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Beyond water quality — Sewage treatment in a circular economy

European Environment Agency

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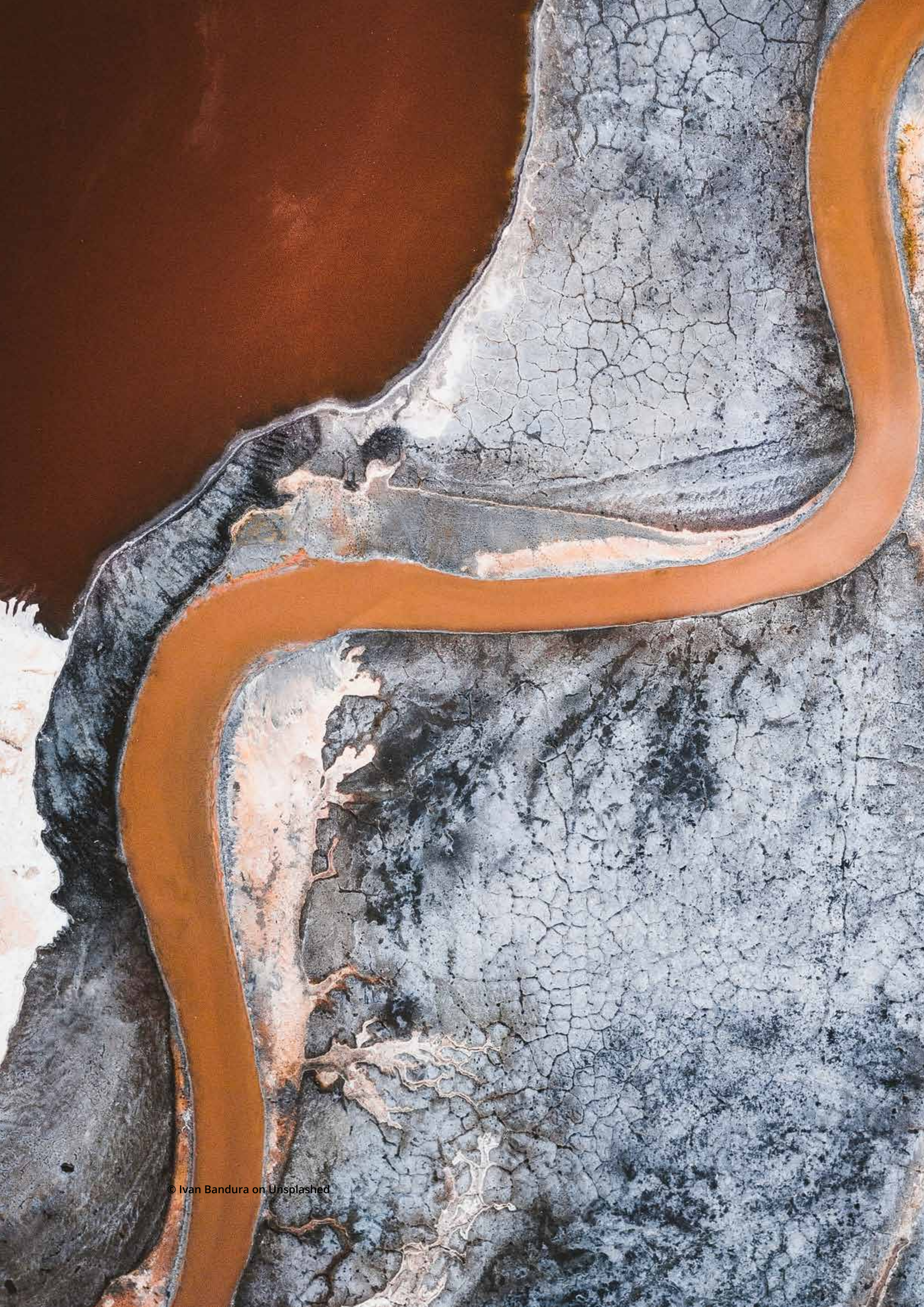

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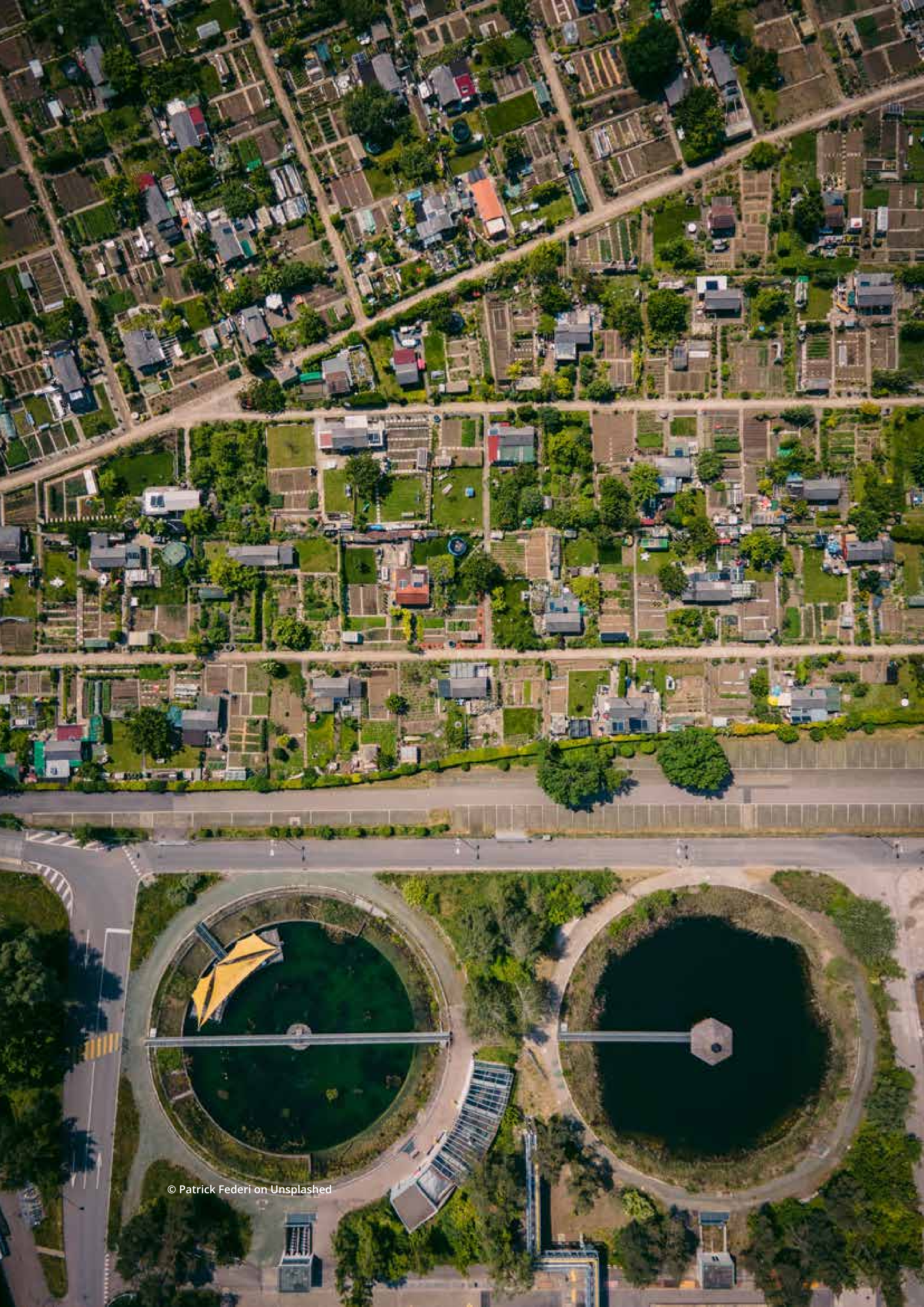

Key messages

- Treatment to clean up our sewage is essential to protect human health and the environment, with urban waste water treatment key to improvements in the quality of Europe's waters in recent decades.

- Treatment of sewage is not 'one size fits all'. Local conditions call for local solutions. Financial resources, the availability of land, population density, nature of the receiving water and types of industrial activity all influence the options available. Ensuring flexible approaches to meet necessary quality standards can enable innovation and locally-appropriate solutions.

- For all of us, a first step is to become more water-efficient, as this reduces the total amount of water required to be abstracted from the environment, pumped and treated.

- Urban waste water treatment has focused on cleaning water to return it to the environment — a linear approach. Yet there is significant potential to become more resource efficient and much more circular, as is being demonstrated through innovation for water utilities in some countries to meet climate neutral targets for operations by 2030.

- Nevertheless, urban waste water treatment remains energy intensive, and greenhouse gases can be emitted at many stages, embedded in infrastructure like sewers or released during waste water and sludge treatment.

- Urban waste water treatment plants (UWWTPs) can act as 'resource hubs' integral to resource recovery, rather than just a form of waste management. Reclaimed water, energy, nutrients and organic materials all have proven potential for reuse, recycling and recovery.

- Economic incentives for recycling and more favourable legislative frameworks are needed to scale up circular approaches to urban waste water treatment, enabling recovered resources to enter the market, while legal barriers limiting the use of such resources — for example treated sewage sludge — should be revisited.

- A major barrier to achieving circularity lies in the persistent pollutants that can be discharged to or run off into urban waste water, which then need to be removed and which may contaminate sewage sludge. Upstream measures are needed to keep these out of waste water, through restrictions, controls at source, and development of more sustainable alternatives to the harmful substances currently in use.

- While large UWWTPs can deliver considerable efficiencies of scale, effective sewage treatment can also be achieved through local, decentralised facilities, ranging in scale from individual buildings up to small towns. Technologies such as separated waste water systems enable sewage to be safely treated while recovering both energy and nutrients. Waste water from washing and cooking can be reused for applications where lower quality water will suffice, such as irrigation of parks and gardens.

- Achieving the transition to sewage treatment and a circular economy requires change not only in regulatory and institutional approaches, but also in how we as citizens appreciate our individual and collective responsibilities towards sewage management. Nature-based solutions, which provide benefits such as green space and flood alleviation — for example reed beds — can generate local support.

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Executive summary

The European Green Deal sets out an ambitious agenda 'to transform the EU into a fair and prosperous society, with a resource-efficient and competitive economy where there are no net emissions of greenhouse gases' (EC, 2019a).

Sewage treatment is an essential service that can deliver clean water, nutrients and organic fertiliser (Figure ES1). It can and should contribute to delivering the broad goals of the Green Deal, with a key role in supporting the ambition to achieve zero pollution. Reviews and evaluations of key parts of European legislation, such as the Urban Waste Water Treatment and the Sewage Sludge Directives, present the opportunity to modernise and improve coherency across the sector. While recognising the broad scope of sewage treatment, it must be appreciated that the primary priority is to protect human health and the environment from the harm caused by insufficiently-treated sewage.

This report focuses on water management, but action is needed in other sectors to support this area in achieving the ambitions of the Green Deal. In particular, planning legislation should enable innovative sewage treatment, while upstream efforts on water efficiency and pollution control must minimise both the volume of water to be treated and the level of contamination. Innovation is needed not only in technical approaches but also at cultural levels, for example in allowing citizens to take part in local decisions on approaches to water and sewage management.

Together with other parts of the economy, the water sector has significant potential to become more resource efficient and much more circular than at present. As well as water, energy, nutrients and organic materials all have proven potential for reuse, recycling and recovery.

EU water legislation has focused on the water cycle, improving water quality and aiming to restore biodiversity. It has little influence on reducing water use, either in abstraction from the environment or in the water efficiency of networks and products. It controls what can be discharged back into water and on to land, but the list of controlled substances is small compared with the range now used and produced, and it does not include greenhouse gases. The 1991 Urban Waste Water Treatment Directive (UWWTD) has improved water quality in Europe, but urban waste water treatment plants (UWWTPs) still represent the major point source of pollutants of Europe's waters (EEA, 2018a; EC, 2019b).

Compliance with the UWWTD requires the building of collection and treatment facilities, usually involving the use of energy-intensive materials such as concrete and steel, and is energy-intensive in operations. However, the UWWTD does not consider greenhouse gas emissions of methane and nitrous oxides, nor resource recovery. We need to review the sustainability of such approaches and move to more resource efficient and circular practice.

Solutions for sewage and urban waste water treatment are necessarily local and need to take into account the local situation. An optimal approach for a densely populated city is unlikely to apply to a low-density, rural population. Focusing on the desired outcome could provide flexibility in finding local solutions.

Water managers have already identified ways to become more energy efficient and reduce operational greenhouse gas emissions. Some UWWTPs generate more energy than they use, through biogas generation and waste water heat recovery. Some towns, operators and even countries have ambitious plans for 'net zero' greenhouse gas emissions from the water sector, intensively reviewing their infrastructure and operations.

Alternative approaches to energy-intensive treatment include the effective control of pollution at source and decentralised approaches that treat and dispose of relatively small volumes of waste water. Furthermore, nature-based solutions such as constructed wetlands and reedbeds can provide flood resilience and green space for citizens in a cost-effective manner.

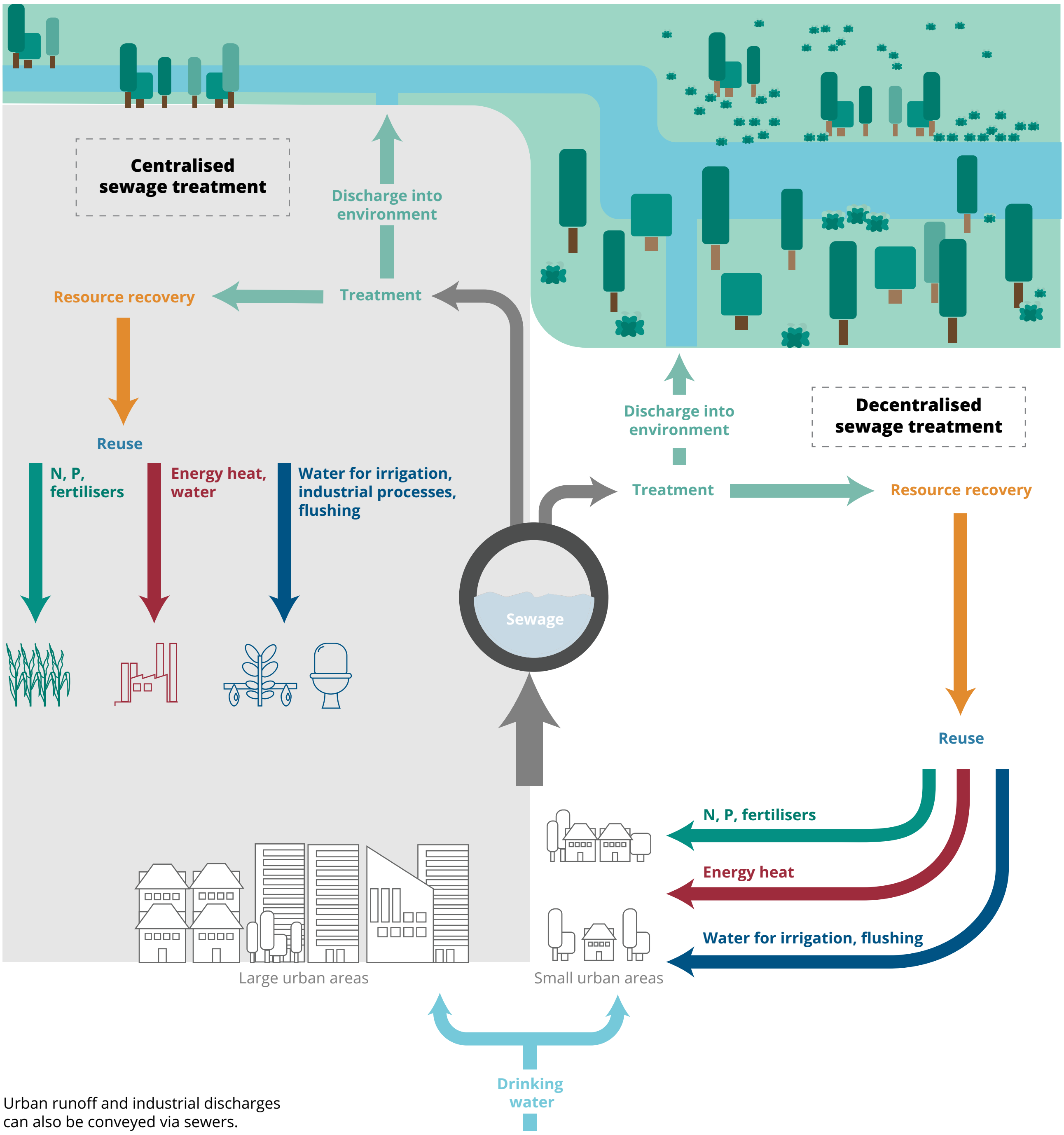
UWWTPs should be more widely recognised as 'resource hubs', integral to resource recovery, rather than 'waste management'. While technical solutions exist, recovered nutrients and other materials from waste water and sludge struggle to compete with mineral fertilisers and other materials on the market. Therefore, both economic incentives for recycling and more favourable legislative frameworks are needed to scale up such circular approaches, enabling recovered resources to enter the market. Legal barriers limiting the use of recovered resources should be revisited, and economic tools to support circularity need to be provided.

A significant barrier to realising circularity in sewage treatment is the presence of harmful chemical pollutants in waste water, coming from hazardous substances in household consumer products, urban run-off and industries connected to UWWTPs. These need advanced treatment to remove them from the water, which may lead to persistent pollutants ending up in sewage sludge. The presence of such persistent pollutants can make the sludge unsuitable for recycling on land. Breaking this cycle over the longer term requires the successful implementation of the Green

Deal 'chemicals strategy for sustainability', and more effective measures to control run-off so that harmful pollutants are no longer present in urban waste water. In the near term, efforts to stop such pollutants entering waste water can drive change upstream, as discharges to the sewerage network are reviewed for their impact on water and sewage sludge quality.

Achieving a circular economy in sewage treatment requires multiple stakeholders to participate, both in contributing solutions and in accepting change. At the infrastructure level of UWWTPs, towns and industry sectors, transition to more sustainable approaches may take time to become widespread, but already innovative towns, cities and utilities are finding solutions (see case studies in chapters 3 and 4). Recognition that as citizens we all have a responsibility for, and can contribute to, a circular economy in sewage management through minimising the discharge of harmful substances 'down the drain', is key to reducing the need for removal of harmful substances from water and enabling reuse of sludge. As essentially renewable resources, sewage and 'waste water' present a prime opportunity to demonstrate the systemic goals of the Green Deal.

Figure ES1 Implementing circularity in sewage treatment



Urban runoff and industrial discharges can also be conveyed via sewers.

1
Introduction — preventing water pollution

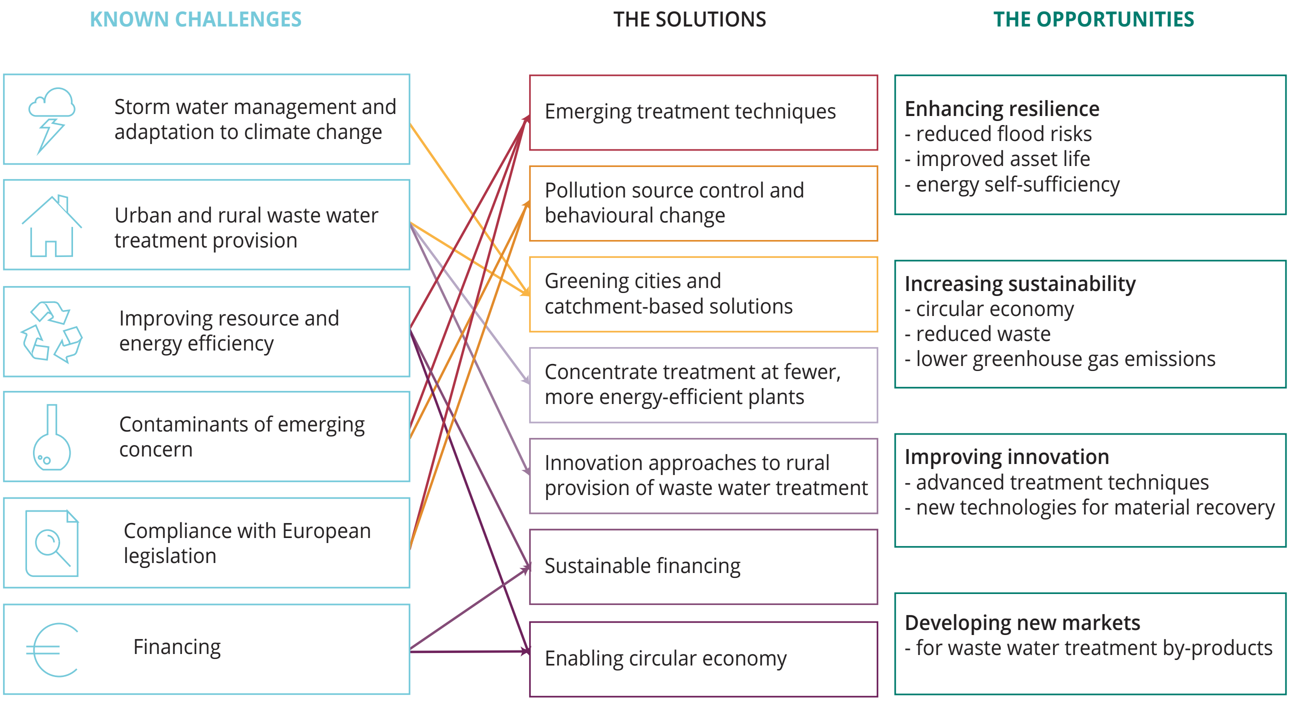
1.1 Aim of the report

Treatment of sewage and urban waste water is essential for the health of both humans and the environment. Originally undertaken to prevent disease through contamination of drinking water supplies, recognition of the potentially harmful role nutrients had on the environment led to the Urban Waste Water Treatment Directive (UWWTD) in 1991 (EEC, 1991).

In recent years, we have become more aware of the many other pollutants in waste water, which are not targeted by the UWWTD. The overarching perspective of the European Green Deal and the Eighth Environmental Action Programme (EC, 2022) also better recognise the broader role that waste water treatment can provide in helping to mitigate climate change. Rather than 'waste', we should consider the treated water and sewage sludge as resources to be reused and recycled in a circular economy. Cleaner water provides more natural habitats than polluted water, benefiting biodiversity. Investment in preventing pollution, including upstream measures such as avoiding the use of harmful chemicals, is key to delivering sustainability.

Figure 1.1 summarises the challenges that urban waste water treatment is facing, together with some of the solutions and opportunities that water managers can and are implementing. From climate and demographic change to compliance and investment, solutions are needed at scales ranging from individual households to cities with millions of inhabitants.

Figure 1.1 Challenges, solutions and opportunities for urban waste water treatment plants



Source: EEA (2019a).

However, if we constrain efforts to those challenges that can be met by water managers alone, we cannot achieve the ambitions of the Green Deal. Planning legislation needs to permit decentralised solutions for and innovation in sewage treatment. Markets need incentivising to enable the viable recovery of resources, such as phosphorus, while the use of hazardous substances in processes and products must be reduced to minimise their ultimate discharge. Citizens should be given more opportunity to contribute to water and sewage management, with consideration given to solutions that offer multiple benefits such as improving biodiversity, recreational space and flood resilience.

This report sets out considerations for sewage treatment to meet the ambitions of the European Green Deal for 2050, focusing on the opportunities to achieve zero pollution and circularity.

1.2 Scope of the report

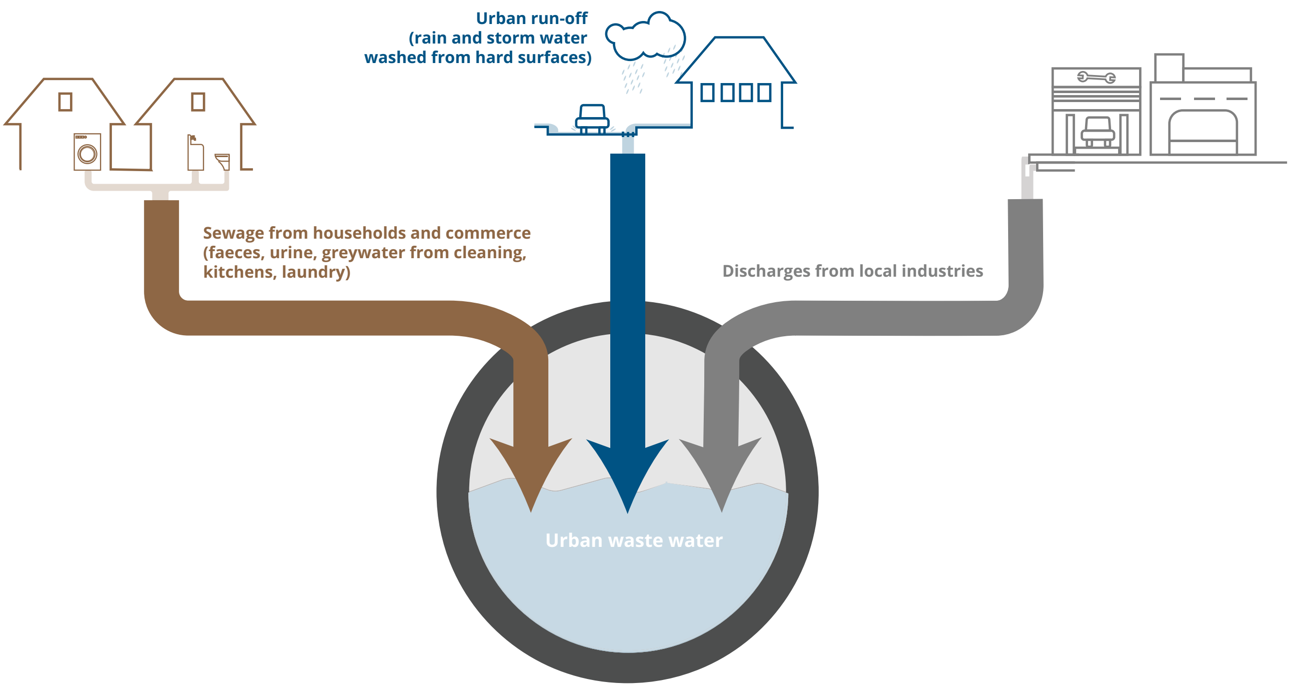
This study focuses on sewage, that is urine, faeces and the dirty ('grey') water we send down sinks, drains and sewers.

The combination of sewage, urban run-off from roads and hard surfaces and industrial waste water is termed 'urban waste water' (Figure 1.2). Left untreated, this waste water pollutes rivers, lakes, groundwater and seas, while potential resources are lost. The treatment required to minimise pollution of water, however, can lead to the production of greenhouse gases and contaminated sludges, which can go on to pollute air, soils and water.

For the 11% of Europeans whose dwellings are not connected to waste water treatment plants (Eurostat, 2019), individual treatment such as septic tanks or package plants are necessary. These too can pollute air and water.

However, it does not have to be this way. By applying a systemic approach to sewage and waste water, Europe can move to a virtuous circle, minimising pollution and using the renewable resources provided by sewage and its treatment. Delivering this will need a range of approaches, including technology, investment in infrastructure, nature-based solutions, changes in legislation and cultural acceptance.

Figure 1.2 Composition of urban waste water



Source: EEA, 2022.

In the broader context of integrated water management and waste management, the first preference is to reduce resource use where possible (Smol et al., 2020; EEA, 2021a). Efficient use of water reduces both the demand on the environment and the amount of waste water to be treated. Smol et al. (2020) elaborate on the EU waste hierarchy (EU, 2008) in the waste water context:

- **reduce** — prevent waste water generation by reducing water use and pollution at source;
- **reclaim** (**remove**) — use technologies to remove pollutants from water and waste water;
- **reuse** — use waste water as an alternative source of water for non-potable use;
- **recycle** — recovery of water from waste water for potable use and sewage sludge for application to land;
- **recover** — resource recovery, e.g. nutrients and energy from water-based waste;
- **rethink**— use resources to create a sustainable economy, 'free' of waste and emissions.

Here, we focus on the prevention of pollution types other than sewage that contaminates water discharged from our homes, and on the resources used in treating water so that it can be safely reused.

The economic aspects of water supply and treatment are very significant. Other related reports perform detailed analysis of costs and benefits, while this assessment provides a narrative of the topic in its broad application (EC, 2019b; OECD, 2020; EC, forthcoming).

With the ambition of the European Green Deal coinciding with the revision of water legislation, there is now an opportunity to reset our approach to the treatment of waste water and set Europe on track for sustainable waste water treatment by 2050.

1.2.1 Structure of the report

Chapter 1 sets out existing policies and relevant legislation. Chapter 2 focuses on the treatment of waste water and pollution, considering the reduction and removal of pollutants. Chapter 3 considers sustainable urban waste water treatment and sludge management, namely water reuse and recycling, and resource recovery. Chapter 4 rethinks our current approach to treatment and how we can deliver more sustainable sewage treatment.

1.3 Sewage management — policies and ambitions

1.3.1 Historical context

Recognition of the link between disease and sewage in the 19th century led to the development of sewerage networks in cities around Europe. Treatment facilities were gradually developed, although even as late as the 1990s and 2000s some European cities were still discharging untreated sewage to their waters (EC, 2002, 2011). Understanding of the association between healthy waters for humans and the environment increased from the 1970s, with the first European Community environment action programme setting out to 'prevent, reduce and as far as possible eliminate pollution and nuisances; maintain a satisfactory ecological balance and ensure the protection of the biosphere; ensure the sound management of and avoid any exploitation of resources or of nature which cause significant damage to the ecological balance' (EEC, 1973). Legislation to protect drinking water (EEC, 1975a) and bathing water (EEC, 1976) and other water pollution prevention measures followed.

Recognising the harm caused by excessive nutrients in sewage discharged to surface waters, the UWWTD (EEC, 1991) was adopted in 1991 with the objective of protecting the environment from the adverse effects of the treatment and discharge of urban waste water and from certain industrial sectors. This directive set requirements for minimum levels of treatment for urban areas (so-called 'agglomerations') of 2,000 population equivalents (p.e.) ([1]) and above. More demanding levels of treatment were required for larger populations and where the discharge was into sensitive waters.

1.3.2 Current policies and ambitions

The European Green Deal (EC, 2019a) sets out an ambition to reset the Commission's commitment to tackling climate- and environment-related challenges. It also aims to protect, conserve and enhance the EU's natural capital, and to protect the health and well-being of citizens from environment-related risks and impacts. Alongside this strategic direction for Europe, the Eighth Environment Action Programme (EC, 2022a) aims at 'accelerating the transition to a climate-neutral, resource efficient, clean and circular economy in a just and inclusive way'. Living well, within the limits of our planet, requires in Europe a fundamental reappraisal of how we use and recycle resources. This sets a bold context

([1]) Population equivalent is a unit used to measure the amount of sewage. A population equivalent of 1 expresses the amount of sewage generated by one person per day and it corresponds to the organic biodegradable load having a 5-day biochemical oxygen demand (BOD5) of 60g of oxygen.

for waste water treatment, where the opportunity to move to a circular economy exists in tandem with reducing pollution.

Looking at the Green Deal, the zero pollution ambition is to reduce pollution 'to levels no longer considered harmful to health and natural ecosystems' and which respect planetary boundaries (EC, 2021a). Waste water treatment has a key role to play here, representing the last chance to prevent pollutants in urban waste water reaching the aquatic environment; however, the focus on minimising pollutants in the effluent has, until recently, not considered the gaseous and solid waste emissions to a similar degree. Greenhouse gases can be released during treatment, energy used in pumping water is significant, while sewage sludge can contain the substances 'cleaned' from the water. The Sewage Sludge Directive is currently being evaluated. It currently contains limits only on metals (EEC, 1986); however, there are concerns that the limits are set too high and other pollutants are not considered (Anderson et al., 2021). Reflecting the pressures on water availability already affecting some Member States, the Water Reuse Regulation (EU, 2020a) sets standards for treated waste water to be used for irrigation, such as on chemical and microbiological contamination levels. An integrated nutrient management plan is being developed under the circular economy action plan to use nutrients more sustainably and stimulate markets for recovered nutrients (EC, 2020a).

In recent decades, it has been increasingly understood that the development of many more chemicals and products has led to many thousands of chemicals potentially being released to the environment. We have little knowledge of the behaviour and fate of many of these, yet the risk posed by some could be high. Alongside this, there is a crisis in biodiversity driven by factors such as changes in land and sea use, over-exploitation, climate change, pollution, and invasive species (EC, 2020b). Ensuring that we limit pollution from sewage and waste water is essential, but this is an 'end-of-pipe' solution. It is very complex to identify the origin of pollutants in sewage and to try and exclude them from product chains (Anderson et al., 2021). While chemical source control legislation such as REACH (Regulation on Registration, Evaluation, Authorisation and Restriction of Chemicals) aims to protect human health and the environment (EU, 2006a), a more fundamental review of the chemicals and products we use in our homes and workplaces is needed. The chemicals strategy for sustainability sets out the ambition towards a toxin-free environment, with the aim that chemicals are made safe and sustainable by design, and will be produced and used in a way that maximises their contribution to society, while avoiding harm (EC, 2020c).

The overarching Water Framework Directive (WFD) (EU, 2000) provides a framework for the management of Europe's waters. In surface waters, the WFD considers both chemical and ecological status, with the objective that all water bodies should be of good status. Nutrient pollution caused by insufficiently treated waste water is a pressure on the natural ecosystem, most immediately affecting the ecological status. Chemical pollution, with toxic, bioaccumulative and persistent substances, can be recorded under chemical status (if the substance is listed under the Environmental Quality Standards Directive (EU, 2008, 2013). Other substances in excessive amounts can lead to failure of ecological status if they are regarded as 'specific pollutants' at the river basin level. For these reasons, the UWWTD is a basic measure under the WFD, as failure to fully implement the UWWTD is likely to lead to failure to achieve good status requirements under the WFD.

An additional driver for the implementation of the UWWTD in some areas has been the Bathing Water Directive (EEC, 1976; EU, 2006b). With its focus on human health, the need to reduce faecal contamination of bathing waters has driven high standards of waste water treatment, such as disinfection where beach tourism is a significant industry. Protection of drinking waters from microbiological, chemical and physical contamination has a long history in the EU, with the 1975 Drinking Water Directive being recast in 2020 to reflect more recent understanding about contaminants (EEC, 1975b; EU 2020b).

United Nations Sustainable Development Goal 6 is to ensure the availability and sustainable management of water and sanitation for all (UN, n.d.). While much of the EU considers implementation of more advanced waste water treatment, we should not overlook those who still lack access to sanitation (e.g. Filčák et al., 2018; Heidegger and Wiese, 2020). In 2021, the World Health Organization estimated that there were over 30 million people in this position in the European region: significant inequalities persist between rural and urban areas, and between rich and poor people, with rural dwellers and the poorest being the most disadvantaged (WHO, 2021a).

In line with the precautionary principle towards the environment, set out in the Treaty on the Functioning of the EU, A.191 (EU, 1992), much of the EU policy on chemicals takes a 'source control' approach, which aims to prevent pollution, while the WFD provides a mechanism to monitor the most harmful substances present in water. Thus, the 2006 REACH Regulation aims to improve the protection of human health and the environment through better and earlier identification of the intrinsic properties of chemical substances (EU, 2006a). Meanwhile, the Industrial Emissions Directive (IED) targets discharges from industrial installations, while the European Pollutant Release and Transfer Register (E-PRTR) requires operators to record pollutant emissions above certain thresholds (EU, 2010; EU, 2006c). E-PRTR reporting allows the identification of major sources, with thresholds aiming to address 90% of pollutants released by a sector. The IED and E-PRTR Regulation are currently under revision, with the proposals tightening permit controls on emissions to air and water, and consideration being given to the reporting of the use of energy and resources and of water use. (EC, 2022a,b). The E-PRTR requires urban waste water treatment plants to report when they are over a threshold of 100 000 p.e., which is considered as a rather high threshold, owing to a significant proportion of pollutants being missed as they are released by smaller treatment plants (ETC/ICM, 2017; ICF Consulting Services, 2020).

2
Urban waste water treatment, health and pollution

2.1 Introduction

The primary reason for treating sewage is to protect human health and the environment. Lack of sanitation pollutes drinking water and leads to disease in humans. In 1991, the Urban Waste Water Treatment Directive (UWWTD) focused on organic and nutrient pollution (primarily nitrogen and phosphorus) in efforts to reduce oxygen depletion and the eutrophication of Europe's rivers, lakes and seas. Together with legislation to restrict pollution from industry, this action has been effective in seeing life return to 'dead rivers'.

In Europe, most sewage enters sewers to be conveyed to a waste water treatment plant where it is treated to reduce the pollutant load. The effluent is then discharged to the environment, typically rivers, lakes and coastal zones. In less densely populated areas, or those where investment in infrastructure is lacking, individual solutions need to be found for sewage, such as package plants, nature-based solutions (e.g. reed beds) and infiltration of different kinds (e.g. from septic tanks). The construction, maintenance and operation of waste water collection and treatment comes at high financial and greenhouse gas emission costs. Furthermore, biological and chemical sludges arising from the treatment process must be regularly removed from the plant and treated.

Nowadays, we know that there are many more pollutants in sewage than were recognised in 1991. We have limited understanding of the risks to aquatic life presented by mixtures of chemicals in surface waters, and many of these chemicals have come from products used in our own homes ([2]). We also know that in the future there are likely to be risks of which we are not necessarily yet aware. Moreover, the coronavirus pandemic has reminded us of the value of waste water as a way to monitor disease in the community (EC, n.d.).

When source control of pollution fails, the treatment of urban waste water presents the last chance to protect the environment from the pollutants it contains, and it is 'end-of-pipe' control. Treatment to clean the water can transfer pollutants to the atmosphere, to sewage sludge and treatment sludges, potentially requiring management of solid waste.

While we may think of urban waste water treatment plants (UWWTPs) as being 'sources of pollution', it must be remembered that the pollution is not derived from the plant itself: rather, it arises from the many sources in the sewerage network — homes, industry, schools, etc.— which are collected at the plant.

The enormous effort to reduce sewage pollution, underpinned by the UWWTD and supported by other EU and national legislation and EU funding, has led to a significant improvement in the quality of Europe's surface waters in recent decades. Such efforts cannot stand still: the additional cost of achieving and maintaining compliance with the UWWTD has been estimated at EUR 253 billion between 2019 and 2030 (EC, 2019b). Without tackling the root causes of harmful pollutants, doing 'more of the same' will not be a sustainable way of managing an essentially renewable resource.

2.2 Sewage and urban waste water treatment

'Show me your waste water and I will tell you who you are.' Composition of waste water reflects all human activities, life style, materials used in homes. It provides information on the use of medicines and personal care products, and on environmental behaviour' (Henze et al., 2008).

2.2.1 What's in sewage and urban waste water?

Sewage is mainly water (UN, 2017). It includes excreted human waste, as well as 'grey' water drained from kitchens, bathrooms and laundry. Together with run-off and industrial discharges, urban waste water contains a range of organic and inorganic substances, and dissolved and suspended solids (Table 2.1). Large volumes of urban waste water are generated every day.

([2]) For example, polyfluorinated alkyl substances (PFASs), pharmaceuticals, antibacterial silver, mercury from our amalgam fillings.

Table 2.1 Typical constituents of sewage and urban waste water

Substance	Examples	Source	Impact
Microorganisms	Pathogenic bacteria, viruses, worms and their eggs, protozoa	Faeces	Human health risks when bathing, eating shellfish
Biodegradable, organic materials	Carbohydrates, starch, volatile fatty acids, proteins, cellulose	Faeces, food	Oxygen depletion in rivers and lakes causing deaths of fish and other aquatic life forms , odour
Other organic materials	Fats and oils, solvents, phenols, surfactants, detergents	Kitchen and domestic waste, industry	Toxicity, bioaccumulation
Nutrients	Nitrogen, phosphorus, ammonium	Urine and faeces, food	Eutrophication, oxygen depletion, toxicity
Micropollutants	Medicines, food additives, phthalates, biocides, flame retardants, PFASs, pesticides, plastics, etc.	Urine and faeces, food, human activities, industry	Toxicity, bioaccumulation, sublethal effects, e.g. on growth and reproduction. Contamination of drinking water resources
Metals	Zinc, copper, cadmium, lead, chromium, mercury, nickel, silver	Homes and industry	Toxicity, bioaccumulation
Other inorganic materials	Acids (e.g. hydrogen sulphide), alkalis	Homes and industry	Corrosion, toxicity

Note: PFASs, polyfluorinated alkyl substances.

Source: Adapted from Henze et al. (2008).

Urban waste water is characterised by parameters describing its polluting potential. Total suspended solids represent the organic and inorganic matter present in waste water but which could settle out in calmer conditions, while the load of organic matter in the waste water is represented by biological oxygen demand (BOD), chemical oxygen demand (COD) or total organic carbon. Concentrations of nutrients, total phosphorus and total nitrogen, determine the eutrophication potential of waste water. Other waste water characteristics affecting treatment process include pH, alkalinity and chloride concentration. Some of these parameters are used for regulatory purposes and in the design of waste water treatment plants. The UWWTD sets emission limit values for the BOD, COD, total suspended solids, total nitrogen and total phosphorus. Some Member States set stricter emission limit values and regulate a wider scope of pollutants to meet the objectives of the Water Framework Directive (WFD). The volumes treated are large, e.g. in Sweden, with 10 million inhabitants, over a billion tonnes of waste water were collected and treated in 2018 (Statistics Sweden, n.d.).

Untreated sewage is infectious and contains a diversity of bacteria, mainly intestinal and soil inhabiting, e.g. coliforms, streptococci and clostridia. There are also protozoa, viruses, fungi, worms and microalgae. Discharge of untreated sewage can create serious public health risks, leading to outbreaks of cholera, for example (WHO, 2021b).

2.2.2 Treatment methods

Waste water treatment lowers the concentration of organic matter, nutrients and disease-causing microorganisms in sewage, prior to its discharge back into the environment. Sewage can be treated in various ways, locally in septic tanks or domestic treatment systems, centrally at municipal treatment plants or by using decentralised treatment, including nature-based methods such as constructed wetlands.

Biological waste water treatment, which is the most common process for treating sewage, uses bacteria and other microorganisms to degrade organic matter and use the nutrients for their growth. It resembles self-purification processes occurring naturally in the aquatic environment. Waste water treatment intensifies and controls these processes to achieve optimal levels of pollutant removal.

At treatment plants, the sewage usually goes through several consecutive treatment steps (see Table 2.2): pre-treatment, primary treatment, secondary treatment (Image 2.1) and, possibly, advanced treatment.

After secondary treatment, waste water is pumped into the secondary settling tanks, where sludge is separated from treated water. Treated water is then discharged into the receiving water. When the quality of effluent from secondary treatment does not meet the required emission standards, specific types of advanced treatment (also known as tertiary treatment) will be

Image 2.1 Secondary treatment

© Caroline Whalley.

Table 2.2 Urban waste water treatment processes

Treatment	Process	Typical technologies	Treats/removes
Pre-treatment	Physical separation	Screening, sedimentation, flotation	Debris, grit, fibres, sand, oil, grease
Primary	Physical separation	Sedimentation, flotation	Suspended solids, oils
Secondary	Biochemical degradation Physical separation	Activated sludge process Trickling filters Sequential batch reactor Moving bed biofilm reactor Membrane bioreactor Oxidation ponds/lagoon-constructed wetlands	Organics, partial treatment of nutrients (nitrogen and phosphorus), microorganisms ([a])
Advanced	Physical separation Chemical degradation Biochemical degradation	Disinfection (chlorination, ozonisation and ultraviolet (UV) treatment) Activated carbon filtration, advanced oxidation Advanced biological treatment, reverse osmosis, coagulation, microfiltration, ultrafiltration	Microorganisms, nutrients, highly biologically active and difficult to biodegrade substances (micropollutants)

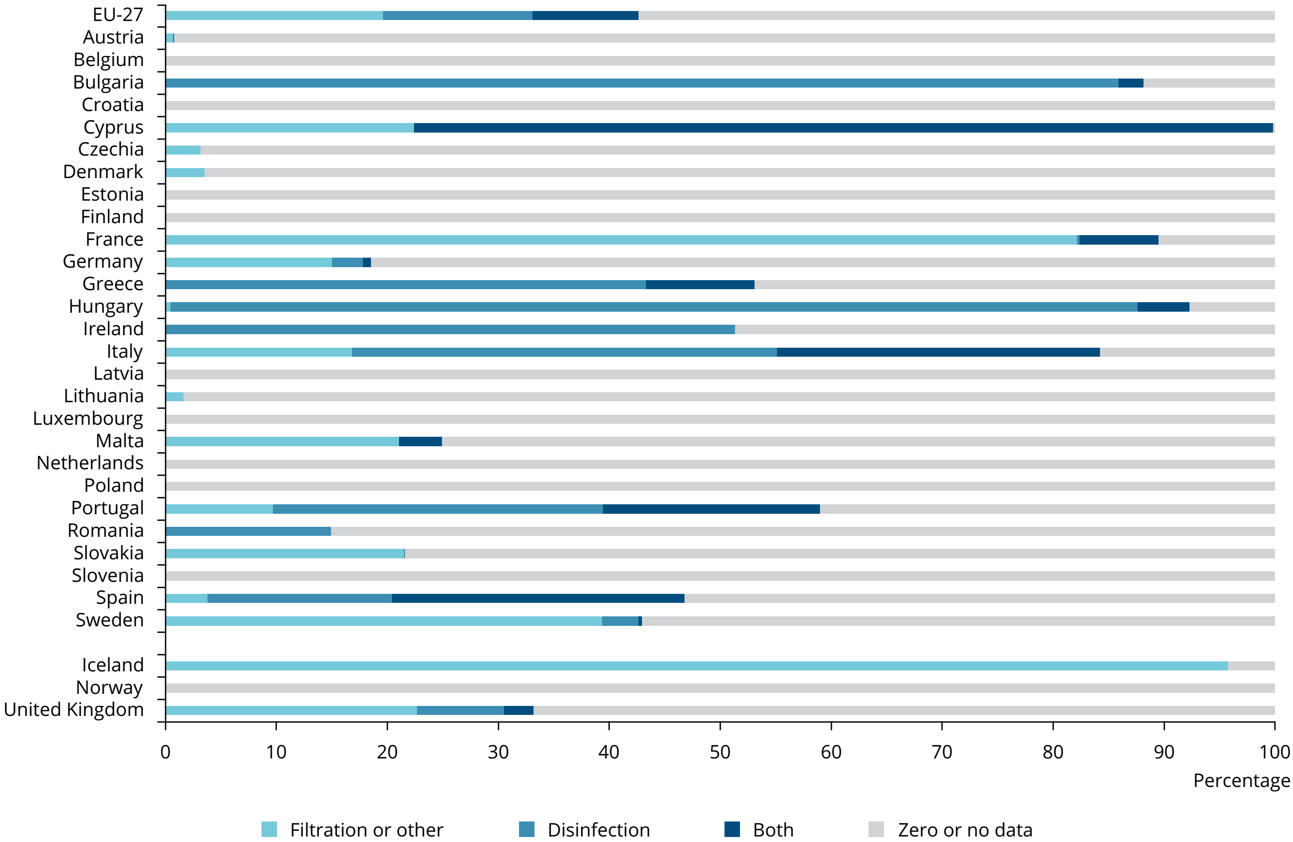
Note: ([a]) Although conventional secondary treatment has not been designed to remove nutrients or micropollutants, waste water treatment plants do remove some nutrients and micropollutants to some extent (including some pharmaceuticals and metals).

required, to tackle specific substances (e.g. nitrogen, phosphorus, micropollutants) and harmful microorganisms (by disinfection).

The UWWTD requires that, in agglomerations larger than 10,000 p.e. located in areas sensitive to eutrophication, Member States apply an advanced treatment to remove nitrogen and phosphorus from waste water prior to discharge (called 'more stringent treatment'). Application of other types of advanced treatment is not mandatory but should be used to ensure that the receiving water body meets quality objectives after the discharge of treated waste water. In 2007, 20% of the total waste water treated in Member States was subject to advanced treatment, which had risen to 41% ([3]) in 2018 ([4]), although there was wide variation between countries (Figure 2.1) (EEA, 2020a). Sand filtration and microfiltration were the most commonly used advanced treatment methods.

([3]) The 27 Member States of the EU (EU-27) and Iceland (IS), Norway (NO) and the United Kingdom (UK).
([4]) Values reflect advanced treatment, excluding nitrogen and phosphorus removal.

Figure 2.1 **Proportion of waste water load subjected to advanced treatment, 2018**



Notes: Treated waste water measured in population equivalents. Nitrogen and phosphorus treatment not included.

Source EEA (2020a).

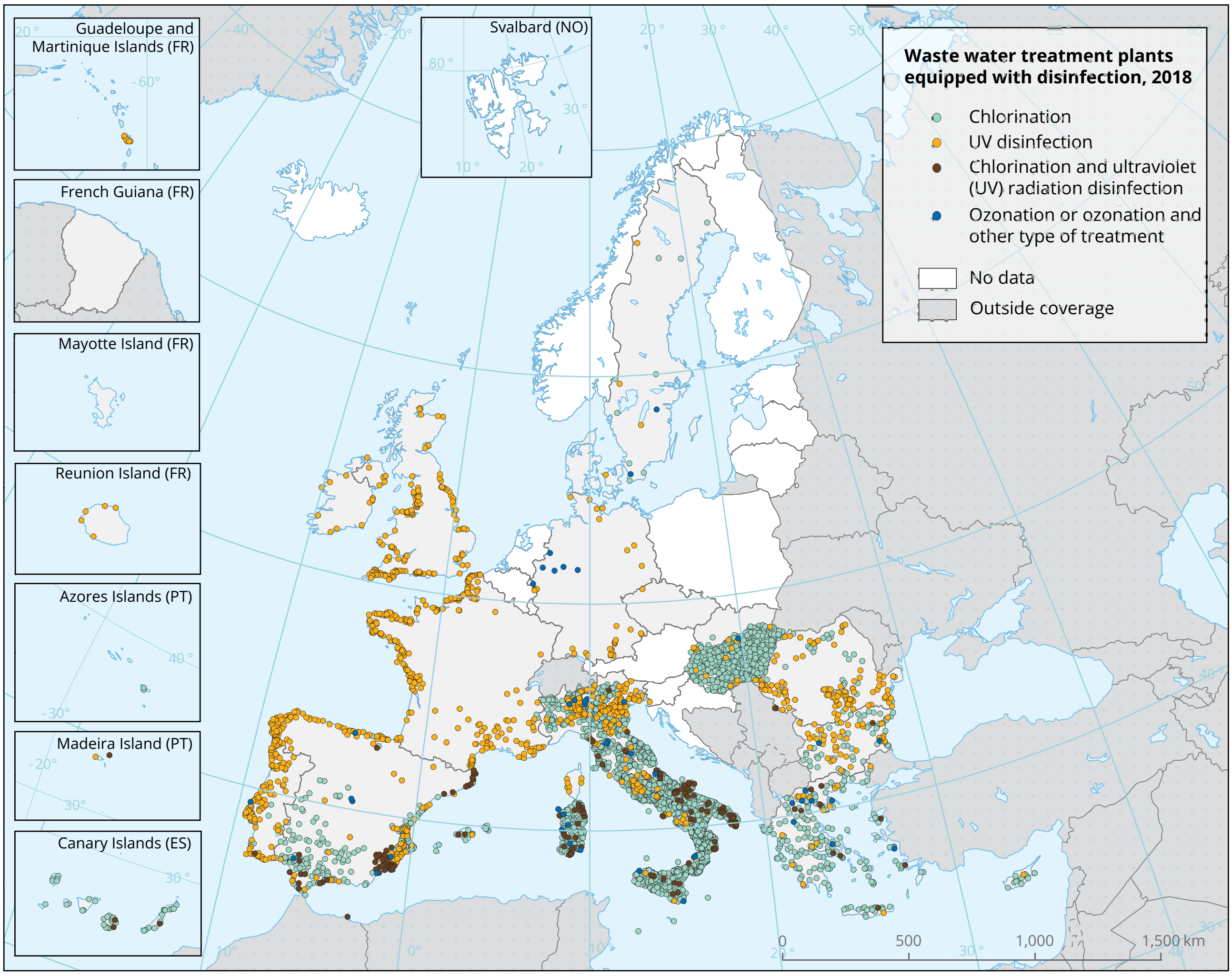
Map 2.1 shows that disinfection is commonly used to treat waste water prior to discharge into coastal waters or estuaries (31% of waste water treated in treatment plants ([5]) discharging into coastal waters or estuaries). Disinfection is also applied to discharges at inland plants (17% of the waste water treated in treatment plants discharging into fresh water or on land). Chlorination is still the most widely applied disinfection method, followed by ultraviolet (UV) radiation treatment. In southern Europe, disinfection may be primarily used during the summer bathing water period when there also is lower water availability.

Most of the advanced treatment methods require the input of extra energy and/or resources, e.g. energy for ozone generation or UV treatment in disinfection, or the use of activated carbon in micropollutant reduction. Energy consumption may be increased by between 10% and 60% with these advanced methods. Meanwhile, optimisation of biological treatment for nutrient removal from water also supports reductions in the concentrations of many micropollutants.

Treatment needs to take account of local characteristics. For example, ozonation of water containing bromide above a certain level presents a risk of carcinogenic bromated organic compounds being formed (Kehrein et al., 2020).

([5]) The EU-27 Member States plus IS, NO and the UK.

Map 2.1 Waste water treatment plants equipped with disinfection, 2018



Reference data: ©ESRI | ©EuroGeographics

Note: UV, ultraviolet treatment.

Source: EEA (2020a).

2.3 Dwellings not connected to a sewerage system

Dwellings that are not connected to UWWTPs can be a source of diffuse pollution if sewage is directly released into the environment without treatment, or when local sewage treatment is applied but the system is not well maintained or operated (EC, 2007). Approximately 11% of the EU population (55 million people) was not connected to a waste water collection network in 2017 (Eurostat, 2019). Reporting under the WFD showed that non-connected dwellings were a significant diffuse pollution pressure, affecting 8.5% of surface water bodies and 4% of groundwater area (Grebot et al., 2019; EEA, 2021b).

The UWWTD requires that waste water produced and collected in urban settlements under 2 000 p.e. must be suitably treated. For some areas, this can be a small UWWTP but in other, often less densely populated areas, individual or other appropriate systems ([6]) (IASs) (e.g. septic tanks, domestic waste water treatment plants) can be used (see Image 2.2). These solutions can be used when building a collecting system is not justified because it has 'no environmental benefit or because it would involve excessive cost', and must be able to ensure that discharged waste water allows the receiving waters to meet the relevant quality objectives and the relevant provisions of the UWWTD. Reporting on the implementation of the UWWTD in 2018 (for urban settlements above 2,000 p.e.) showed that about 9.9 million p.e. ([7]) was neither collected nor received any

([6]) IAS equate to 'non-connected dwellings' under the WFD.
([7]) EU-27, plus IS, NO and the UK.

treatment, mainly among newer Member States (Figure 2.2). It also indicated that 13.8 million p.e. of waste water was collected and treated via IASs, with some countries relying on this approach for a significant proportion of their sewage (Figure 2.3).

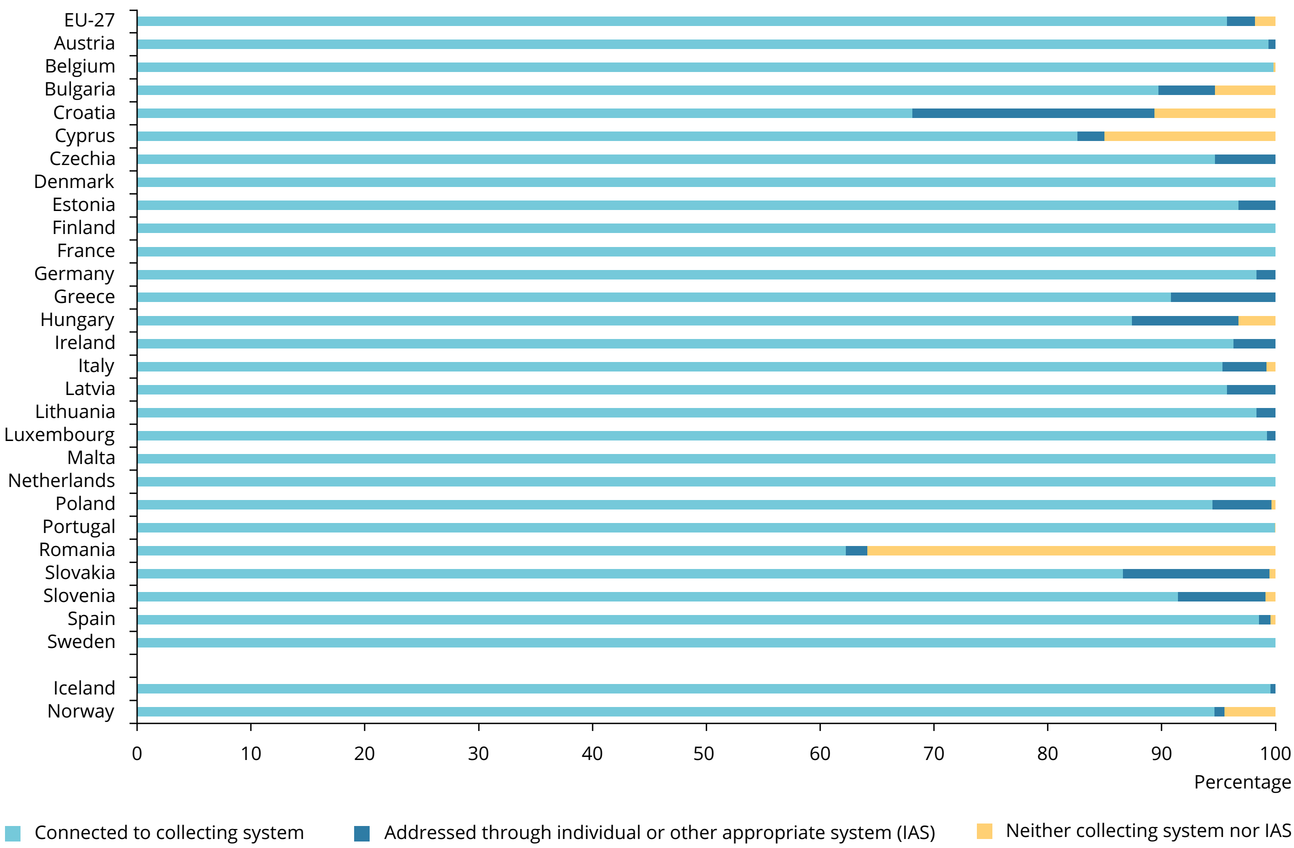
Non-connected dwellings and small settlements can treat sewage effectively, for example through small treatment plants, reed beds, infiltration systems and constructed wetlands, although typically this requires strong oversight (Grebot et al., 2019). Owners of individual systems need to take care not to disrupt the treatment process, e.g. avoiding the flushing of harmful substances (Mulder, 2019). Regulation of waste water treatment in urban areas below 2,000 p.e. is the responsibility of national authorities.

For example, in Finland, with approximately 1 million people living in urban areas below 2,000 p.e. (*c.*18% of total population) and with an additional 1 million holidaymakers, extensive legislation applies regulating the operation of IASs (Grebot et al., 2019). However, more often regulation is relatively weak, not least because such facilities are usually on private land, and it can be a challenge to ensure effective treatment when financial resources, as well as skilled personnel, may be lacking (Grebot et al., 2019).

Image 2.2 A non-connected toilet, with a pit that requires emptying

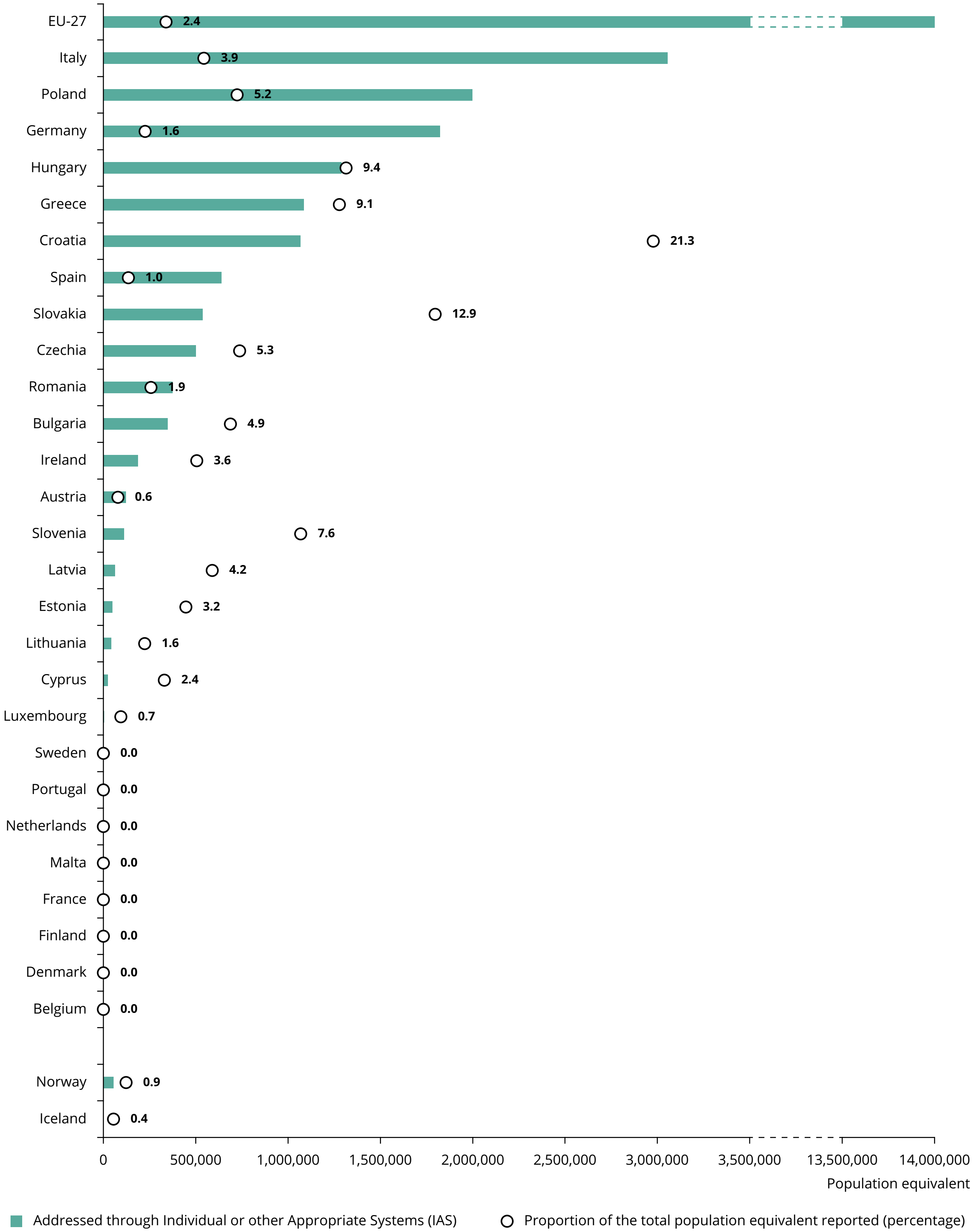
© Caroline Whalley.

Figure 2.2 Percentage of waste water load collected in collecting systems, addressed through IASs or discharged without treatment in Europe, 2018



Source: EEA (2020a).

Figure 2.3 **Actual waste water load treated via IAS, 2018**



Source: EEA (2020a).

2.4 Storm overflows

Rain and storm water or water from melted snow, which does not soak into the soil, forms surface run-off. The quality of surface run-off is determined by land use characteristics. Water falling on impervious surfaces, such as roads, streets, roofs, industrial and construction facilities, is recognised as a significant source of pollutants to water bodies originating in the urban environment.

Urban run-off is collected in sewers. In separated sewerage systems, run-off is conveyed separately and discharged without treatment into nearby waterways, whereas in combined sewers, it is collected together with waste water and travels to a UWWTP. To prevent flooding of the UWWTP during heavy rainfall, combined sewerage systems are equipped with combined sewer overflows (CSOs). This allows discharge of a mixture of run-off and urban waste water directly into surface waters, thus leading to their pollution.

There are over 3 million kilometres of sewerage systems across Europe, with at least 650,000 CSOs (EurEau, 2020). In the second reporting under the WFD, 4% of surface water bodies were reported to be affected by pollution from storm overflows (from 18 Member States) (EEA, 2021b), although the actual proportion of water bodies affected may be higher, as there are few data enabling the quantification of the impacts of discharges on water bodies. While separated sewers can reduce pollution from CSO discharges, challenges such as the direct discharge of road run-off would remain.

Studies into the implementation of the UWWTD found that under full compliance ([8]) with the directive, CSOs can contribute to 50% or more of the remaining impact on waterbodies and that the management of CSOs and urban run-off would offer a significant reduction in the pollution load that ends up in the environment (EC, 2019b).

To reduce the frequency of CSO discharges, some UWWTPs have temporary storage tanks that hold the 'first flush' of storm water, which is considered to be the most contaminated. Sewerage systems are expensive — the Thames Tideway Tunnel in London, which is being built to reduce CSO discharges, is expected to cost about EUR 6 billion (Thames Water, 2021).

Conventional methods for storm water management have often involved channelisation and concrete infrastructures. However, nature-based solutions are a subject of increasing interest, owing to their potential for multiple benefits. In a pilot study for storm water management in northern France, Bézannes Joint Development Zone constructed a landscaped park (Oppla, 2021). Aims included reducing the flood risk to and load on sewerage systems by controlling the quantity of water upstream, restoring ecosystems and their functions, improving water quality, and increasing biodiversity, accessibility to green space and well-being through nature-based solutions.

With climate change increasing the frequency of heavy rainfall events in some areas, without additional efforts the problems related to CSO discharges are likely to increase. Adapting to sudden, heavy rainfall is a priority in some European cities, not least to avoid tragic consequences such as those in Austria, Belgium and Germany in the summer of 2021.

2.5 Waste water from industry

Small-scale manufacturers and food and drink producers typically discharge to the sewerage system, where the waste water is treated at the UWWTP. Member States must ensure that the discharge of industrial waste water to the sewer can be effectively treated by the UWWTP, so that it neither damages equipment nor affects the biological treatment process, and so that the resulting sludge can be treated and disposed of in an environmentally sound manner. In contrast, large industrial sources, such as the pulp and paper, metals, energy supply and chemicals sectors, have on-site treatment facilities. Such installations are regulated under the Industrial Emissions Directive (IED) (EU, 2010; EEA, 2018b).

While not regulated under the IED, emissions to water from large UWWTPs are reported and publicly available under the European Pollutant Release and Transfer Register (E-PRTR) Regulation (EC, 2006c; EU, 2010; EEA, n.d.). Minimum reporting thresholds apply, to limit the reporting burden, based on installation size and pollutant quantity released. A relatively small proportion of the reporting concerns emissions to water, and a relatively small number of UWWTPs report data to the portal (in 2017, 901 reports in the 27 EU Member States (EU-27)). Both the IED and the E-PRTR are currently under review, with UWWTP capacity thresholds one of the areas under consideration (ICF Consulting Services, 2020). Even with the limited reporting under the E-PRTR, UWWTPs represent the major 'point source' of pollution to water (EEA 2018a; EEA, 2018b).

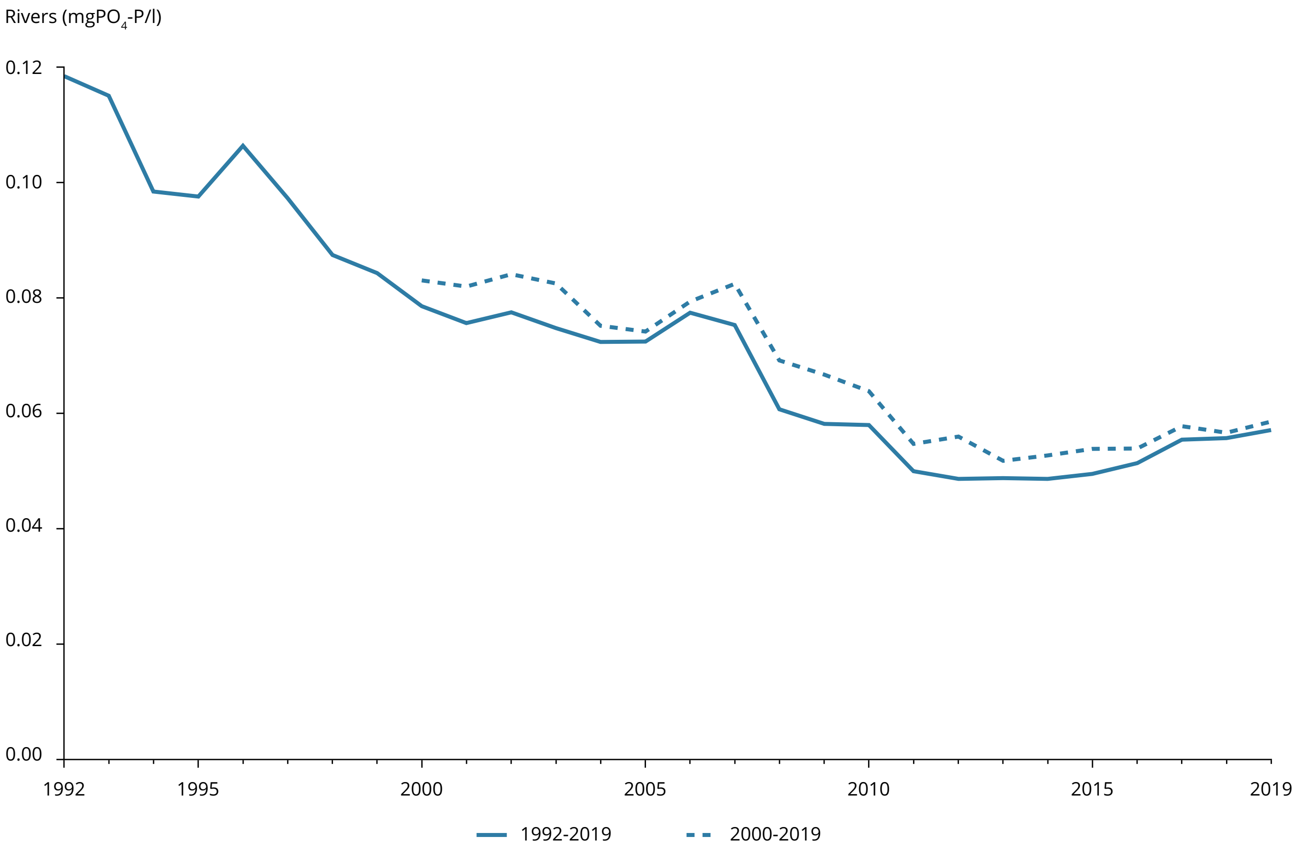
([8]) According to the UWWTD, full compliance is achieved when all load generated in agglomerations ≥ 2,000 p.e. is treated in line with requirements of article 3, 4 and 5 of the Directive. The only exception to meeting the obligation to collect and treat urban waste waters (article 3) is for the management of storm water (EEC, 1991).

2.6 Pollution from sewage

2.6.1 Nutrients

Excess nutrients, such as nitrogen and phosphorus, cause eutrophication resulting in excessive growth of algae and aquatic plants, increased water turbidity and oxygen depletion. The evaluation of the UWWTD (EC, 2019b) found that the discharged loads of BOD, nitrogen and phosphorus had fallen by 61%, 32% and 44%, respectively, between 1990 and 2014, showing the impact of this policy, and data on the concentrations of phosphate in rivers show a significant decline (Figure 2.4). Despite these improvements, eutrophication remains an issue of concern, particularly in coastal areas such as the Baltic and Mediterranean (Pavlidou, et al., 2019). Diffuse pollution from agriculture is a major pressure on water, particularly as it relates to nutrients (EEA, 2018a).

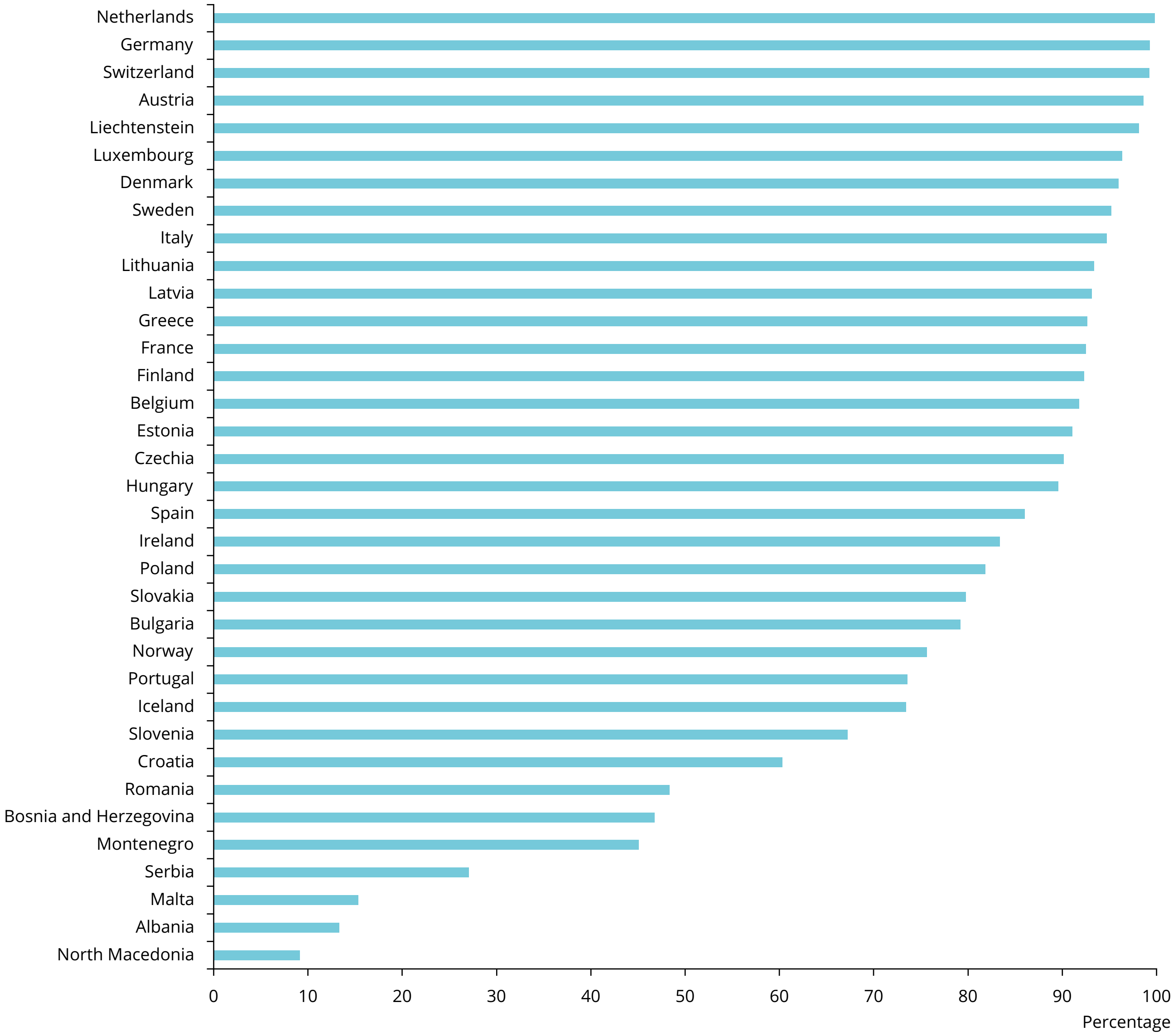
Figure 2.4 Phosphorus in rivers in European water bodies, 1992-2019



Note: Concentrations in milligrams of phosphorus per litre (mg PO_4-P/l)

Source: EEA, 2022.

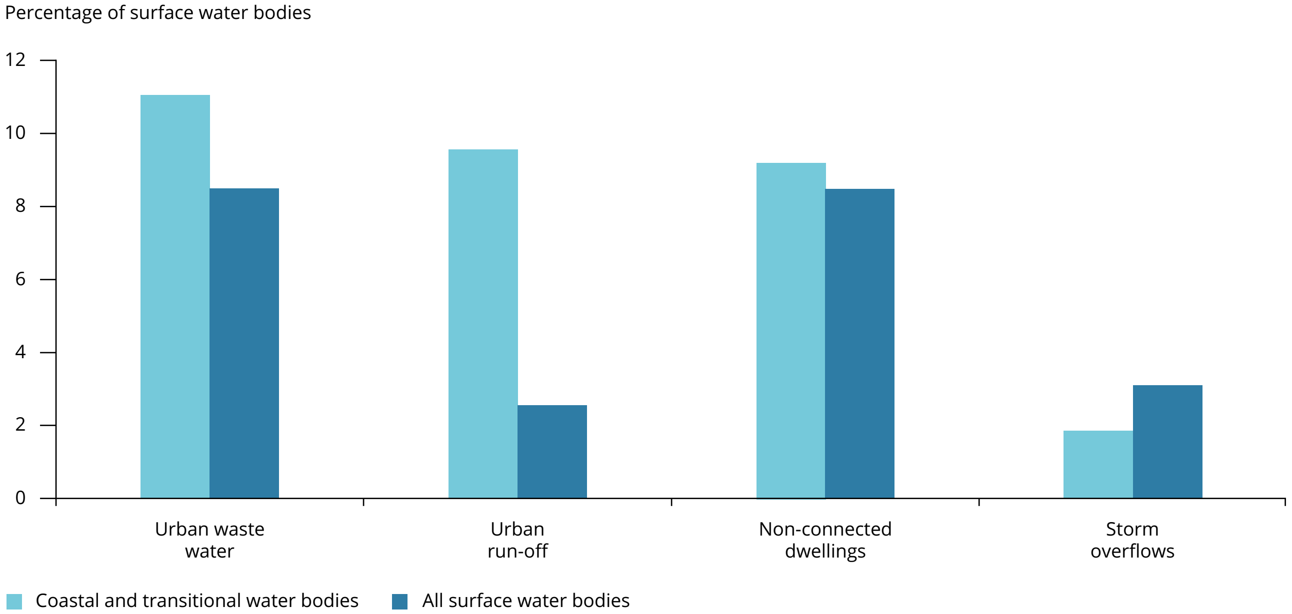
Figure 2.5 **Proportion (%) of domestic waste water safely treated in Europe, 2020**



Source: UN, 2021.

However, challenges to fully comply with the UWWTD in ensuring that waste water is both collected from most dwellings and treated to an acceptable standard before being discharged back to the water environment persist in some Member states (EC, 2020d). Monitoring in European countries for Sustainable Development Goal (SDG) 6.3.1 — the proportion of waste water safely treated — calculated as a proportion of all domestic waste water generated based on household per capita water use data, shows significant challenges still to be addressed in some areas (Figure 2.5).

Figure 2.6 Selected significant pressures causing failure to achieve good ecological status (under second river basin management plans)



Source: WFD database https://www.eea.europa.eu/data-and-maps/dashboards/wise-wfd (EU-27 + NO + UK).

Reporting under the WFD indicates that most Member States are challenged in achieving targets with respect to restoring all water bodies to 'good status' by 2027. Pollution pressures from urban waste water caused failure to achieve good ecological status, arising both from point sources from UWWTPs (8% of water bodies) and storm overflows (3%) and from diffuse sources such as non-connected dwellings (10%) (Figure 2.6) (EEA, 2021b). Urban run-off seems to represent a significant pressure in transitional and coastal waters.

Where sewage discharges have occurred over decades, recovery of an ecosystem can be difficult to assess. However, a historical study on the River Seine in France showed the impact of human activities on migratory fish from the sea to Paris, between the 1900s and 2010s (Beslagic, 2013; Le Pichon et al., 2020). Discharges of untreated sewage and other wastes in the 1970s led to low dissolved oxygen concentrations in the river, leading to a 'chemical barrier' to migration. By the 2010s, improvements to waste water treatment and the implementation of effective fish passages allowed migratory fish to again reach Paris.

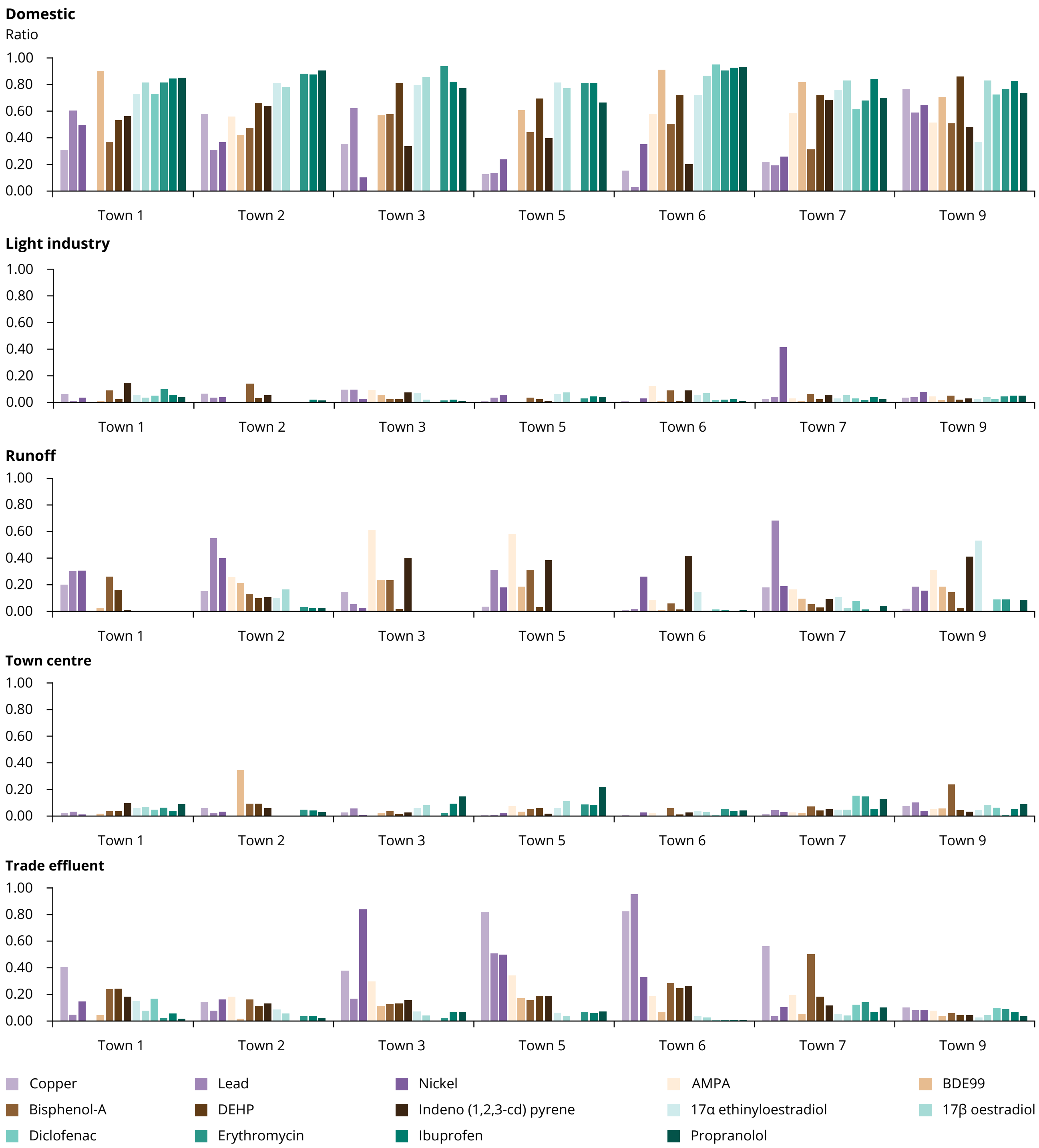
2.6.2 Micropollutants

Understanding of the range of pollutants in water, and our ability to measure them, has come a long way since the UWWTD came into force in 1991. We now recognise that many 'micropollutants' find their way into urban waste water and risk being discharged to the environment if they are not treated or removed (Pistocchi et al., 2019). Such pollutants can arise from both natural sources and human activities, like metals and polycyclic aromatic hydrocarbons (PAHs), as well synthetic biocides, medicines, flame retardants, etc. Waste water treatment is capable of removing relatively high proportions of many of these substances from the water, but often not sufficiently to meet the chemical standards required under the WFD (Gardner et al., 2013). Other substances are not removed at all and pass through the UWWTP to the receiving waters. Furthermore, concern about mixtures in the environment (EC, 2012a; Posthuma et al., 2019) has led to calls for higher rates of removal from urban waste water.

Historically, we have largely understood chemical pollutants as arising from industry and agriculture. However, restrictions on industrial discharges, particularly from point sources, have led to a decline in the significance of this as a source. Research in the United Kingdom showed that the most significant source of micropollutants in UWWTPs was our homes (Figure 2.7) (Comber et al, 2014).

This finding should have a profound impact on our understanding of chemical pollutants in sewage. Rather than being 'someone else's responsibility' with an impact 'somewhere else', these pollutants are in chemicals and products that we use in our homes: substances with harmful characteristics such as carcinogenicity and endocrine disruption, as well as those directly harmful to aquatic life.

Figure 2.7 Pollutant sources to UWWTPs



Notes: AMPA, Aminomethylphosphonic acid. DEHP, di(2-ethylhexyl)phthalate. BDE, brominated diphenylether.

Sources: UK WIR Chemical Investigation Programme (Comber et al, 2015).

Citizens are concerned. 84% of Europeans are worried about the impact of chemicals present in everyday products on their health, and 90% are worried about the impact of chemicals on the environment (EC, 2020c). In Switzerland, studies on the impact of micropollutants on surface water status and on drinking water resources, and a lack of effective strategies for control at source, resulted in a referendum and then legislation to upgrade existing waste water treatment plants to remove micropollutants (Logar et al., 2014).

Despite restrictions on certain substances through source control legislation such as the Regulation on Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) (EU, 2006a), the number of chemicals in everyday use has grown enormously in recent decades (EEA, 2019b). Efforts are in place to break a cycle where restriction of one substance has merely led to its replacement by a similar (unrestricted) molecule — so-called 'regrettable substitution' (ECHA, n.d.; Kemi, n.d.) — and moving to safe and sustainable-by-design criteria for chemicals (EC, 2020c).

2.6.3 Disease and antimicrobial resistance

One of the 'discoveries' of the COVID-19 pandemic was the role that waste water monitoring can play in tracking the presence of the virus, such that the European Commission recommended a common approach to establish systematic surveillance of SARS-CoV-2 (EC, 2021b,c). In fact, such monitoring has a long history, with polio being monitored this way in the 1940s (Schmidt, 2020). Pathogens excreted through bodily fluids, skin and hair find their way into sewers through toilet flushing and cleaning (e.g. bathing, floor washing) (Sinclair et al., 2008). Use of waste water monitoring for early warning and tracking of disease outbreaks seems likely to continue, given its potential for widespread coverage and its relatively low cost (~EUR 25,000 for one UWWTP per year) (Gawlik et al., 2021b).

There is real concern about the risk represented by antimicrobial resistance, in which antibiotics are no longer able to cure common infections (WHO, 2021c). Intensive studies comparable to those carried out in the food and health sectors have not yet been undertaken in an environmental setting (EFSA Panel on Biological Hazards, 2021). Waste water treatment relies on naturally resistant organisms breaking down organic matter and other waste water constituents. Resistance genes may be transferred and generated in the waste water, e.g. through exposure to antibiotic residues excreted by patients, and then transferred into the environment. Large-scale studies to understand the potential for transfer of resistance genes back into people are not yet available, but some smaller studies show contamination, e.g. surfers had three times the level of antibiotic-resistant *Escherichia coli* compared with non-surfers (Leonard et al., 2018). If UWWTPs were found to be a significant cause of the transfer of resistance genes, it is possible that disinfection would be more widely required. Research in this area is ongoing.

2.7 Sludges arising from urban waste water treatment

2.7.1 Sewage sludge

Treatment of urban waste water at UWWTPs produces sewage sludge, which is usually treated (e.g. dewatering, thickening, pasteurisation, sanitation) to ensure that sludge is suitable for its intended use or disposal. Two main types of sewage sludge arise from the waste water treatment process:

1. primary sludge — settleable solids separated during primary treatment of waste water (physical separation such as screening);

2. secondary sludge — organic material produced by bacteria during secondary, biological treatment.

Sewage sludge is characterised by a high carbon and nutrient content and high water content. It may contain pathogens and traces of pollutants such as metals, persistent organic compounds, microplastics and pharmaceuticals. It can have an unpleasant odour. Sludges from treatment of urban waste water are categorised as 'absolute non-hazardous' waste in the European List of Wastes (EC, 2014a).

Following its extraction from the waste water treatment process, sewage sludge requires treatment to enable it to be transported efficiently and safely and for the ultimate recovery (of nutrients or energy) and/or disposal. Common treatment options include thickening, stabilisation, dehydration and sometimes drying of sludge. Additional and well-established management techniques for sewage sludge include lime treatment, anaerobic digestion and composting with other organic waste. Final recovery and disposal options include spreading of treated sludge on farmland, using it in landscaping and incinerating it. The application of sludge onto farmland is allowed only if the sludge content remains under thresholds established for a set of heavy metals and after given time periods have passed between the production of the sludge and its application. Minimum durations are set out in the Sewage Sludge Directive (EEC, 1986).

However, because the sludge can contain pollutants removed from the water, there are concerns about the pollutant load in the sludge (Huygens et al., forthcoming). Limits on metal loads to the soil are set in the Sewage Sludge Directive and some Member States have set stricter limits than those in this old directive (Mudgal et al., 2014; Anderson et al., 2021). Concerns in some Member States about the contaminant load potentially entering human food or animal feed, or being released into the environment, have led to restrictions on sludge being spread on land (e.g. in Germany and the Netherlands). Some countries have found that to maintain consumer confidence, and to protect the environment, they have needed to develop comprehensive assurance schemes for sludge applied to land (see Box 3.2, case study 2).

2.7.2 Process waste

Waste water treatment produces process waste that must be safely disposed of, as well as treated water and sludge. Classification, processing, treatment and disposal of the process waste is subject to waste management legislation. Sending waste to landfill is considered the least preferred waste management option under the EU waste hierarchy (EU, 1999, 2008). Together with aims to ensure a progressive reduction in the landfilling of waste, particularly waste that is suitable for recycling or other recovery, such policies are intended to expand both treatment methods and the use of process waste through reuse and recycling.

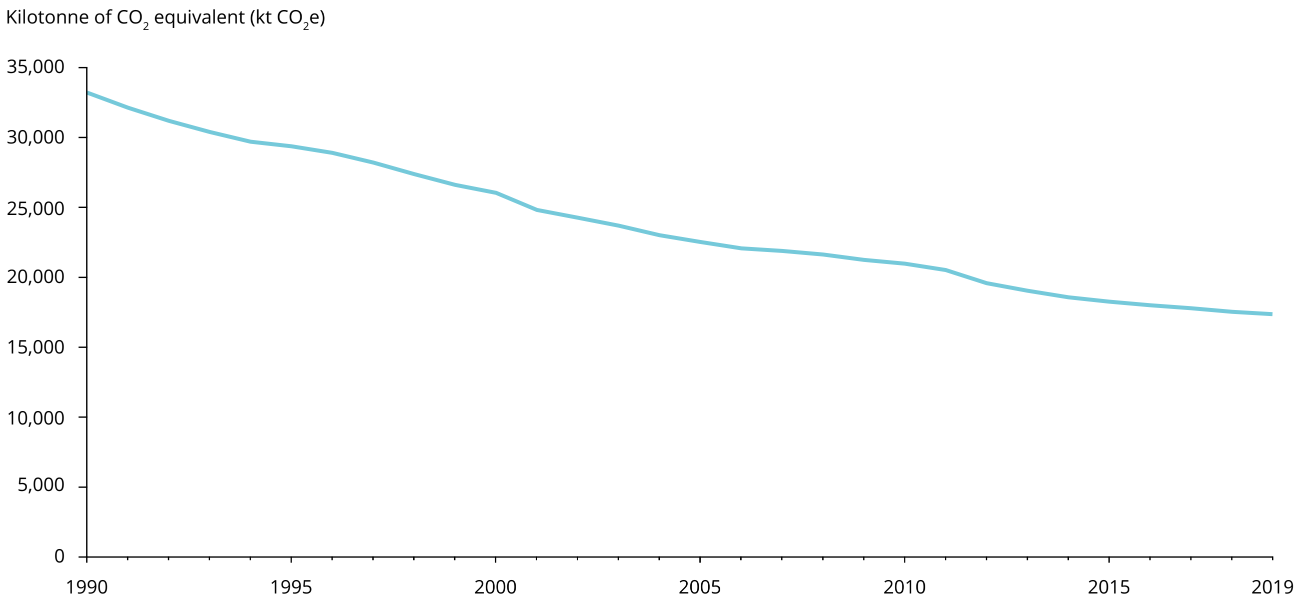
Other process wastes depend on the type of treatment technologies applied and may include chemical sludge from phosphorus precipitation, concentrated liquid wastes from membrane-based treatments and spent, activated carbon. It is difficult to find detail on the amounts of waste produced by waste water treatment processes. The substrate for trickling filters, such as lava rock or plastic substrate, can be used for decades so is understood to be relatively insignificant, while the amounts of sand used in sand filters are relatively small compared with those used in construction, for example. A study by UK Water Industry Research considered the use of activated carbon in micropollutant removal (UKWIR, 2020). Use of granular activated carbon to remove micropollutants was expected to increase carbon emissions from the UK water sector by 7-8%, based on an existing total greenhouse gas emissions of 4 million t/year, and an increase of 2% in total dry solids sludge production (UKWIR, 2020).

The recovery of resources from waste water treatment residues, as an alternative to traditional modes of disposal (landfilling, incineration), is the subject of numerous research project. These study, for example, the conversion of fats, oils and grease from sewage pre-treatment to biofuel using physicochemical processes, or the recovery of resources, e.g. biopolymers from materials recovered from membrane-based technologies applied in advanced treatment.

2.8 Greenhouse gas emissions

Typically, we consider water quality and sewage sludge when thinking about the impacts of waste water treatment. However, direct emissions of greenhouse gases (GHG) arise from the biological treatment of organic material in urban waste water, principally methane (CH_4) and nitrous oxide (N_2O) (which is associated with nitrogen removal). Improved treatment of urban waste water since the 1990s has helped to prevent significant methane emissions, owing to the collection and treatment of waste water in efficient, centralised facilities (EC, 2020e), with emissions steadily declining to 17,351kt CO_2 equivalent (CO_2e) in 2019 (Figure 2.8). The decline has largely been in methane emissions, which have more than halved since 1989, while those of nitrous oxides have changed little since the early 2000s, at about 6,100kt CO_2e per year (EEA, 2021c).

Figure 2.8 CO_2e released by the domestic waste water treatment sector in the EU-27



Notes: Greenhouse gas emissions from the domestic waste water treatment sector. Overall emissions in CO_2e.

Source: EEA, GHG emissions data viewer. Data based on IPCC 2006 guidelines (9).

(9) The numbers differ from the impact assessment for the revision of the UWWTD (EC, forthcoming), as that used modelled greenhouse gas emissions based on IPCC 2019 guidelines.

Indirect emissions from UWWTPs arise mainly from the use of fossil fuels in electricity production and in drying and transporting sewage sludge (Zheng and Ma, 2019).

Infrastructure for urban waste water treatment (Image 2.3) can lead to a high level of embedded greenhouse gases, with estimates suggesting that infrastructure-related greenhouse gas emissions comprise about 50% of the total emitted by waste water treatment (Paravicchini, et al., forthcoming). Emissions arise from the extraction of raw materials, for example those used in concrete and steel for pipes and tanks, and from construction activities. Scottish Water has developed a measure called 'investment intensity' to assess and control emissions of this nature (Scottish Water, 2022). It estimates that 60% of these emissions come from civil engineering, with infrastructure and mechanical and electrical work making up most of the remainder. Scottish Water aims to choose low-emission options, procure low- or zero-emission construction materials and build using low- or zero-carbon construction techniques. This will require innovation in the development of materials, construction methods and equipment.

Emissions of greenhouse gases from waste water treatment can be reduced through a range of methods, from optimising operation to modifying the plant. Emissions of carbon dioxide can be reduced by enhancing the energy efficiency of the treatment, minimising pumping and treatment of surface run-off, and generating biogas from the anaerobic digestion of sewage sludge for heat and energy in combined heat and power production technology or by the production of biomethane. Reductions in emissions of nitrous oxides can be achieved by applying control strategies to prevent incomplete nitrification/denitrification during waste water treatment, while methane emissions can be reduced by improving management systems, for example, to introduce measures to prevent methane gas leakages from sludge handling facilities and to reduce the amounts of methane formed in sewers.

Additional demands for waste water treatment to remove micropollutants are likely to significantly increase energy requirements, as their removal is currently based mostly on energy-intensive methods per unit of pollutant removed (Capodaglio and Olsson, 2019). Strategies that water utilities could adopt to mitigate the carbon impact of micropollutant removal include (Georges et al., 2009):

- **least-carbon end-of-pipe/process addition**, which aims to find the least-carbon solution, acknowledging the embodied and operational carbon emissions associated with additional treatment;
- **increased operational efficiencies**;
- **redeveloping existing treatment processes** to lower energy alternatives;
- **renewable energy generation** to reduce operational emissions, e.g. through on-site generation of energy.

Further analyses of energy use in relation to micropollutant removal have been undertaken as part of the development of the impact assessment for the revision of the UWWTD (EC, forthcoming; Pistocchi et al., forthcoming). These all serve to show that longer-term sustainability requires control of pollution at source.

Image 2.3 Waste water treatment tanks

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3 Energy and resources — reduce, reuse, recycle and recover

3.1 Introduction

'Waste water treatment' aims to deliver clean water that is safe to be returned to the environment. The term reflects a linear process. To better reflect the opportunities presented, the other resources used and generated by sewage treatment need to be considered in the context of integrated water and waste management.

Efficient use of water is necessary to ensure that the use of the resources to treat it can be optimised. Urban waste water treatment currently uses at least 1% of total energy production in Europe (Ganora et al., 2019; Capodaglio and Olsson, 2020). Pumping and treating water makes it the largest municipal user of energy. Energy efficiency can deliver savings on existing treatment costs, while the demand for more intensive treatment is likely to drive up the energy requirement.

Meanwhile, sewage contains valuable resources. This includes not only the water itself but also heat, nutrients such as nitrogen and phosphorus, and energy and other resources that can be derived from sewage sludge. Treated sewage sludge itself is valued for its nutrient and organic matter for agriculture in parts of Europe; however, concerns about mainly chemical contamination constrain its potential applications.

Considering these issues, the best operating plants are able to meet environmental discharge limits and generate at least enough energy to power their own energy needs. By driving quality requirements on incoming effluent through to resource recovery, these 'resource hubs' can underpin a circular economy.

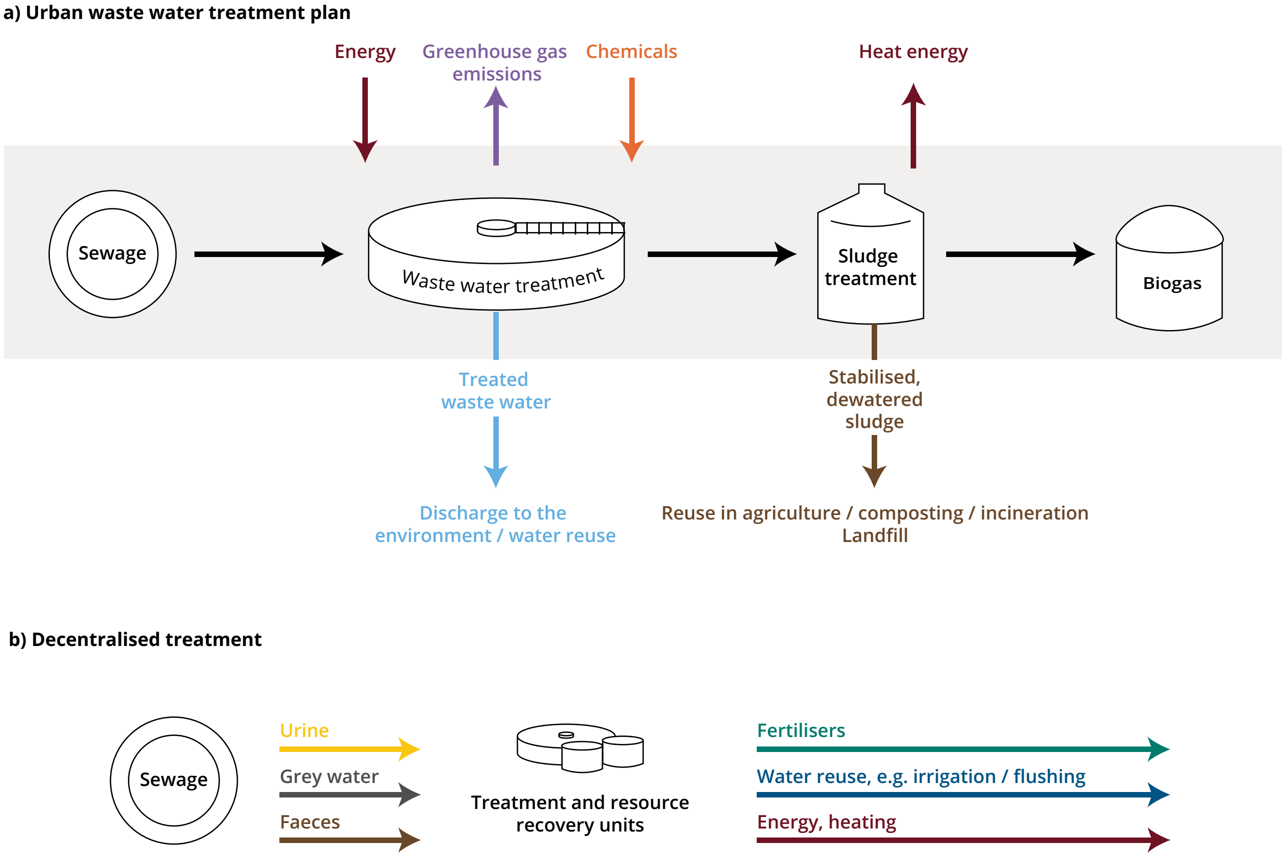
3.2 Energy use and efficiency

3.2.1 Sustainable use of resources

Minimising the unnecessary use of resources is the first step towards sustainability and can often provide financial savings to operators. In the context of water, efficient use of this essential resource should be high priority, because water can be in short supply, and because pumping and treatment are expensive in both energy and financial terms. Furthermore, water saved from use does not become waste water. The circular economy action plan under the European Green Deal sets out the European Commission's ambitions for a circular economy, focusing on certain product value chains and recognising the relationship between circularity and climate neutrality (EC, 2020a).

Figure 3.1 summarises the inputs and outputs of (a) urban waste water treatment and (b) sewage treatment separated at source, such as in decentralised treatment facilities. While many of the products are similar, the main difference is scale — typically, (a) might apply from 50 people to millions, while currently (b) would mainly apply in Europe to pilot studies. This chapter mainly focuses on conventional treatment (a) as the dominant approach. However, the importance of decentralised approaches (b) is increasing, as used by innovative towns and operators.

Figure 3.1 Inputs and outputs of sewage treatment



3.2.2 *UWWTP energy use and efficiency*

Energy use by an individual urban waste water treatment plant (UWWTP) is determined by the location, the characteristics of sewage, treatment plant size, treatment technology used and the quality requirements of the treated water. For example, location, elevation and slope of terrain determine whether the sewage will be gravity fed or pumped to the UWWTP. Large plants treating large volumes of sewage consume more energy than smaller plants, but typically have much higher energy efficiency, owing to modern technologies and more advanced methods of operation, such as automatic regulation of processes (Ganora et al., 2019). Pumps, mechanical aerators or blowers and sludge handling systems account for the largest share of total energy consumption. The Enerwater study showed that secondary treatment consumes the most energy in the treatment process, consuming between 64% and 74% of the total energy used by UWWTPs (size ranging from below 2,000 population equivalents (p.e.) to over 100,000 p.e.) (Longo et al., 2019).

Increasing energy costs, as well as pressure to reduce greenhouse gas emissions, have driven waste water treatment operators to look for ways to optimise energy consumption and navigate towards energy neutrality or even positivity, resulting in energy self-sufficiency or surplus (see Section 3.3.4). Sweden and Denmark have recently set targets to have climate-neutral operation of their water and waste water sectors by 2030. Reductions in energy consumption can be achieved through a variety of means, for example:

- installing energy-efficient aeration equipment in secondary treatment;
- improving process control;
- reducing leakage and energy efficiency approaches to sludge thickening.

Case study 1 (Box 3.1) looks at how efficiencies at the Sofia UWWTP were achieved, even as the plant increased its capacity by one third, between 2014 and 2017.

Box 3.1 Case study 1— Improvements in energy efficiency in Sofia, Bulgaria

The Sofia waste water treatment plant was commissioned in 1984 and historically consumed between 16,000MWh and 24,000MWh electricity per year. Following the installation of combined heat and power (CHP) units in 2010, the energy produced annually on site rose from 15,288MWh to 23,100MWh in 2017. Measures implemented to reduce energy consumption included optimising the aeration process via air flow regulation, improving the anaerobic digestion process and using the heat potential of on-site CHPs. This led to the plant producing 23% more energy than was needed for its operation in 2017 (i.e. 4300MWh).

Source: CircE (2018).

It is estimated that, if all UWWTPs that use more than the current average amount of energy were shifted to the EU average value, the saving would be slightly more than 5,500GWh/year. With highly stringent targets of efficiency improvement, saving of about 13,500GWh/year could be expected (Ganora et al., 2019).

Although the waste water treatment industry is not targeted by the EU Energy Efficiency Directive (EU, 2018), water utilities use benchmarking and energy audit procedures as tools to optimise energy consumption and greenhouse gas emissions in waste water treatment (Clos et al., 2020). Currently, there is no systematic EU-wide data collection of the energy efficiency of urban waste water treatment, as a standardised methodology at European level has not been adopted. Enerwater has developed a methodology for assessing and improving energy efficiency and labelling of waste water treatment plants, enabling rapid auditing and assessment to support decision-making (Longo et al., 2019).

3.3 Recovering resources from sewage and sewage sludge

3.3.1 Sewage sludge

Unsustainable land use and management has led to the degradation of EU soils (EC, 2021d). Sewage sludge has been used for centuries as a fertiliser (Mulder, 2019). Addition of sewage sludge to land can provide nutrients such as nitrogen and phosphorus, as well as micronutrients and humus that can help the soil structure. Long-term experiments show enhanced fertility after sewage sludge application, resulting from reduced soil bulk density and increased soil carbon concentration (Börjesson and Kätterer, 2018). Lime-treated sludge can also help reduce the acidity of agricultural soils. The Sewage Sludge Directive (EEC, 1986) sets minimum treatment standards to protect against health and pollution risks from sludge application to land. This old directive is currently under evaluation (June 2022). However, concerns remain that the treated sludge has effectively collected many of the persistent pollutants present in waste water, which may then be dispersed on to the land and become a source of diffuse pollution. A study in Norway on microplastics in sludge concluded that they could be a major source to the environment, but there was no assessment of the risk that this might present (Lusher et al., 2017). Recent Swedish studies show that about 40-60% of the microplastics present in incoming waste water were subsequently found in the anaerobically digested sludge, with the rest being removed or disintegrating/degrading during treatment. The concentration of microplastics in sludge from three UWWTPs corresponded to between 5 and 8g/p.e. per year. Meanwhile, sludge used as fertiliser for 35 years seemed not to cause an elevated microplastic concentration in the soil in one study (Tumlin and Bertholds, 2020). Knowledge about the sources and presence of microplastics in water is still limited (ETC/WGME, 2021).

A study investigating concentrations of metals and several pharmaceuticals in the sludge itself, from 11 UWWTPs over 1 year, calculated that concentrations in the soil would be below the predicted no-effect concentrations (UKWIR, 2018).

Across Europe, there are polarising opinions as to the fate of sewage sludge. In Germany there is a national strategy to end the application of sewage sludge to soil, with a deadline of 2032 for UWWTPs over 50,000 p.e., although sludge from smaller plants may still be used (Anderson et al., 2021). In parallel, the ProgGress strategy requires the recovery of phosphorus from the sludge through mono-incineration from UWWTPs larger than 50,000 p.e. (BMUB, 2016). Meanwhile, in Sweden, policy has shifted towards treated sludge going to land as part of a more circular approach (see Box 3.2, case study 2). Achieving this has required significant effort among all stakeholders to avoid chemical contamination of waste water, so that the resulting sludge does not contain persistent pollutants, and customer confidence in food quality can be maintained.

Box 3.2 Case study 2 — REVAQ-certified waste water treatment plants, Sweden

In Sweden, concerns about contaminants in sludge led to recommendations not to apply sludge to land during the early 2000s (Anderson et al., 2021). However, in 2008 a collaboration between farmers, regulators and the water and food industries led to a certification scheme, 'REVAQ', which assures a certain level of control at source, upstream measures and the safety of sludge applied to agricultural land, in relation to the quality of soil and food and to water quality. An industry is not allowed to connect to a REVAQ waste water treatment plant if it handles, uses or produces any of the chemicals on the Swedish Chemicals Agency's list for phasing out (*c.*7,500 substances) (Kemi, n.d; ChemSec, n.d.). This has increased confidence among farmers and the food industry in using sludge, with the amount applied to land rising from 22% in 2011 to 45% in 2018 (Anderson et al., 2021). Studies showed that 'there is clear evidence that sludge fertiliser application supplies plant nutrients and humus that agriculture demands.'

Source: Ministry of the Environment of Sweden (2020).

3.3.2 Sewage sludge production

The annual production of sewage sludge in the 32 member countries of the EEA (EEA-32) was about 11.1 million tonnes in 2018, which equates to about 17 kg per person, of which 94% was disposed of (Anderson et al., 2021).

Figure 3.2 shows a wide variation in the destinations of sewage sludge. Based on data reported by 2022, 34% of the sewage sludge was used in agriculture, 31% was incinerated, 12% used in compost and other applications, 12% went to landfill, and 10% was used in another way. Some countries predominantly send treated sewage sludge to land, while others incinerate it. Decisions are based partly on geography (e.g. availability of land) and also on the level of concern about pollutant loads in the sludge. There is a lack of data on sludge destinations for a number of European countries.

The cost of treatment plus disposal of sludge in European countries has been estimated to reach, on average, approximately EUR 200 per tonne of dry mass, according to the type of treatment and disposal (Capodaglio and Olsson, 2020).

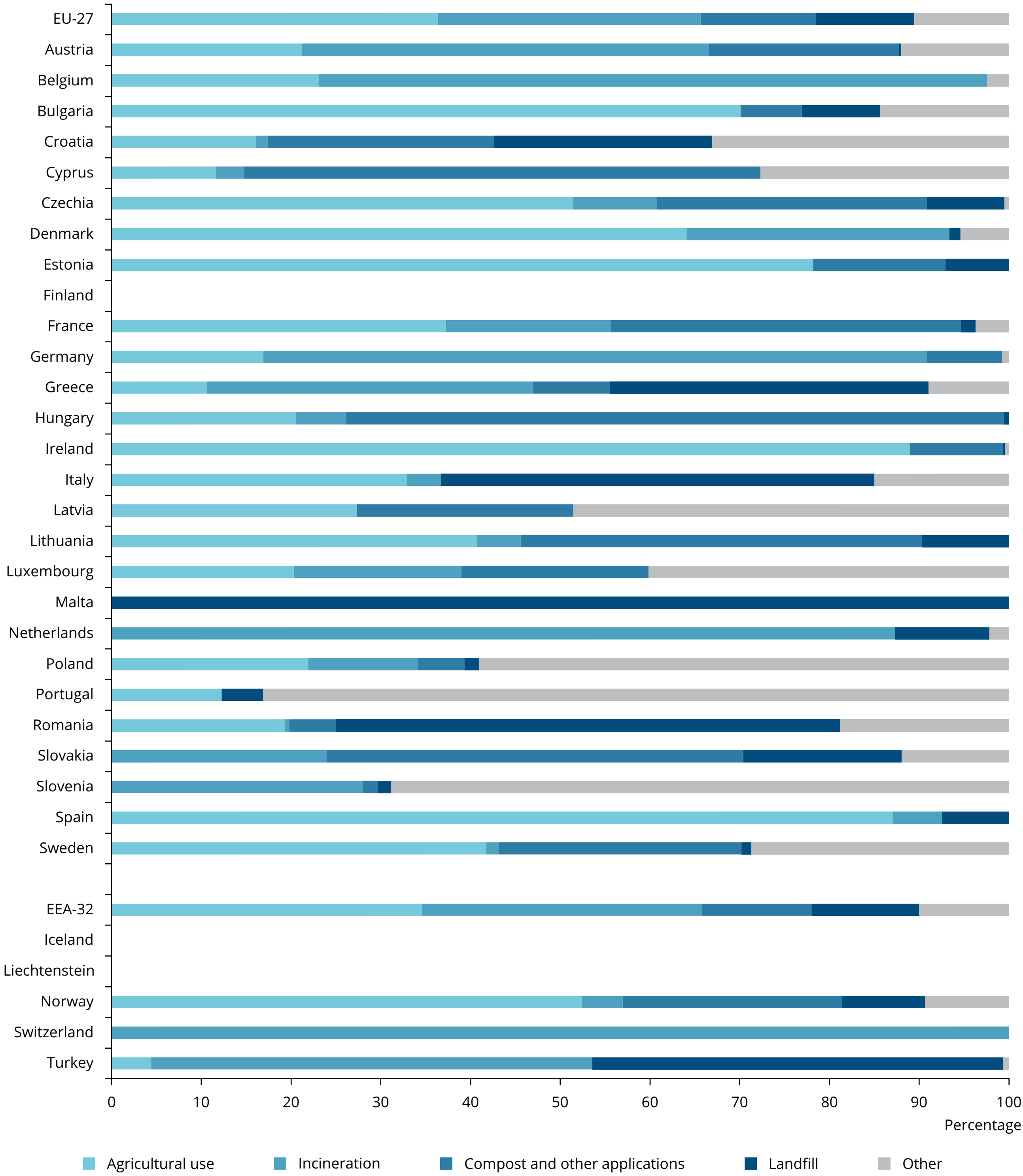
With regard to sludge production, the treatment can have two objectives:

1. recovery of materials or energy from sludge, using its resource potential;

2. reduction in the amount of sludge produced, minimising waste.

Sludge dewatering significantly reduces the volume of wet sludge for disposal and increases the solid content of sludge. Methods based on physical, mechanical, chemical, thermal and biological treatments are used to reduce the dry mass of sludge, which reduces the solid content and further decreases the volume. Most methods aim to solubilise the solids and destroy bacterial cells in the sludge.

Figure 3.2 **Sewage sludge management approaches in Europe**



Notes: Reported data for each of the different uses was compared with the total disposed, according to various categories - agricultural use, compost and other applications, landfill, incineration, and other.

Data from 2018 and 2019, except for France and Switzerland (2017); Portugal (2016); Denmark and Italy (2010).

Source: Eurostat (2022).

3.3.3 Resource recovery from sewage sludge

Owing to its high nutrient and organic matter content, and the energy content of dried sludge being comparable to that of woody biomass, sewage sludge is a prospective secondary resource that can contribute to Europe's transition to a circular economy (Anderson et al., 2021). A potential obstacle for promoting sludge recycling and recovery stems from two policy objectives, which may be in conflict:

- protecting the environment and human health, which requires that sludge for recycling complies with specific quality standards;
- promoting the use of sludge in agriculture in the interests of resource efficiency, ensuring the recycling and recovery of valuable and finite nutrients.

Preventing contamination of sewage by persistent, hazardous pollutants would allow recycling of sewage sludge on land without giving rise to concern that this might lead to diffuse pollution by these substances of soils, plants and water.

The estimated annual amount of nutrients that could be potentially recovered from sewage sludge produced in UWWTPs in the 27 EU Member States (EU-27) ranges between 6,900 and 63,000t of phosphorus and between 12,400 and 87,500t of nitrogen (for the EEA-32, this ranges between 8,100 and 68,100t of phosphorus and between 14,600 and 94,700t of nitrogen) (see Image 3.1). These amounts correspond to 0.6-6% of total phosphorus fertilisers and 0.1-1% of total nitrogen fertilisers used in the EU in 2018, respectively (Anderson et al., 2021).

Phosphorus

The Commission has identified phosphate rock as a critical raw material (EC, 2014b). As an essential nutrient for the food system, the recovery and reuse of phosphorus is of high priority. Policies under the European Green Deal are addressing this: as part of the circular economy action plan, an integrated nutrient management plan will be developed to ensure the sustainable application of nutrients and to stimulate markets for recovered nutrients (EC, 2020a). More broadly, the chemicals strategy for sustainability aims to promote the resilience of supply and sustainability of critical chemicals in the EU (EC, 2020c). At the same time, the farm to fork strategy envisages a reduction in nutrient losses from agriculture by at least 50%, while ensuring no deterioration in soil fertility and a reduction in the use of fertilisers of at least 20% by 2030 (EC, 2020f).

The recovery of phosphorus from sewage sludge is a great challenge for countries where sewage sludge is incinerated and where nutrients are not being recycled. Various recovery processes exist, but they are not (yet) cost-effective and are therefore not yet applied to large-scale UWWTPs. In Switzerland, regulatory changes envisage phosphorus recovery from sewage sludge becoming mandatory. Some incineration plants already store sludge ash in order to recover the phosphorus in future.

Significant efforts have been made to recover phosphorus from sewage sludge based on the precipitation of phosphorus minerals, e.g. in the form of struvites. These recovery technologies have been developed and are in operation largely in Canada, Japan and the Netherlands (Tchobanoglous et al., 2014). Global demand for fertiliser is expected to increase by 4% a year because of population growth, so it can be expected that fertiliser recovery from waste water will gain further importance in the future. However, to not only recover but also recycle phosphorus in agriculture, market incentives for using the recovered nutrient must be created, since the price of recovered phosphorus is currently unable to compete with mineral sources ([10]). As well as conventional fertiliser, manure from livestock production also competes with fertiliser recovered from waste water. In livestock-rich areas, manure may be a more cost-effective solution than treated sewage sludge, demonstrating again the need to apply local solutions to sewage treatment (Kehrein et al., 2020).

Image 3.1 Fertiliser derived from sewage sludge

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([10]) Recent events in eastern Europe may promote interest in ensuring the resilience of fertiliser supply.

Other resources can be recovered from waste water and sewage sludge, e.g. nitrogen, cellulose, bioplastics and alginic acid (Kehrein et al., 2020), with potential cellulose pulp production at 1-3 kg/person per year (Ostermeyer et al., 2022). Case studies illustrate a wide variety of possible recovery options, as well as the technical solutions for resource recovery, e.g. UWWTP Amsterdam West, which considered the recovered products alginic acid, bioplastic, cellulose, phosphorus and biogas (van der Hoek et al., 2016). It is not the availability of technology that is preventing the wide-scale application of resource recovery but the lack of both incentives encouraging circularity and a planning and design methodology to identify and deploy the most sustainable solutions in a given context. The WOW! Interreg project considers the market potential for products such as biochar and acetic acid, noting challenges such as high prices owing to small sizes of UWWTPs, consistently meeting quality requirements and legal issues in the registration of products derived from waste water (Interreg North-West Europe WoW!, 2020).

Actions leading to a more circular and sustainable economy revolve around reduction, reuse and recycling. Bottlenecks that can hinder the successful implementation of these can be grouped into three categories: (1) economics and value chain; (2) environment and health; and (3) society and policy. Recovering the value from sewage sludge illustrates aspects of bottlenecks, such as process costs, resource quality, market value and competition, and use and application in the value chain assessment. Legislation to create strong markets and demand for recovered phosphorus and nitrogen may be required (Duong and Saphores, 2015; Kehrein et al., 2020; Mesa-Pérez and Berbel, 2020). Societal acceptance of the recycling of treated sewage sludge and the resources recovered from it — overcoming the 'yuck' factor — is an area with significant challenges.

3.3.4 Energy generation

Although UWWTPs use significant amounts of energy, the waste water theoretically contains between five and ten times more chemical and thermal energy than that needed for treatment. While only some of this energy can be recovered, it is possible for the biggest UWWTPs to be net energy producers (Riley et al., 2020).

Energy recovery of the chemical, thermal and hydrodynamic energy contained in sewage can provide electricity, biogas, steam and hot water. The energy content of the sludge is typically similar to the energy content of low-grade coal (Rafie et al., 2016). Energy can be generated from sewage sludge through pre-treatment by anaerobic digestion to produce biogas and/or by incineration, pyrolysis and gasification of the sludge. Biogas (Image 3.2) comprises 60-70% methane, 30-40% carbon dioxide and trace amounts of other gases (e.g. hydrogen, hydrogen sulphide and nitrogen). Biomethane recovered from biogas can be used as vehicle fuel, in gas engines and for generating electricity and/or heat. Serious accidents can occur with biogas generation (e.g. BBC, 2020), and the ability to meet necessary safety standards as part of the transition to greater sustainability is an important consideration.

Image 3.2 Biogas generation in anaerobic digesters.

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Several studies have made estimations of the additional energy potential (i.e. on top of that already recovered) by assessing different sewage sludge options. Direct comparison of the results is difficult, owing to differences in starting assumptions. Anderson et al. (2021) considered the amount of sewage sludge sent to landfill and composting, i.e. from 30% of the total sludge produced in the EU. They estimated that the EU-27 could potentially recover between 1,800GWh and 3,200GWh of energy (net heat and electricity) through anaerobic digestion of the total sewage sludge generated, and 250GWh (net electricity) through incineration of the total sewage sludge generated that is currently sent to landfill. This represents 7%, 13% and 1%, respectively, of the total waste water sector energy needs in the EU-27 in 2018.

Using an alternative approach to energy calculation, including of the available sludge, Huygens et al. (forthcoming) estimated that up to an additional 3,285GWh could potentially be recovered through anaerobic digestion of the total sewage sludge applied directly to land (30% of the total) and 850GWh resulting from the incineration of sludge currently sent to landfill.

Considering energy production if all sewage sludge was anaerobically digested, Svenskt Vatten estimated that about 3,000kWh of biogas can be recovered per tonne of dry sewage sludge (with 1 t representing the annual load of 33 p.e.). Biogas production from Swedish UWWTPs was 721GWh in 2020, with a total energy potential estimated at 800GWh for its population of 10 million (Svenskt Vatten, 2021).

Selection of the optimum option for energy recovery from sewage sludge must consider additional energy demands and greenhouse gas losses that arise from sludge processing. Energy savings and burdens need to be summed to derive net values for assessed energy recovery options. Huygens et al. concluded that, of the different sewage sludge options, anaerobic digestion followed by use on land and co-incineration were the options that have the lowest (but still net positive) greenhouse gas emissions.

Most focus on energy generation from waste water treatment has been on anaerobic digestion and incineration, but operators may have other options. For instance, solar and wind energy generation can make a contribution, while heat recovery from the waste water itself can be a significant source of energy. At the Katri Vala heat recovery plant in Finland, the estimated potential heat energy recovery represents up to 500% of a plant's heat energy consumption (Heinonen, personal communication).

Actual solutions for a particular plant depend on local circumstances. For instance, incineration facilities may not be available, while biogas generation may not be an economic option at some smaller sites. District heating schemes using heat recovered from waste water are applicable if there are buildings needing heating and where it makes sense to build a central heating network.

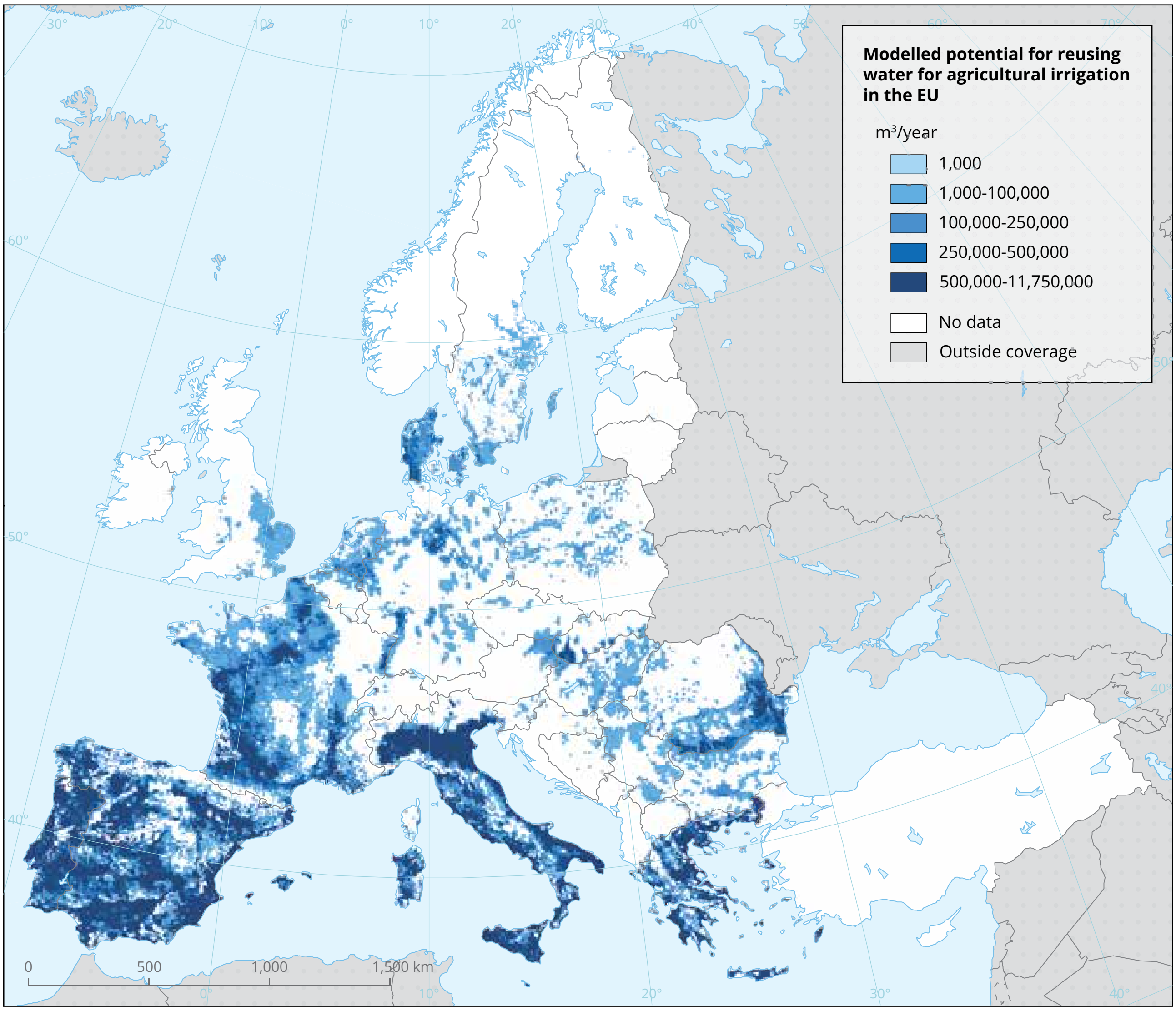
3.3.5 Water reuse

A perhaps less recognised benefit of waste water treatment is that it enables others to reuse this precious resource. Cleaning the water allows its use for other human activities, avoiding abstraction from other, possibly non-renewable sources, such as groundwater.

The return of suitably clean water is also important for aquatic life, ensuring sufficient water in lakes and rivers for life to persist. In parts of Europe, particularly the south, climate change is predicted to lower river discharge levels by up to 40% under a 3 ^{o}C temperature rise scenario (EEA, 2021a). The Water Framework Directive and biodiversity strategy (EC, 2020g) both consider ecological flows, i.e. the amount of water required for the aquatic ecosystem to continue to thrive and provide the services we rely upon (EC, 2016), but Member States are in the early stages of implementation (EEA, 2021a).

Water reuse has become a key part of water resource management in countries suffering the greatest water stress and where the costs already favour reuse. Where water resources are abundant or under less stress, waste water reuse is driven by other factors, e.g. conservation of groundwater resources; reduction of costs; and the precautionary principle, whereby prevention of possible harm is prioritised (EEA, 2019c). The primary use of reused water is in irrigation for agriculture; the modelled potential for reuse is shown in Map 3.1. Other uses are in irrigation of urban spaces such as parks and sports fields, groundwater recharge and improvement of river flow.

Map 3.1 Modelled potential for reusing water for agricultural irrigation in the EU



Reference data: ©ESRI

Note: Average irrigation water requirement, computed with the EPIC model.

Source: Pistocchi et al. (2017).

Water reuse can be classified as indirect or direct:

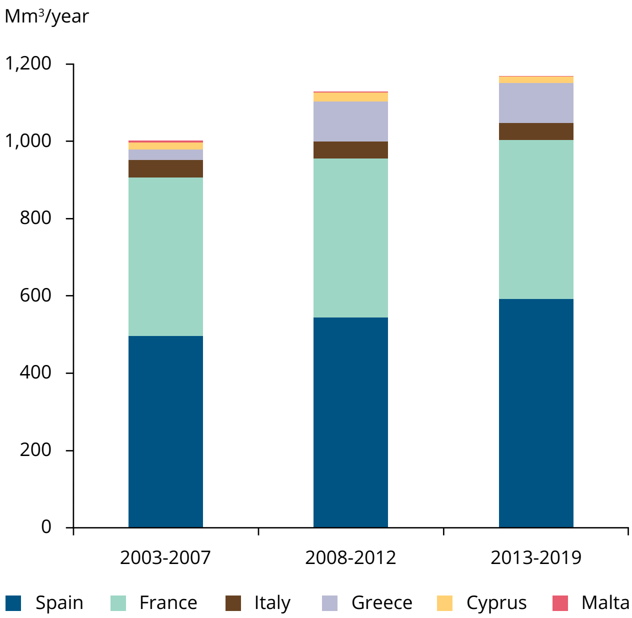
- Indirect reuse is the reuse of treated waste water that is stored in a water body, such as a lake, river or aquifer, and then some of it is retrieved for later use.
- Direct reuse of treated waste water refers to the introduction of treated waste water via pipelines, storage tanks and other infrastructure directly from a water treatment plant, e.g. distributing treated waste water to be used directly in agricultural irrigation.

The quality requirement for reclaimed water is dictated by the final use (agricultural, industrial, urban, environmental, recreational), which determines the treatment technology applied. Waste water treatment plants producing water intended for reuse may be equipped with an advanced treatment composed of various technologies (e.g. coagulation/flocculation, filtration, ultrafiltration, reverse osmosis, disinfection) which determine the costs of investment, maintenance and operation.

Reusing water is not widespread in the EU, although it is increasing in some Member States (Figure 3.3) and may be expected to become more widespread (EU, 2020a). It has been estimated that the potential for treated urban effluent in the EU is six times higher than the current level of reuse (Pistocchi et al., 2017). In countries with significant problems of water stress or water scarcity, water reuse practices have been developed, facilitated by national guidelines. Data are hard to come by but suggest that Cyprus reuses more than 90% of its waste water, followed by Greece, Malta, Portugal, Italy and Spain, where the share of reused urban effluent ranges between 1 and 12% (EEA, 2020a). Experience in these countries might benefit other countries expecting a decline in water availability. Water reuse schemes have been locally applied in other EU countries, e.g. Belgium and Germany, for purposes such as urban irrigation, industrial uses and aquifer recharge. In Sweden, a key driver of water reuse was the protection of coastal water quality and conservation of groundwater resources. Analysis carried out in preparation for the Water Reuse Regulation expected a total cost for the reclaimed water of less than EUR 0.5 per cubic metre (EC, 2018b).

The reuse of treated water helps to increase the amount of water available at a relatively low marginal cost. The treated effluent quality can be adapted to the user's needs, allowing economic efficiency. The costs of treated waste water may be lower where users are close to each other, owing to savings in infrastructure and transport costs. However, issues such as the social acceptability of reusing 'waste water', the costs in comparison with abstracted water and the infrastructure investment that may be needed can hinder the implementation of water reuse.

Figure 3.3 Water reuse in Mediterranean EU Member States



Source: EEA (2020b).

Case study 3 (Box 3.3) provides an example of waste water reuse building on historical practice to deliver water for irrigation, which otherwise might need to be met from the drinking water supply. Meanwhile, treatment to produce a beer in Czechia (Box 3.4, case study 4) is a clear challenge for the quality of treated waste water, demonstrating the high standards it is possible to achieve. Such examples provide a way of increasing public confidence in treated 'waste' water.

Box 3.3 Case study 3 — Reusing waste water for irrigation in Milan, Italy

Reusing waste water for irrigation reduces the quantity of drinking water used for irrigation and guarantees the supply of high-quality water for farmers in the Milan area. All the water treated by the Nosedo and San Rocco plants meets the requirements applicable to reuse for irrigation purposes, as certified by the regional environmental protection agency (ARPA), and it is used to irrigate a substantial portion of farmland with a surface area of over 100km^2. It has been estimated to save farmers between EUR 2 million and EUR 4 million in a year in water costs. This practice of irrigating the rural areas outside the city has its roots in the past.

Source: MMSPA (2018).

Box 3.4 Case study 4 — Beer brewed using recycled waste water at Čížová microbrewery, Czechia

To raise public awareness of the importance of preserving water, Veolia, together with the Čížová microbrewery in Czechia, developed a beer brewed using recycled waste water. Veolia recovers waste water at its Prague treatment plant and then treats the water using a mobile membrane water reclamation unit. The treatment comprises coagulation, followed by ultrafiltration and reverse osmosis, in which ultra-fine synthetic membranes serve as a filter that lets water pass through and retains suspended solids and other substances, such as microorganisms and viruses. The water is then filtered through granulated activated carbon and disinfected. The advantage of membrane technology is that the filtration does not need added chemicals and the new types of membranes have lower energy consumption than in the past. The treated water is then transported to Čížová microbrewery, where it is used to brew Erko beer. In May 2019, 15 hectolitres of lager were produced and production continues to increase as interest in supporting recycling schemes grows.

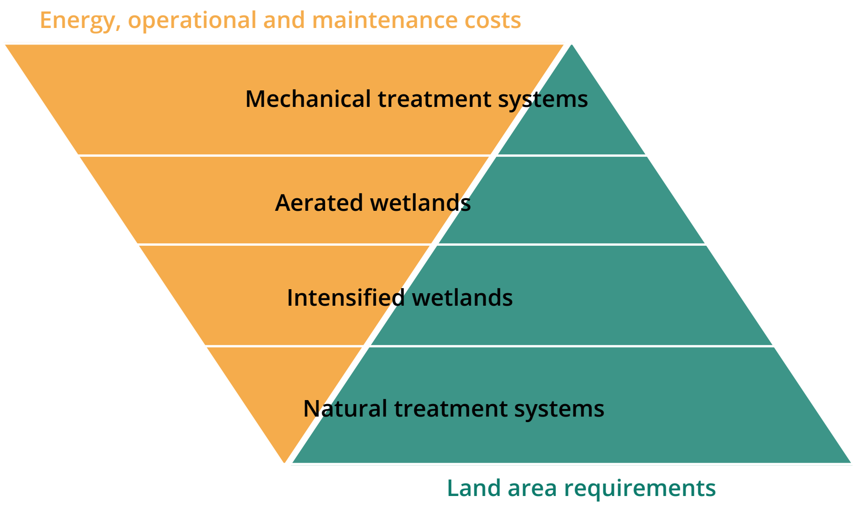
Source: Veolia (2019).

Despite the Water Reuse Regulation of 2020, which recognises that water reuse will become more necessary and so sets standards for the agricultural reuse of waste water, numerous barriers to water reuse still exist in Europe. Drivers of reuse include population pressure and water scarcity. A coherent legislative framework is needed that provides flexibility in treated water quality, depending on destination uses, and that allows for governance structures enabling interdependencies between waste water providers and users of reused water (Guerra-Rodriguez et al., 2020). Under the circular economy action plan, the Commission will facilitate water reuse and efficiency, including in industrial processes (EC, 2020a).

3.4 Decentralised sewage system

Options for urban waste water treatment are constrained by local factors. A densely populated city, with many industries and limited land availability, presents one extreme, while sparsely populated, rural areas represent another. Construction of waste water treatment plants can involve greenhouse gas-intensive activities and high costs, in both the building and operating phases. Alternative solutions can use less energy, release fewer harmful emissions and provide local benefits and control (WaterProjectsOnline, 2019). Figure 3.4 illustrates the sorts of considerations, in relation to operational costs, energy and land use, that are needed when planning sewage treatment solutions.

Figure 3.4 Qualitative comparison of the need for land, energy and maintenance between constructed wetlands and conventional urban waste water treatment



Source: Adapted from Stefanakis (2019).

A focus on nature-based solutions under the EU's biodiversity strategy (EC, 2020b) highlights small-scale solutions for sewage treatment. Natural wetland systems and reed beds can transform and/or remove various pollutants through a series of physical, biological and chemical processes, thereby improving water quality (Image 3.3). These processes are mimicked in 'constructed' wetlands, which treat waste water near its source, without high demands in terms of infrastructure and operational costs, while enabling the use of resources from waste water and increasing green space in rural or peri-urban areas. In a study in Slovenia, the Joint Research Council compared various solutions in terms of cost-effectiveness and socio-economic acceptability. They found that nature-based solutions were a preferred option for areas with predominantly rural, scattered dwellings and small settlements. The concept was proposed as a mainstream solution for the less urbanised areas of the Lower Danube region (Pistocchi et al., 2020).

Owing to their low costs and low maintenance requirement, constructed wetlands are popular in low-income regions. However, they can also be used as a decentralised approach for blocks of buildings, neighbourhoods, commercial facilities, isolated communities and remote areas. They can deliver similar results to tertiary treatment in terms of reducing nutrient concentrations (Cooper et al., 2020). Studies on micropollutants suggest that such constructed wetlands can be effective at preventing their release to water (Gorito et al., 2018), although care must be taken to ensure that oxidation conditions in constructed wetlands are appropriate to address organic micropollutants (Reyes Contreras et al., 2019).

Recent technological advances have significantly closed the gap between nature-based sewage treatment solutions and conventional, mechanical technologies in terms of land requirement (e.g. the compact, mobile aerated constructed wetland) (Stefanakis, 2019). Such solutions can be integrated in urban and peri-urban areas for waste water treatment and urban run-off control and management, following the decentralised approach. For example, the Innoqua Horizon 2020 project investigated a modular system for water treatment based on the purifying capacity of biological microorganisms (earthworms, zooplankton and microalgae), developing a technology for decentralised waste water treatment (Innoqua, 2018).

In the context of resource recovery, technological solutions based on source separation are promising approaches in decentralised sewage treatment. Source separation technologies consist of the separate collection and treatment of concentrated fractions of sewage (urine, faeces and grey water). Numerous studies have shown that treating concentrated, unmixed fractions is more resource efficient than treating highly diluted, combined fractions (Larsen and Gujer, 1997). Resource recovery from sewage is not a novel concept: traditional agricultural societies recognised the nutrient and organic value of sewage, recovering the nutrients and organic matter from household wastes by returning them to the soil, which enabled those societies to live for centuries in closed loop systems (Bracken et al., 2007). Modern examples of decentralised closed loop systems for resource recovery, encompass, for instance, modern urine separating flush toilets invented in Sweden in the 1990s (Hellström and Johansson, 1999) or an integrated concept for decentralised waste water treatment and energy production that applies a source separation approach to sewage treatment and on-site resources and energy recovery in newly developed residential areas, e.g. Hamburg Water Cycle (Augustin et al., 2014).

Image 3.3 Nature-based solution to treat combined sewer overflows at Gorla Maggiore (Oppla, n.d.).

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4
Embedding circularity in sewage treatment

4.1 Introduction

Treatment to clean our sewage is essential to protect human health and the environment. Waste water treatment is also expensive and resource intensive and can generate significant greenhouse gas emissions. In seeking to protect the environment from micropollutants generated by our modern way of living, we solve the issue by adding yet more resource-intensive solutions, creating further waste and emissions. In our focus on ensuring that the water cycle is respected, we have developed a linear solution — missing the circularity that sewage treatment should represent. This approach is an unsustainable way to resolve an issue of a 'waste' that will be continuously generated.

A central problem that we create for ourselves is the use of substances that are harmful to the environment, traces of which can enter the water system from our homes, schools and workplaces. While other sources, such as traffic and industry, also contribute pollutants to waste water, Section 2.6.2 showed that micropollutants mainly come from domestic sources. Some of these substances are essential and alternatives may not be available. But for others, achieving the aims of the chemicals strategy for sustainability will provide a long-term solution. Transitioning to a society in which chemicals and products no longer contain substances of concern ([11]) not only advances zero pollution but also allows circularity, within both the product and the 'waste water' chain. Before achieving that ambition, we will nevertheless have to manage pollutants that are already in use and in circulation.

Historically, we have left it to water managers to solve society's waste problem — at the end of the pipe. River basin management planning under the Water Framework Directive has shown how cross-sectoral efforts can be joined up to manage water: a much greater multi-sectoral effort is required to deliver circularity in sewage treatment. Already, more sustainable solutions are being trialled by innovative utility companies, towns and cities. By recognising the central role that sewage and waste water treatment can play in a circular economy, and enabling the conditions to support circularity, efforts to protect waste water can drive change upstream.

4.2 Rethinking 'urban waste water treatment'

As a society, we have gone to considerable lengths to address the harm that our untreated sewage causes to human and environmental health. The 1991 Urban Waste Water Treatment Directive (UWWTD) required that Member States provide collection systems and treatment of waste water, which has led to significant improvement in Europe's water quality. But this has come at considerable cost, not only financial but also in pollutant discharges to water and to air as greenhouse gas emissions, and, as the climate changes, it brings with it new challenges. More intense rainfall in parts of Europe is leading to more frequent surface water flooding and discharge or run-off of pollutants. In other areas, lack of water resources is becoming a key concern. Demographic change can lead to over- and under-capacity in water utilities such as urban waste water treatment plants (UWWTPs), which reduces their efficiency.

Practically, we have built a system that requires dilution of a nutrient- and energy-rich natural resource with clean water, mixing that with other potentially harmful substances, then draining or pumping this mixture through an extensive pipeline network to a central point. Here, energy is used to aerate and pump 'waste water' through various filters and treatment facilities, dry out the solid material and then discharge the cleaned water. Disposal of the sewage sludge faces continual challenges in finding politically acceptable and economically viable routes. This linear approach focuses on water quality, giving a lower priority to other environmental dimensions.

There are other ways to manage our sewage safely and with less carbon-intensive infrastructure. Keeping faeces and urine separate from grey water, such as that from washing, allows

([11]) That is, those with persistent, toxic, bioaccumulative and mobile characteristics.

alternative, water-less treatment to kill pathogens and recover the nutrients and/or energy (Zeeman and Kujawa-Roeleveld, 2011). Meanwhile, less energy-intensive treatment allows the grey water to be reused where quality demands are lower, e.g. in parks and gardens. Such decentralised schemes can operate at a very local scale, e.g. buildings and streets.

Clearly, such approaches are niche in the near term. Conventional safe treatment and management of human waste mostly relies on expert engineers and water managers, and the infrastructure in homes, schools and workplaces mostly relies on connection to UWWTPs. Experiments with building-focused sewage treatment and water reuse have already highlighted the problems associated with mistakes in construction, where effluent from other non-drinking water systems in buildings have been introduced into the drinking water distribution system, compromising human health (EC, 2021e). Less immediately, environmental harm may be caused if the waste from ourselves and our houses continues to be contaminated with micropollutants (Comber et al., 2014, KomS, 2021; Zintz et al., 2021), despite efforts made by households with individual treatment systems, such as septic tanks, being careful not to poison those systems (Mulder, 2019). Realising the ambitions of the chemicals strategy for sustainability over the longer term is key to reducing harmful micropollutants at source. 'Hybrid grey and green' water infrastructure combines centralised and decentralised water treatment, reducing water loss, increasing water reuse, optimising the exploitation of alternative water sources in a circular economy and strengthening resilience against climate change events (Water Europe, 2020).

One of the features of such a local approach is that it already provides the opportunity for small, remote or under-served communities to tackle sewage treatment in areas where it is still lacking or insufficient, and to develop skills and capabilities in 'new' technologies (or re-learning traditional recycling). Options to meet stringent, new quality standards at Ingoldisthorpe included a new treatment plant with both high capital and carbon costs, but collaboration between the water utility, environmental regulator, local community and landowner allowed the establishment of a water-treating wetland ecosystem (Box 4.1, case study 5).

Box 4.1 Case study 5 — Collaboration at village level, Ingoldisthorpe, United Kingdom

The River Ingol is one of only 200 chalk rivers in the world and provides an extremely rare habitat for a variety of plants and wildlife. The river was threatened by increased levels of phosphate and ammonia released into the river by a UWWTP. Initial plans to build a new treatment plant would have had both high capital and carbon costs. Instead, Anglian Water, the environmental regulator, local organisations such as the Norfolk Rivers Trust and the local community arrived at a 'soft engineering' solution. The project created a natural wetland of one hectare, to naturally filter the water downstream from the UWWTP and to improve the quality of water flowing into the River Ingol. The outcomes were high water quality, a thriving habitat for wildlife and reduced flood risk. Provoked by customer support for natural capital solutions, Anglian Water committed to undertake a further 30 feasibility studies for wetland treatment sites.

Source: WaterProjectsOnline, 2019; WWF, 2020.

Box 4.2 Case study 6 — Collaboration at city level, Amsterdam, Netherlands

In Buiksloterham, a collaboration between the water board, the municipality and a housing corporation is piloting a study on separating waste water at source, to test the sustainability of decentralised sewage treatment. An innovative vacuum sewer and floating treatment plant has been built with a capacity of 1,550p.e., with vacuum toilets installed in 47 floating homes.

The traditional waste water sewerage system has been replaced by a multiple sewer system, which consists of a vacuum pipe with a small diameter for the collection of concentrated sewage and a free-fall pipeline for grey water. This collection method enables efficient local water treatment, and raw materials (phosphate), heat and energy (biogas) can be recovered and reused locally. This primarily provides raw materials and energy, but also saves energy by avoiding pumping the waste water over long distances.

Amsterdam plans to learn from Buiksloterham in its development of Strandeiland, a new island in IJburg where approximately 8,000 homes will be built. The water board and the municipality want to apply 'new sanitation' there, as well as using thermal energy from waste water and surface water to make Strandeiland energy neutral.

Source: Waternet (2020a,b).

New building in urban areas can also provide opportunities for purpose built, decentralised treatment approaches, such as the brownfield development site at Buiksloterham (see Box 4.2, case study 6).

Health protection and prevention of pollution continue to be the key purpose of sewage and urban waste water treatment. Improved scientific knowledge since the 1990s has shown the presence of many pollutants in surface waters, and many of these arise from chemicals and products that we use in our homes and workplaces. Such societal and sectoral issues are beyond the capacity of water managers to resolve; rather they require wholesale review of what substances we choose or allow to be used. Such is the role of the chemicals strategy for sustainability, launched by the European Commission in 2020 (EC, 2020c). Among its ambitions, the strategy aims to ban the most harmful chemicals in consumer products, allowing their use only when essential. This limitation is key, both to lowering direct human exposure to harmful chemicals and to reducing releases of harmful chemicals to water. The ambition to boost the production and use of chemicals that are safe and sustainable by design should lead to less chemical pollution over the longer term. In turn, lower pollution loads in waste water will reduce the need for advanced, energy-intensive treatment than at present, i.e. turning waste water treatment from a vicious into a virtuous circle.

Meanwhile, UWWTPs face the challenge of cleaning up waste water to meet more demanding standards set in legislation. Modelling for the revised UWWTD by Pistocchi et al. has examined the costs and benefits of micropollutant removal, considering *c*.1,200 chemicals assumed to be a proxy of the total pollution conveyed by raw waste water. This has shown that advanced treatment for micropollutants at all plants in Europe with a capacity of 100,000p.e. or more could reduce the overall toxicity of discharged effluents by about 40% (Pistocchi et al., forthcoming).

The solutions identified to address sewage and urban waste water treatment are necessarily local. Water managers aim to optimise solutions according to local requirements and possibilities: ensuring that circularity principles form part of those considerations, and enabling them to do so, is the role of policymakers. When trade-offs come into play, ensuring the protection of human health and the environment should take priority.

4.3 Circular economy — from 'waste water treatment' to resource hub

The goal of a circular economy is to manage natural resources efficiently and sustainably (EEA, 2016). Respecting planetary boundaries by increasing the proportion used of renewable resources while reducing the consumption of raw materials and energy, and cutting emissions and material losses, meets goals set for both sustainability and business efficiency. The circular economy action plan under the European Green Deal seeks to accelerate the transition towards a regenerative growth model and to move towards keeping resource consumption within planetary boundaries (EC, 2020a). Three principles underpin the process of achieving a circular economy (Ellen MacArthur Foundation, n.d.):

1. eliminate waste and pollution;
2. circulate products and materials;
3. regenerate nature.

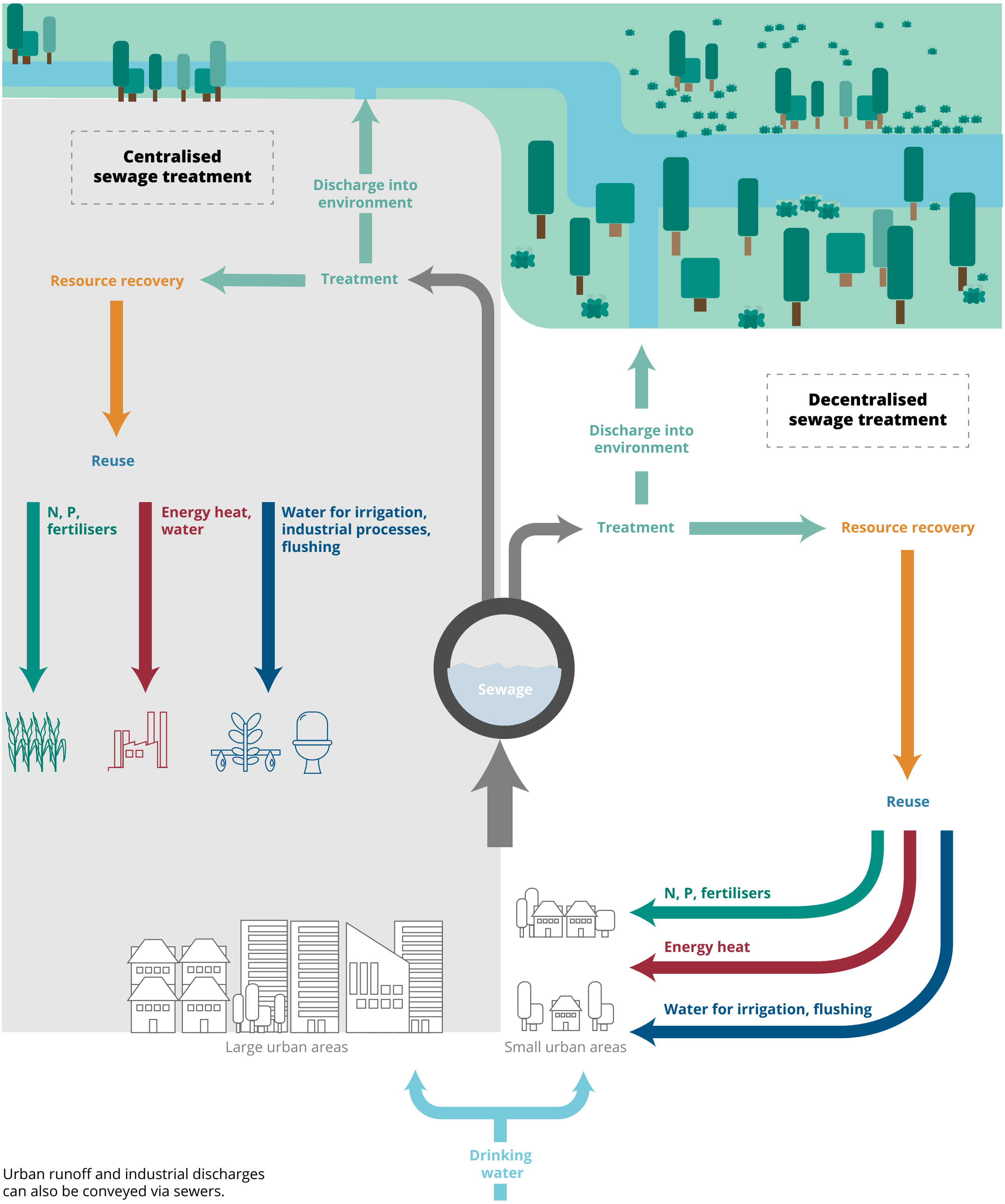
If water use is based on a linear 'take-make-consume-dispose' model, as it has been historically, the quality of water declines until it becomes unfit for further use by humans and ecosystems (Stuchtey, 2015). Urban waste water treatment breaks into this linear approach by cleaning the used water, returning it to the environment for reuse and allowing sludge to be recycled on land or the resources it contains to be recovered. However, focusing only on the treatment process itself will not lead to circularity, as the principles of minimising water use and preventing pollution of urban waste water need to be applied upstream (Smol et al., 2020).

Pollution prevention at UWWTPs can be improved by reducing greenhouse gas emissions and enhancing the removal of micropollutants. Circularity can be supported by the transition of UWWTPs from a role of 'pollutant removal' to resource recovery, becoming 'resource hubs'. A wide range of technologies is available for water reuse and for energy and resource recovery, despite their limited full-scale application (Kehrein et al., 2020; Veolia, n.d.). Returning water to the environment and recycling it for potable and non-potable use contribute to regenerating nature.

Figure 4.1 depicts the circularity that can be achieved in sewage treatment by both UWWTPs and decentralised approaches. Both start with sewage from households, but, whereas decentralised treatment retains resources for local reuse and recycling, the scale of treatment and recovery at UWWTPs can be more intensive and much larger.

Smol et al. (2020) noted the need to 'rethink' our approach to the reuse and recycling of resources from waste water treatment. From the water treatment perspective, there are difficulties relating to the regulatory environment and to opaque market conditions (IWA, 2016). Implementing circularity may require changes in building regulations, for example to allow decentralised and/or nature-based solutions, and extending the regulatory context in which water utilities operate, for instance where UWWTPs could become energy producers. Meanwhile mechanisms are needed to incentivise the use of recovered resources, such

Figure 4.1 Implementing circularity in sewage treatment



Urban runoff and industrial discharges can also be conveyed via sewers.

as phosphorus in struvite, over those from non-renewable sources, which are currently uneconomic compared with commercial fertilisers (see Box 4.5, case study 9).

A key input into the circle is customer feedback defining the quality of products. Specific value chains, embedded in local or regional economies, may need to be established, such as in the REVAQ scheme for sewage sludge (see Box 3.2, case study 2).

4.4 Accelerating the transition

Sewage treatment is an essential service that can provide clean water, nutrients and renewable energy. However, in its current form it uses significant amounts of energy, leads to significant emissions of greenhouse gases and produces large quantities of sewage sludge that may represent disposal problem for utilities. The shift from 'waste water management' to 'resource hubs' is already happening in some forward-thinking towns and utility organisations. A determination to reach net zero emissions drives analysis of both capital and operational expenditure, allowing investment in innovative solutions where necessary.

Case study 7 (Box 4.3) outlines the fundamental review that Scottish Water is undertaking across its operations as it aims to reach zero greenhouse gas emissions, while the Marselisborg UWWTP (Box 4.4, case study 8) focuses on the city scale.

Innovation can play a major role in enabling circularity. More efficient technologies that can reduce the energy costs of resource recovery and increase recovery rates are perhaps familiar, but innovation also applies to new partnerships. These may extend across public administration, research, industry and citizens, with new business models and

Box 4.3 Case study 7 — Net zero emissions, Scottish Water, United Kingdom

Scottish Water has a target to reach net zero greenhouse gas emissions by 2040. Some actions are directly under its control, such as improving energy efficiency and hosting renewable energy. Others, however, require efforts to influence customers and supply chains, such as the amount of water people use, removing surface water from sewers and reducing emissions from the cement the organisation buys. It has identified areas for innovation, such as low-energy treatment methods; ammonia and methane recovery; the need for digital and analytical tools; and low-/zero-emission materials for investment and operations.

Source: Scottish Water, 2022.

Box 4.4 Case study 8 — Energy efficiency and recovery, Marselisborg UWWTP, Denmark

In 2005, Aarhus City Council decided to upgrade and consolidate its municipal waste water treatment system, which at that time comprised 17 small facilities. In 2019, the Danish water sector set out its ambition to be climate and energy neutral by 2030.

The Marselisborg urban waste water treatment plant has increased plant efficiency and reduced energy consumption by optimising its processes. It now produces 50% more electricity than it needs for waste water treatment and 2.9GW of heat for the district heating system. Energy-saving technologies include an advanced control system, a new turbo compressor, sludge liquor treatment and optimisation of the bubble aeration system. This has resulted in savings of approximately 1GWh/year (c.25%) in power consumption. By implementing energy-efficient solutions and producing biogas from the sludge, the utility is able to cover almost all the energy needed for the whole water cycle, from groundwater extraction, to pump stations, water distribution and waste water treatment

Source: Aarhus Vand A/S (n.d.).

new forms of water governance that can also stimulate and support technological innovation (Ellen MacArthur Foundation, 2015; Arup et al., 2019). The strategic implementation plan for the European Innovative Partnership on Water identifies several areas for stimulating innovative solutions, such as water reuse and recycling; water and waste water treatment; the water-energy nexus; and cross-cutting issues including water governance; decision support systems and monitoring and financing (EC, 2012b). Digitalisation can help in the delivery of improved efficiency and productivity and of rapid monitoring to inform decision-making (EC, 2021f; Mbavarira and Grimm 2021). Mechanisms to promote a shift towards markets for recovered resources and sustainable technologies may be required. Practically, achieving circular practice can require sustained efforts by many players, not least in enabling legislation, as demonstrated by the work done so far in the Netherlands to allow phosphorus recovery from sewage sludge (Box 4.5, case study 9).

4.4.1 Decentralised solutions for circularity

One of the empowering aspects of sewage treatment is that local conditions necessarily lead to local solutions (Aqua Publica Europea, 2019). There are tools for individual houses, small villages and towns, and including major cities (Daigger, 2009).

Decentralised waste water management is used to treat and dispose of, at or near the source, relatively small volumes of waste water, originating from single households or groups of dwellings located in relatively close proximity (less than c.3-5km) and not served by a central sewerage system connecting them to a regional UWWTP. They include nature-based solutions (Figure 4.2).

While still needing a local collection system, decentralised waste water treatment is likely to be smaller scale and less expensive than conventional, centralised treatment, especially when the grey water components have been separated from human waste (Capodaglio, 2017; Capodaglio et al., 2017).

Decentralised systems focus on the on-site treatment of waste water and on local reuse and recycling of resources contained in domestic waste water. They are particularly attractive because of the possibility of reducing long-term treatment costs. The systems can be easily adapted to local conditions and capacity can be added incrementally and quickly. Therefore, they can serve as (possibly cheaper) alternatives to conventional expansion/refurbishment of the sewerage network. The use of remote control and monitoring contributes to operational and management improvements and resolves problems arising from a lack of skilled personnel. Nature-based solutions can contribute to biodiversity and provide additional benefits, such as biomass production, carbon sequestration, flood mitigation, aesthetic value and opportunities for recreation. Decentralised solutions allow source separation of urine and faeces, and the reuse of grey water or other water saving systems, which can further enhance the recovery of resources and energy. They can help support local water use and reuse in that treated water can be used in agriculture, or (in more urban areas) can be used instead of high-quality drinking water for purposes such landscaping, recreation, groundwater recharge or industrial cooling, which have lower quality requirements (Capodaglio, 2017). Implementation of a decentralised solution to waste water treatment needs local discussion, which can attract the interest of local stakeholders. Stakeholder involvement can also help in establishing closed loops for local reuse and recycling of recovered resources, and thus contribute to establishing a viable value chain for recovered resources. In this way, they can serve as sources of novel ideas and provide pilot studies that can be extrapolated to larger scales.

4.4.2 Individual action

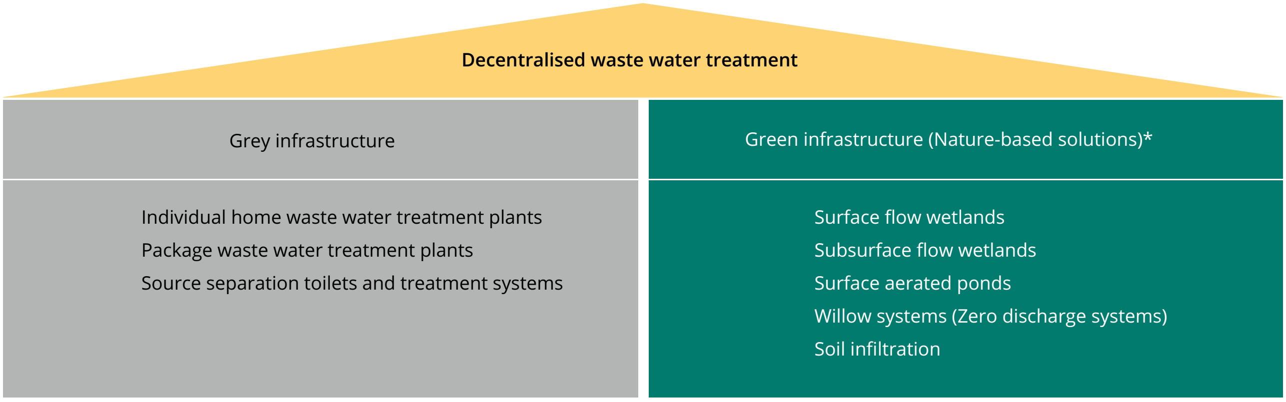
For those of us living in areas where our sewage and waste water disappears down the pipe, our influence on reducing the environmental impact of waste water treatment might

Box 4.5 Case study 9 — Legislative barriers to urban phosphorus recovery, the Netherlands

Phosphorus can be recovered in different products from sewage sludge, for example as struvite (which can be used as a slow-release fertiliser) or in ash following mono-incineration (i.e. when the sludge is not mixed with other wastes). In the Netherlands, experiments to recover struvite from urban waste water treatment plants at full scale started in 2006, but its introduction to the fertiliser market was hindered by the classification of struvite as a waste, with the Fertilisers Act prohibiting the use of wastes (van Nieuwenhuijzen et al., 2009). A change in legislation was supported by studies examining struvite's use as a fertiliser and various initiatives undertaken by the Dutch Nutrient Platform (Ehlert et al., 2013), particularly the Dutch Phosphate Value Chain Agreement, signed by more than 30 businesses, research institutes, non-governmental organisations and the Dutch Ministry of Infrastructure and Water Management, to initiate a sustainable market for reusable phosphate streams (Nutrient Platform, 2018). The use of struvite and another two recovered phosphates as fertilisers was eventually approved in 2015. Even so, struvite today still forms a very small part (less than 1%) of the EU fertiliser market

Source: Muys et al. (2021).

Figure 4.2 Decentralised sewage treatment



Note: *Treatment of raw waste water, grey water or waste water after primary treatment.
Further information on grey infrastructure available in Grebot et al. (2019) and on green infrastructure in Cross et al. (2021).

seem somewhat remote; however, we all have a part to play, for example by:

1. Using water more efficiently. This not only saves water, but also the energy used for treating it and pumping it to the tap, and subsequently the resources required to take it through the sewage treatment process. Energy-efficient appliances, such as dishwashers, also tend to be water efficient.

2. Avoiding putting harmful pollutants down the sink and drain. This avoids the need to remove them from the water — if indeed that is possible. Safe disposal of pollutants is usually offered by local councils, while leftover medicines can be taken back to pharmacies. Look for products with an ecolabel, such as the Nordic Swan, which sets requirements, e.g. for cosmetics and household chemicals (Nordic ecolabelling, n.d.).

3. Choosing environmentally friendly materials when replacing clothes, textiles and furniture, where possible. This helps avoid pollutants in such products being washed out and then eventually reaching the sewerage system.

4.5 What needs to change

With no change in the current direction, the trajectory for urban waste water treatment in Europe will be towards more energy-intensive treatment to remove micropollutants, about which we are becoming increasingly aware. Concern about pollutants transferred to sludge during water treatment will continue to limit opportunities for applying sewage sludge to land, leading to increased demand for incineration and problems for regions lacking such capacity or those with soils lacking organic matter. Infrastructure investment costs will continue to increase, along with the greenhouse gas emissions embedded in concrete, plastics and steel for sewerage networks and treatment plants. Accepting this situation risks accepting that Europe will become locked-in to an unsustainable process (EEA, 2019b).

Water managers are skilled at optimising processes within their remit. UWWTP processes can be optimised to improve energy efficiency. Greenhouse gases released during treatment can be reduced and more energy recovered from the waste water treatment cycle, such as in biogas and through heat recovery. Restrictions on the application of sewage sludge to land and phosphorus recovery requirements are leading some utility organisations towards solutions such as mono-incineration and finding innovative applications for recycling the remaining ash.

Meeting the aims of the European Green Deal requires a fundamental review of human activities to find approaches that can deliver long-term sustainability. Protecting human health and the environment from sewage does not necessarily require the major infrastructure programme that we have developed up until now. Decentralised approaches, including nature-based solutions such as reed beds, enable low-input, effective sewage treatment, while at the same time producing local environmental benefits such as green space. Large UWWTPs can become energy-efficient resource hubs, promoting reuse and recycling. While the treatment solution at a particular place has to reflect the local situation, more sustainable approaches are available and must be enabled.

Achieving a circular economy in sewage treatment is a long-term project and is dependent on multiple contributors, many of them outside the water sector. As well as water managers, stakeholders include citizens, the chemicals sector and urban planners, while innovation and enabling legislation are needed at all levels, together with efforts to establish viable markets for recycled products. This is what we need to do to transition towards the level of sustainability demanded by the Green Deal.

Abbreviations

BOD	Biological oxygen demand
CSO	Combined sewer overflow
E-PRTR	European Pollutant Release and Transfer Register
GHG	Greenhouse gas
IAS	Individual or other appropriate system
IED	Industrial Emissions Directive
JRC	Joint Research Council
PAHs	Polycyclic aromatic hydrocarbons
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
REVAQ	Swedish certification system ensuring quality of sewage sludge
SDG	Sustainable Development Goal
UV	Ultraviolet
UWWTD	Urban Waste Water Treatment Directive
UWWTP	Urban waste water treatment plant
WFD	Water Framework Directive

Glossary

Word	Meaning
Advanced treatment	Advanced (tertiary) treatment can involve (biological or chemical) nutrient removal to help prevent eutrophication and/or removal of specific toxic substances, disinfection (to reduce pathogenic bacterial and viral organisms), e.g. by treating waste water with ultraviolet light (UV treatment) or by ozonisation or chlorination. In the Urban Waste Water Treatment Directive, nitrogen and phosphorus removal is called 'more stringent treatment'.
Agglomeration	An area where the population and/or economic activities are sufficiently concentrated for urban waste water to be collected/treated.
Circular economy	The circular economy offers an opportunity to recognise and capture the full value of water — as a service, an input to processes, a source of energy and a carrier of nutrients and other materials. In a circular economy, water is seen as the finite resource it is. Using water is avoided whenever possible and water and other resources are reused.
Eutrophication	The enrichment of water by nutrients, especially compounds of nitrogen and/or phosphorus, causing accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance in the balance of organisms present in the water and in the quality of the water concerned.
Grey water	Waste water that comes from sinks, washing machines, bathtubs and showers.
Population equivalent (p.e.)	The organic biodegradable load having a 5-day biochemical oxygen demand (BOD5) of 60g of oxygen per day. It corresponds to the average oxygen demand of the waste water produced by one person per day.
Pressure	An effect of an anthropogenic activity. There are three main types: (1) excessive use of environmental resources; (2) changes in land use; and (3) emissions (of pollutants, waste, radiation, noise) to air, water and soil.
Primary treatment	A physical and/or chemically enhanced settlement of suspended solids in waste water.
Receiving water	Water body (stream, river, pond, lake, coastal, transitional) into which treated or untreated waste water is discharged.
Secondary treatment	'Biological' treatment, using bacteria to degrade the biodegradable matter in waste water.
Sewage	A mixture of domestic waste water from baths, sinks, washing machines and toilets.
Urban waste water	A mixture of sewage (domestic waste water), industrial waste water, and rain water and runoff which drains from urban areas into sewers.

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