated for Australia to fall between €180 to €330 per tonne.
			No cost-effective processes for recovering phosphorus from iron phosphide have yet been developed.
			Phosphorus recovery from sludge incineration ash requires specialised and expensive incinerators.

48 Kehrein P. et al., A critical review of resource recovery from municipal wastewater treatment plants – market supply potentials, technologies and bottlenecks: Environ. Sci.: Water Res. Technol. (2020).

49 Struvite (magnesium ammonium phosphate) is a phosphate mineral that is used as a fertiliser and is an alternative source of rock phosphate to maintain the agricultural production system.

Category A. Economics and value chain			
Bottleneck	**Description**	**Resource**	**Consideration**
		Other products	Recovery processes of polyhydroxyalkanoates can be more costly than conventional production routes. Recovery costs depend greatly on applied downstream processes and may range from €1.4 to €1.95 per kilogram. Carbon recovery from biogas is economically feasible only if a biogas upgrading unit is already present. Payback times for recovery equipment may vary between 1–12 years. Bioelectrochemical systems may require expensive electrodes (such as platinum cathodes). Microbial electrolysis cells using $CO_2$for chemical production require extra energy input depending on the electron donor used. The potential of municipal wastewater as electron donor is not quantified yet.
Resource quantity	Compared with conventional production systems, only small quantities of a resource can be recovered at a wastewater treatment plant. This may be due to low process yields, low resource concentrations or low overall resource quantities in the wastewater stream	Energy	Combined heat and power units for recovered CH_4 have high conversion losses of ca. 60%. Chemical oxygen demand may be too diluted for effective direct anaerobic digestion of wastewater. 750 mg COD per litre is a medium concentration for municipal wastewater treatment plant influents. Dark fermentation of sludge shows very low H_2 yields of ca. 17%.
		Fertiliser	Nutrient quantities recoverable from wastewater are low compared with industrial production rates. For example, in Flanders (Belgium) yearly mined phosphorus imports amount to 44 100 tonnes while combined wastewater treatment plant influent-phosphorus only amounts to 3 350 tonnes. Struvite: low phosphorus concentrations limit precipitation which requires at least 100 mg P/l. Struvite: only soluble phosphorus fraction of side streams is recovered. Low nitrogen concentrations of only 30 mg/l NH4-N in average Dutch wastewater may make NH4 recovery uneconomical.
		Other products	Volatile fatty acid concentration in wastewater and fermenter effluent may be too low for economical extraction. Optimisation by economies of scale is limited due to low resource quantities in wastewater.
Resource quality		Fertiliser	The quality of a recovered resource is not high enough to market easily. This may be due to contaminants or impurities in the resource. Possible contamination of struvite.
		Other products	Recovered biochemicals often lack the purity demanded by chemical industries. Controlling the product spectrum in open-culture volatile fatty acid fermentation is a challenge and depends on pH, temperature, dilution rate, types of carbohydrates present and feeding patterns.

Category A. Economics and value chain			
Bottleneck	**Description**	**Resource**	**Consideration**
			Uncertainty about whether mixed culture derived polyhydroxyalkanoates from municipal wastewater can deliver reliable quality remains to be resolved although pioneer pilot testing has been conducted with promising results.
Market value and competition	Conventional production systems potentially outcompete resource recovery and reuse. This may be due to various factors, including higher product quality and quantities and lower production costs	Energy	CH_4 has a low market value (EU-28 average 2019: €0.046/kWh for household consumers). Electricity has a low market value (EU-28 average 2019: €0.22/kWh for household consumers).
		Fertiliser	Bulk nutrients from the fertiliser industry are available cheaply (phosphate rock: $110/tonne in 2014). In livestock intensive regions, phosphorus-rich manure is often abundantly available as an alternative fertiliser. The market value of struvite is hard to estimate due to farmers' lack of knowledge and trust about its fertilising potential.
		Other products	Petrol-based plastics may outcompete bioplastics and the latter are produced more economically from pure microbial cultures using sugar as feedstock instead from mixed microbial cultures applied to wastewater. Finding real advantages of recovered biochemicals over fuel- or sugar-based alternatives to justify higher price of biodegradable/bio-based plastics compared to conventional plastics ($2.5/kg compared to $1.5/kg in 2014).
Utilisation and applications	The usefulness of recovered resources might be unknown. New market niches, applications and partners have to be found to make resource recovery and reuse successful	Other products	Identifying niche markets (local or otherwise) and applications with unique selling propositions to increase competitiveness. Developing public-private partnerships to market products can be a challenge. New product utilisation routes for polyhydroxyalkanoates have to be found.
Logistics	If recovered resources are not used on site, distribution and transport have to be organised. This may be challenging due to geographical and temporal discrepancies between supply and demand, lack of infrastructure, or cost	Water	Temporal and geographical discrepancies between supply of and demand for water must be considered. Topographical location of the wastewater treatment plant might require uphill pumping of reclaimed water. A 100 metre vertical lift is as costly as a 100 km horizontal transport ($0.05-0.06/m^3 in 2005). Possible need for new pipeline infrastructure for reclaimed water.
		Energy	Temporal and geographical discrepancies between supply of and demand for thermal energy need to be balanced out. Costs of pressurising and transporting CH_4 if no connection to the natural-gas grid is present.
		Fertiliser	In-field sludge application: transport between wastewater treatment plants and arable land might be too costly due to high water content.

Category B. Environment and health			
Bottleneck	**Description**	**Resource**	**Issue**
Emissions and health risk	The use of recovered resources or the recovery process may entail risks to human health due to contaminants, or may cause emissions and environmental problems. This may be due to insufficient process control	Water	Potable water reuse has been evaluated as too great a health risk (by Amsterdam water board). Incomplete removal of chemicals or pathogens during treatment may cause disease. Chemical biocides used in tertiary treatment can generate harmful by-products. Plant or soil contamination as consequence of wastewater reuse for irrigation.
		Energy	Unheated anaerobic digesters may promote emissions of solubilised CH_4.
		Fertiliser	Struvite may be contaminated with emerging pollutants and heavy metals. Biomass of polyhydroxyalkanoates may accumulate contaminants if sludge is applied to agricultural land.
Category C. Society and policy			
Bottleneck	**Description**	**Resource**	**Issue**
Acceptance	User acceptance of resources recovered from wastewater may be low due to fears or misconceptions about the risks they pose	Water	Water reuse projects can rarely be implemented without social acceptance. Direct potable water reuse raises psychological barriers.
		Other products	Toilet-paper production from recovered cellulose may not be accepted by consumers. Single-cell protein: negative perception of faecal matter as source for feed/food production.
Policy	To be successful, resource recovery and reuse needs adequate policy and legal frameworks. A lack of legislation, political will or economic incentives may hinder successful implementation	Water	Government incentives are needed to make water reuse financially attractive (in China). A lack of common regulations is a barrier to water reuse (in southern Europe). Lack of political will to implement legislation and policies for water reuse.
		Energy	Anaerobic digestion needs to be subsidised to become competitive with natural gas.
		Fertiliser	Lack of legislation on in-field struvite application.
		Other products	Legislation forbids the use of protein produced from faecal substrate (in Europe).

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