



# Beyond water quality: sewage treatment in a circular economy

## Subtitle

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## Key messages

- Treatment to clean up our sewage is essential to protect human health and the environment.
- Urban waste water treatment (UWWT) has been key to improving the quality of Europe's waters in recent decades, shown in the significant improvement of bathing water quality. However, treatment methods can be energy- and water- intensive.
- Many chemicals from our homes and workplaces, such as plasticisers and personal care products, end up in waste water. These then need removing, as waste water treatment remains the last chance to protect our waters from chemical pollution.
- Greenhouse gases are emitted at many stages of UWWT, from those embedded in infrastructure like sewers to sludge management.
- We can move from our linear approach to waste water treatment, which focuses on the water cycle and water treatment, to a genuinely circular approach, which considers all the inputs and emissions related to sewage treatment.
- Sewage treatment can generate energy and allow resource recovery, e.g. of phosphorus, leading to sustainability.
- Treatment of sewage is not "one size fits all". Local conditions call for local solutions. Financial resources, the availability of land, the density of population and types of industry are among the factors which influence potential options.
- Technical solutions already exist to deliver circularity in sewage treatment. Vacuum toilets enable sewage to be safely treated within buildings or streets, recovering both energy and nutrients. Meantime, waste water from washing and cooking can be reused for lower quality applications. We need to enable implementation of such innovative approaches, through regulations, institutional and cultural shifts.
- A key component for longer term circularity of sewage treatment is to ensure that harmful chemicals no longer reach sewage. This requires implementation of the Chemicals Strategy for Sustainability under the European Green Deal.



## Executive summary

The European Green Deal sets 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, 2019).

Sewage treatment is an essential service which can deliver clean water, nutrients and organic fertiliser. It can and should contribute to delivering the Green Deal, while recognising that the primary priority is to protect human health and the environment from harm caused by insufficiently treated sewage.

EU water legislation has focused on the water cycle, improving water quality and aiming to restore biodiversity. The Urban Waste Water Treatment Directive 1991 (UWWTD) has led to improved water quality in Europe, but urban waste water treatment plants (UWWTP) still represent the major point source of pollutants to Europe’s waters (EC, 2019; EEA ). Compliance with the UWWTD requires building collection and treatment facilities, usually involving use of energy-intensive materials such as concrete and steel, with energy-intensive operation, while not covering greenhouse gas emissions of methane and nitrous oxides (Fig ES-1).

Water managers have already identified ways to become more energy efficient and reduce operational greenhouse gas emissions (GHG). Some UWWTPs generate more energy than they use, through biogas generation and waste water heat recovery. Some towns and operators have ambitious plans for “net zero” GHG emissions and are intensively reviewing their infrastructure and processes. Alternative approaches to energy-intensive treatment include constructed wetlands which in addition can provide green space for citizens, and decentralised approaches which treat and dispose, at or near the source, relatively small volumes of waste water.

Sewage treatment should be recognised as integral to resource recovery, rather than “waste management”. Incentives for reuse and recovery are needed to enable use of a range of products recovered from the waste water stream. Legal barriers limiting use of recovered resources should be revisited. Coherent legislative frameworks for all relevant sectors along potential value chains should be in place to enable recovered resources to enter the market.

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 be the same as for a low density, rural population. At legislative level, a focus on the desired outcome could provide flexibility for local solutions.

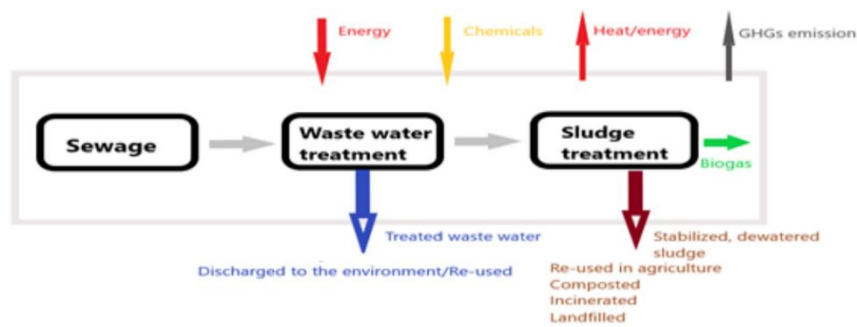
A significant blocker in realising circularity in sewage treatment is the presence of harmful chemical pollutants in waste water. This leads to the need for intensive treatment to remove them and then the presence of persistent pollutants in sludge, making that unsuitable for reuse on land. Breaking this cycle requires the successful implementation of the Green Deal “Chemicals Strategy for Sustainability”, so that harmful pollutants are no longer present in the sewage.

Achieving a circular economy in sewage treatment is a long term project and is dependent on many contributors. Case studies show the opportunity. At national and regional level, social acceptance of change is crucial for successful implementation. Strategic goals, giving industry and the public confidence in long term direction, enable investment in innovative approaches. Certification schemes can build public confidence in circular products and improve social acceptance. Collaboration across sectors and partners is essential for a successful outcome. At municipal level, projects require significant local input and energy.

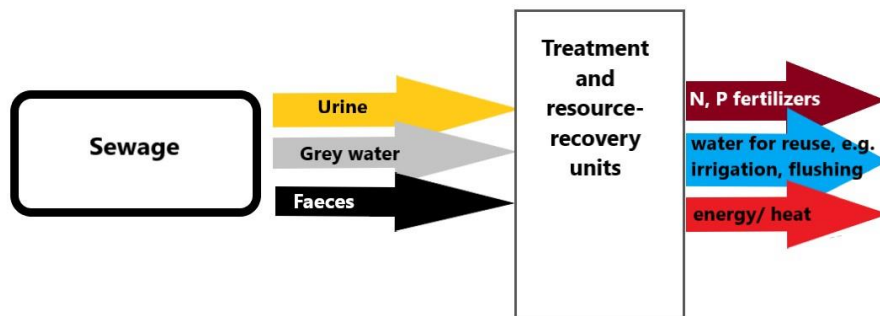


Figure ES 1 Inputs and outputs of sewage treatment,

a)



b)



a) at WWTP, b) source separation sewage treatment



# 1 Introduction – prevention of water pollution

## 1.1 Aim of the report

Treatment of urban waste water – sewage and water used in homes and workplaces - 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 harmful role nutrients had on the environment led to the [agreement] on the Urban Waste Water Treatment Directive (UWWTD) in 1991. In recent years, we have become more aware of the many other pollutants in waste water, which are not targeted by that Directive. With the over-arching perspective of the European Green Deal and 8<sup>th</sup> Environmental Action Programme we 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 in a circular economy. Cleaner water provides more natural habitats, benefitting biodiversity. Investment in prevention of pollution, including upstream measures such as avoiding use of harmful chemicals, is key to delivering sustainability.

This report sets out considerations for sewage treatment towards meeting the ambitions of the Green Deal for 2050, through targeting zero pollution and circularity.

## 1.2 Scope of the report

This study focuses on sewage and the dirty (“grey”) water we send down sinks, drains and sewers. Left untreated, this waste water pollutes rivers, lakes, groundwater and seas. The treatment required to minimise pollution of water however, can lead to production of greenhouse gases and contaminated sludges, which can go on to pollute air, soils and water.

The combination of sewage and grey water, “urban waste water”, is usually treated in urban waste water treatment plants, but for the 11 % of Europeans whose dwellings are not connected to waste water treatment (Eurostat, 2019), individual treatment such as septic tanks or package plants are necessary. These too can pollute air and water.

It doesn’t have to be this way. Applying a systemic approach to sewage and waste water, Europe can move to a virtuous circle, minimising pollution and utilising the renewable resources provided by sewage and its treatment. Delivering this needs a range of approaches, including technology, infrastructure investment, nature-based solutions, changes in legislation and cultural acceptance.

With the ambition of the European Green Deal coinciding with the refit of Water legislation, there is now an opportunity to re-set our approach to the treatment of Urban Waste Water Treatment 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. Chapter 3 considers the resources used in treatment of sewage, and the resources which could be reused and recovered. Chapter 4 considers a systemic approach to delivering 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 nineteenth century led to the development of sewer networks in cities around Europe. Treatment facilities were gradually developed, though even into the 1990's and 2000's 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 1970's, with the first 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, 1975) bathing water in 1975 (EEC, 1975) and other water pollution prevention measures followed.

Recognising the harm caused by excessive nutrients in sewage discharged to surface waters, the Urban Waste Water Treatment Directive (UWWTD) (EEC, 1991) was adopted in 1991 with the objective to protect 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 2000 population equivalents<sup>1</sup> (p.e.) 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, 2019) sets out an ambition to reset the Commission's commitment to tackling climate and environmental-related challenges. It also aims to protect, conserve and enhance the EU's natural capital, and protect the health and well-being of citizens from environment-related risks and impacts. Alongside this strategic direction for Europe, the draft 8th Environment Action Programme (EC, 2020) 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 re-appraisal of how we use and recycle resources. This sets a bold context 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 for pollution to be reduced to levels no longer considered harmful to health and natural ecosystems, and which respect planetary boundaries (EC, 2021). 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, but 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 (1986) is currently being evaluated, but currently contains limits only on metals. This is despite concerns that the limits are too high and do not consider other pollutants (Ricardo, 2021). Reflecting the

<sup>1</sup> Population equivalent is a unit to measure the amount of sewage generated in agglomerations. 1 population equivalent expresses an amount of sewage generated by one person per day and it corresponds to the organic biodegradable load having a five-day biochemical oxygen demand (BOD5) of 60 g of oxygen



pressures on water availability already affecting some Member States, the Water Reuse Regulation (EC, 2020) sets standards for treated waste water to be used in irrigation, such as on chemical and microbiological contamination. 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, 2020).

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. Our knowledge of the behaviour and fate of many of these is low, yet the risk posed by some could be high. Alongside this, there is a crisis in biodiversity driven by factors such as climate change, pollution, over-exploitation, land and sea use and invasive species. Ensuring we limit pollution from sewage and waste water is essential. But this is an “end of pipe” solution. It is very complex to work back from the pollutants in sewage to try and exclude from product chains (Ricardo, 2021). A more fundamental review of what chemicals and products we use in our homes and workplaces is needed. The Chemicals Strategy for Sustainability sets out the ambition towards a toxic-free environment, with the aim that chemicals are made safe-and-sustainable-by-design, and thereby will be produced and used in a way that maximises their contribution to society, while avoiding harm.

The over-arching Water Framework Directive (WFD) (EC, 2000) provides a framework for management of Europe’s waters. In surface waters, the WFD considers both chemical and ecological status, with the objective of all water bodies to be in 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, EC 2008, 2013). Other substances in excessive amounts can lead to failure of ecological status, if they are regarded as 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 of good status requirements under the WFD.

An additional driver for the implementation of the UWWTD in some areas has been the Bathing Water Directive (EC, 2006, EEC 1976). 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 e.g. 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.

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. Szilvasi et al, 2017; Heidegger and Wiese, 2020) - in 2021, the WHO counted 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.

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 around chemicals takes a “source control” approach – aiming to prevent pollution, while the WFD provides a monitoring mechanism to check on the most harmful substances present in water. Thus the 2006



Registration, Evaluation, Authorisation and Restriction of Chemicals Regulation (REACH) aims to improve the protection of human health and the environment through the better and earlier identification of the intrinsic properties of chemical substances. Meanwhile, the Industrial Emissions Directive (IED) targets discharges from large installations, while the European Pollutant Release and Transfer Register (E-PRTR) requires operators to record pollutant emissions above certain thresholds. The IED and E-PRTR are under review and the requirements related to emissions to water may be strengthened for both direct and indirect releases. The E-PRTR currently requires UWWTPs to report where they are over a threshold of 100 000 p.e., which is recognised as being too high for a threshold and not ambitious enough to address the target 90% of pollutants released by this sector (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 UWWTD focused on nutrient pollution (primarily nitrogen and phosphorus) in efforts to reduce 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 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 plant or septic tanks. Construction, maintenance and operation of waste water collection and treatment comes at high financial and greenhouse gas cost. Biological and chemical sludges arising from the treatment process must be regularly removed from the plant and treated.

Nowadays we recognise 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, where many of those chemicals have come from the products in our own homes. We know that in future there are likely to be risks of which we are not necessarily yet aware. The coronavirus pandemic has re-alerted us to the use of waste water as a way to monitor disease in the community (EC, n.d).

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

The enormous effort to reduce sewage pollution, underpinned by the Urban Waste Water Treatment Directive supported by other EU and national legislation, has led to significant improvement of Europe's surface waters in recent decades. Such efforts cannot stand still: achieving and maintaining compliance with the UWWTD has been estimated at costing an additional 253 billion EUR between 2019 - 2030 (EC, 2019). Without tackling the root causes of harmful pollutants, doing "more of the same" will not lead to a sustainable way to 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.*

#### 2.2.1 What's in sewage and urban waste water

Sewage, the faeces and urine we all excrete, is mainly water. The remainder contains a large number of organic and inorganic, suspended and dissolved solids (see Table 2.1). Mixed with



“grey” water drained from kitchens, bathrooms, and laundry, large volumes of urban waste water are generated every day.

**Table 2-1 Typical constituents of sewage and urban waste water**

Substance	Examples	Source	Impact
<b>Microorganisms</b>	Pathogenic bacteria, viruses, worms, eggs, protozoa	Faeces	Human health risks when bathing, eating shellfish
<b>Biodegradable, organic materials</b>	Carbohydrates, starch, volatile fatty acids, proteins, cellulose	Faeces, food	Oxygen depletion in rivers and lakes causing fish deaths, odour
<b>Other organic materials</b>	Fats and oils, solvents, phenols, surfactants, detergents	Kitchen and domestic waste, industry	
<b>Nutrients</b>	Nitrogen, phosphorus, ammonium	Urine and faeces, food	Eutrophication, oxygen depletion, toxicity
<b>Micropollutants</b>	Medicines, food additives, phthalates, biocides, flame retardants, PFAS, pesticides, plastics, etc.	Urine and faeces, food, human activities, industry	Toxicity, bioaccumulation, sub-lethal effects e.g. on growth and reproduction. Contamination of drinking water resources
<b>Metals</b>	Zinc, Copper, Cadmium, Lead, Arsenic, Chromium, Mercury, Nickel	Homes and industry	Toxicity, bioaccumulation
<b>Other inorganic materials</b>	Acids, e.g. hydrogen sulphide, alkalis	Homes and industry	Corrosion, toxicity

Urban waste water is characterised by parameters describing its polluting potential. Total solids characterise organic and inorganic matter that is suspended or dissolved in waste water, while the load of organic matter in the waste water is represented by chemical oxygen demand (COD), biological oxygen demand (BOD) or Total Organic Carbon (TOC). Concentrations of nutrients, total phosphorus and total nitrogen, determine the eutrophication potential of waste water. Other waste water characteristics affecting treatment process are pH, alkalinity and chlorides. 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 biological and chemical oxygen demand (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.

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

### 2.2.2 Treatment methods

Waste water treatment reduces or eliminates organic matter, nutrients and disease-causing microorganisms in sewage, prior its discharge back to 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 nature-based methods (e.g. constructed wetlands).

Biological waste water treatment, which is the most common process to treating sewage, uses bacteria and other micro-organisms to degrade organic matter and utilize 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 steps of treatment (see table 2.2): pre-treatment, primary treatment, secondary treatment 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 either discharged into the recipient, or undergoes advanced treatment tackling specific substances that cannot be adequately removed by secondary treatment (also known as (tertiary treatment). Advanced treatment technologies are sometimes combined with primary or secondary treatment (e.g., biological removal of nitrogen and phosphorus).

**Table 2-2 Urban waste water treatment processes**

Treatment	Process	Typical technologies	Treatment / Removal of
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 Bio Film Reactor Membrane Bioreactor Oxidation ponds/ lagoon-constructed wetlands	organics, partial treatment of nutrients (nitrogen and phosphorus), microorganisms <i>See note</i>
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)

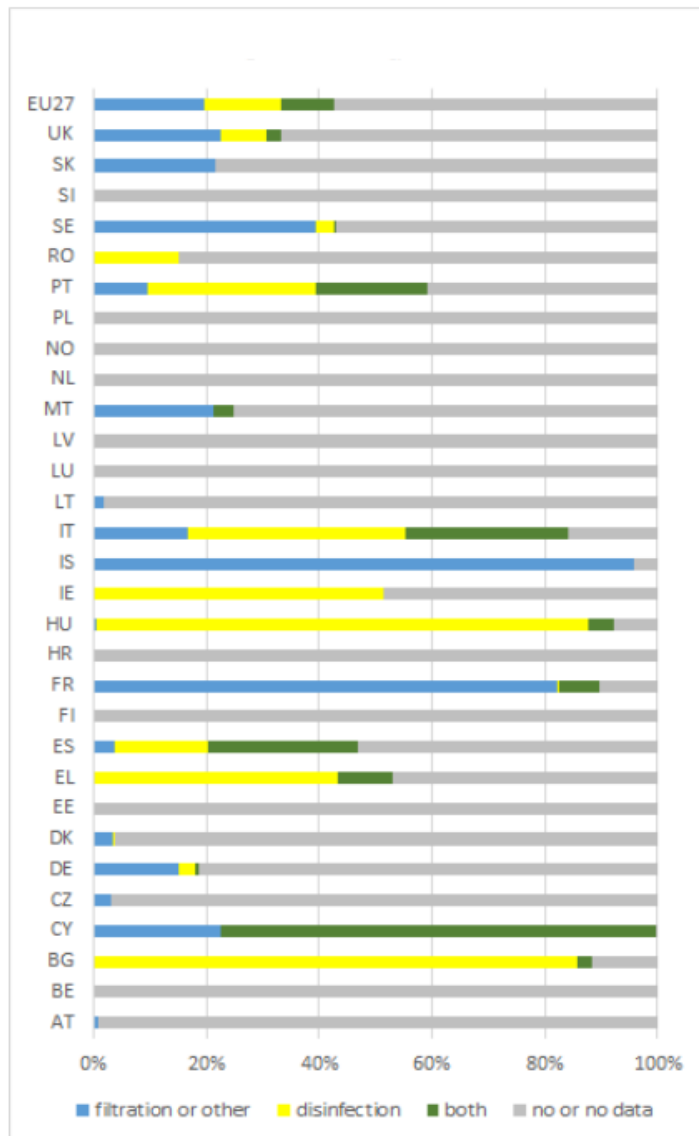
*Note: Although conventional secondary treatment has not been designed to remove nutrients or micropollutants, waste water treatment plants do remove some nutrients and micropollutants to some extent (including some pharmaceuticals and metals)*

The UWWTD requires that in agglomerations bigger 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 discharge (called 'more stringent treatment'). Application of other types of advanced treatment is not mandatory but should be used to ensure that receiving water body meets quality objectives after 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 %<sup>2</sup> in 2018<sup>3</sup> (Fig 2.1) (EEA, 2020). Sand filtration and microfiltration were the most commonly used advanced treatment methods.

**Figure 2-1 Proportion of waste water load subjected to advanced treatment in 2018**



Source: UWWTD database v.8, published 20.11.2020)

Note: Treated waste water measured in p.e.

Figure 2.2 shows that disinfection is common for treated waste water prior to discharge into coastal waters or estuaries (31%<sup>4</sup> of waste water treated in treatment plants 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 UV treatment.

<sup>2</sup> EU 27 Member States, UK, NO and IS including UK

<sup>3</sup> Values reflect advanced treatment, excluding N and P removal.

<sup>4</sup> EU 27 Member States, UK, NO and IS



Figure 2-2 Waste water treatment plants equipped with disinfection (2018)



Source UWWTD database v.8, published 20.11.2020)

Note: UV = ultraviolet radiation



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; the use of activated carbon in micropollutant reduction. Energy consumption may increase by between 10-60% with these advanced methods. Meanwhile, optimisation of biological treatment for nutrient removal from water also supports reductions in concentrations of many micropollutants.

Treatments need to take into account local characteristics. For example, ozonation of water containing certain levels of bromide presents a risk of the formation of carcinogenic bromated organic compounds (Kehrein, 2020).

## 2.3 Pollution from sewage

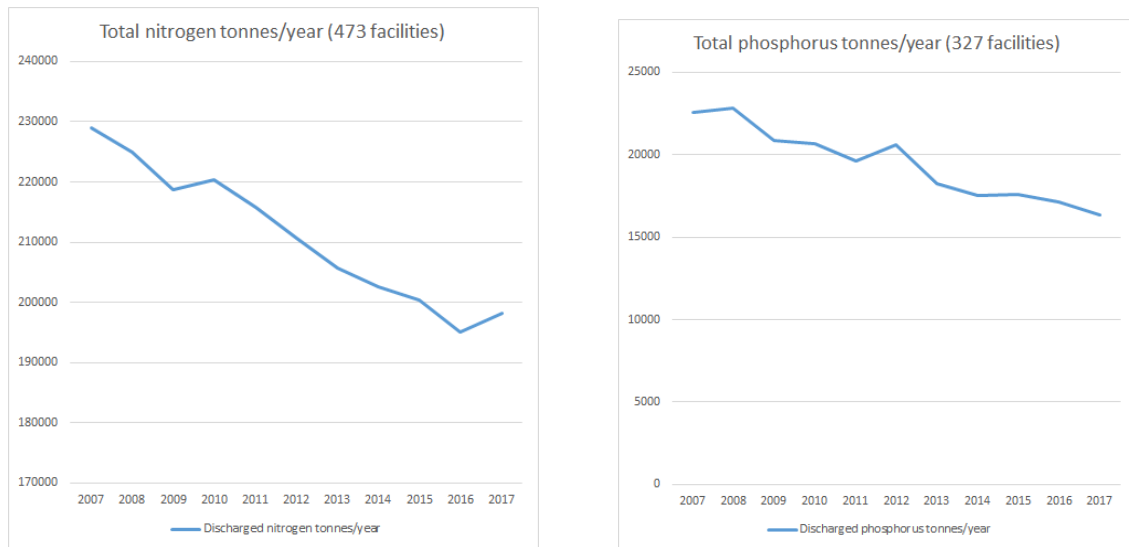
### 2.3.1 Nutrients

Protection of the environment from adverse effects of sewage discharges is the primary objective of the UWWTD. The Evaluation of the UWWTD (EC, 2019) found that the 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 concentrations of phosphate in rivers show a significant decline (Fig 2.3). Similarly, nutrient discharges from large UWWTPs reporting under the E-PRTR were reduced over the period 2007-2018 (Fig 2.5). Coastal concentrations of chlorophyll showed a decline in many places between 1990 – 2017, showing a likely reduction in the amount of coastal eutrophication (Fig 2.4). Despite these advances, eutrophication remains an issue of concern, particularly in coastal areas such as the Baltic and Mediterranean (Pavlidou, et al, 2019).

Figure 2-3 Phosphate in rivers in European water bodies 1992 - 2018	Figure 2-4 Trends in summer chlorophyll concentrations in European Seas 1990 - 2017
	 <p>Trends in summer chlorophyll concentrations in European seas, 1990-2017</p> <ul style="list-style-type: none"><li>● Decrease</li><li>● Increase</li><li>● No trend</li><li>○ Time series ≤10 years</li><li>○ Time series &gt;10 years</li></ul>
Source: <a href="https://www.eea.europa.eu/data-and-maps/indicators/nutrients-in-freshwater/nutrients-in-freshwater-assessment-published-10">https://www.eea.europa.eu/data-and-maps/indicators/nutrients-in-freshwater/nutrients-in-freshwater-assessment-published-10</a>	Source: <a href="https://www.eea.europa.eu/data-and-maps/figures/observed-change-in-chlorophyll-concentrations-2">https://www.eea.europa.eu/data-and-maps/figures/observed-change-in-chlorophyll-concentrations-2</a>



**Figure 2-5 Total nitrogen and phosphorus emissions from UWWTPs (over 100 000 p.e.) 2007 - 2018**

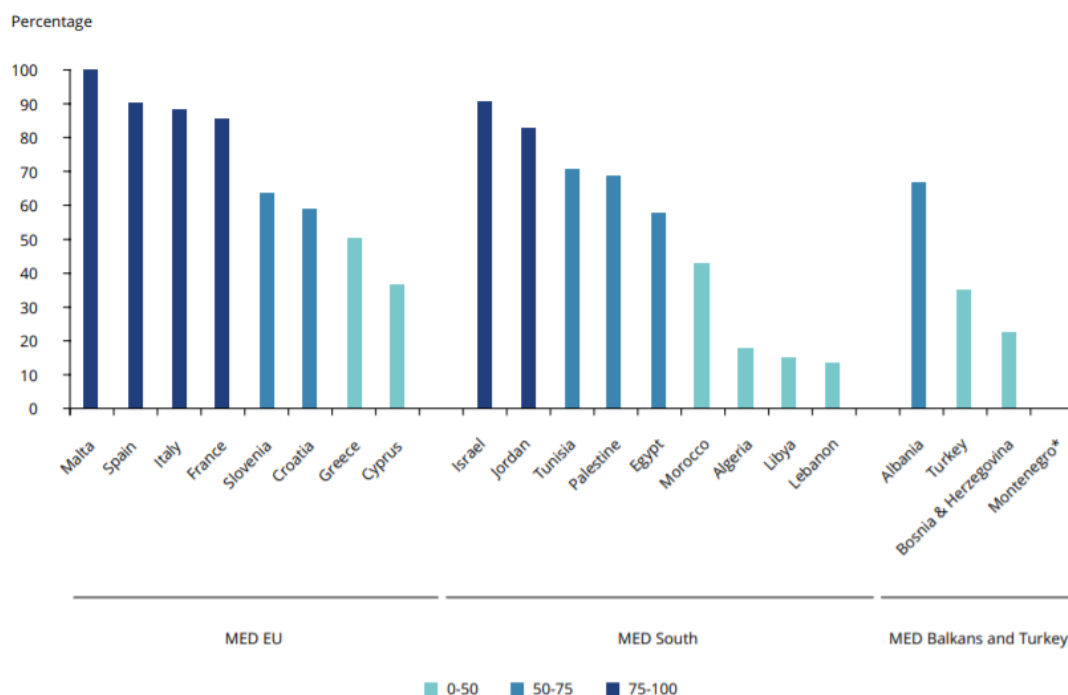


Source: EPTR DB, Trends in pollutant load discharged to water from large UWWTPs (TP with completed timeseries selected, source E-PRTR v.18, EU27+CH+NO+UK)

However, some Member states are yet to fully comply with the UWWTD in ensuring waste water is collected from most dwellings, and treated to an acceptable standard before being discharged back to the water environment (EC, 2020). Monitoring in Mediterranean countries for SDG 6.3.1 – the proportion of waste water safely treated - calculated as a proportion of all domestic wastewater generated based on household per capita water-use data, shows significant challenges still to be addressed (Fig 2.6) (EEA, 2020).

**Figure 2-6 Proportion of waste water safely treated in Mediterranean countries in 2018 (%)**

**Figure 3.23 SDG 6.3.1 — proportion of wastewater safely treated in Mediterranean countries in 2018 (%)**

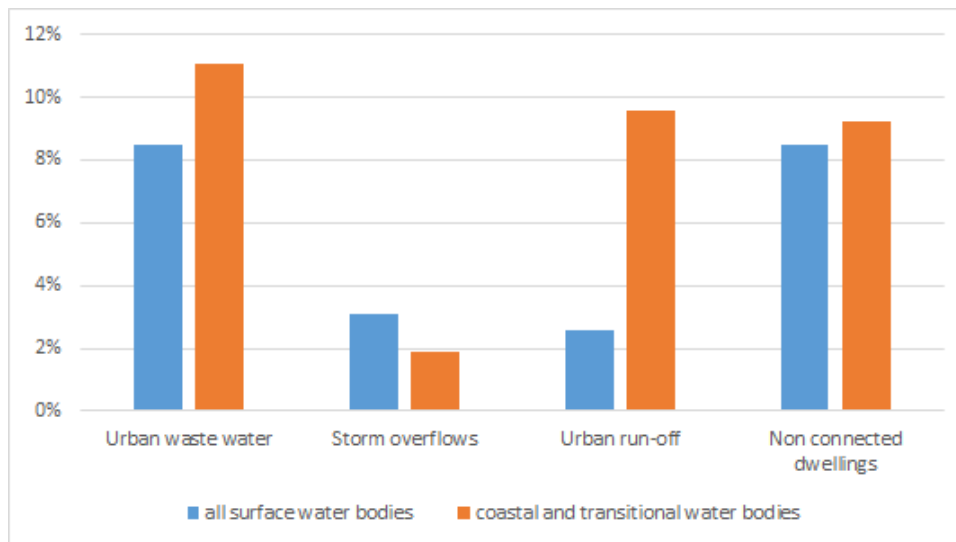


Source: UNSTATS, 2020.



Reporting under the Water Framework Directive indicates that most Member States are challenged in achieving targets with respect to restoring all waterbodies to ‘Good Status’ by 2027. Pollution pressures from sewage caused failure of ecological status, arising both from point sources from UWWTPs (8 % water bodies) and storm overflows (3 %) and from diffuse sources such as non-connected dwellings (10 %) (Fig 2.7) (EEA, 2021). Urban run-off seems to represent a significant pressure in transitional and coastal waters.

**Figure 2-7 Significant pressures causing failure to meet good ecological status (RBMP2)**



Source: Water Framework Directive database <https://www.eea.europa.eu/data-and-maps/dashboards/wise-wfd> (EU27+NO+UK)

Where sewage discharges have occurred over decades, recovery of an ecosystem can be difficult to assess. However, an historical study on the River Seine in France showed the impact of human activities on migratory fish from the sea to Paris, between 1900s and 2010s (Pichon et al, 2020; Beslagic, 2013). 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. Prior to the UWWTD, untreated sewage sludge was dumped at sea. Sewage represents a food source for some species, allowing them to aggressively compete for this resource. Studies of the recovery of a sewage sludge dump site in the North Sea showed that less tolerant benthic species began to live in the site area within 2-3 years’ cessation of dumping (Birchenough and Frid, 2009).

### 2.3.2 Micropollutants

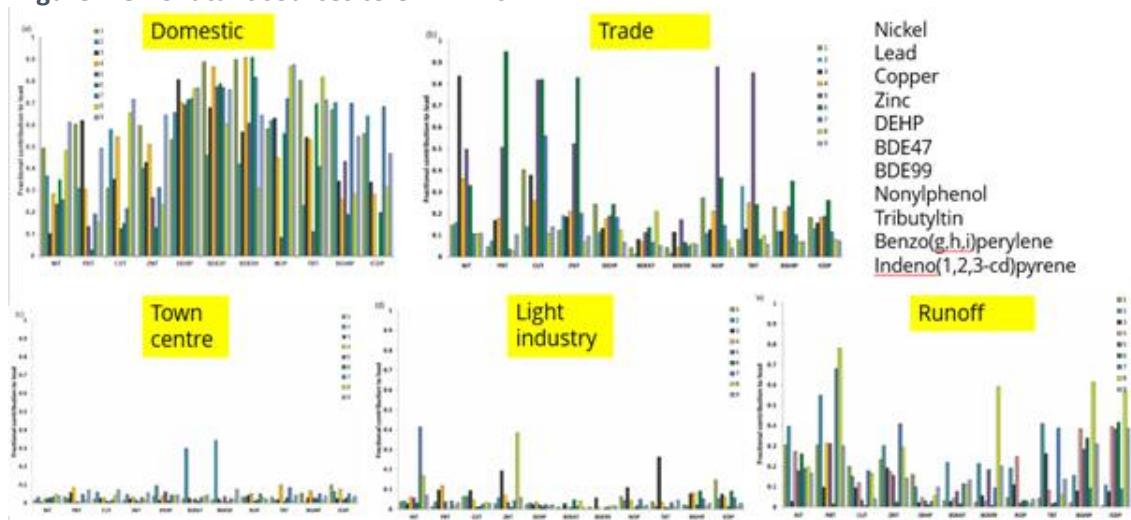
Understanding of the range of pollutants in water, and our ability to measure them, has moved a long way since 1991. We now recognise that many “micropollutants” find their way into urban waste water and risk being discharged to the environment if they are not treated or removed. Such pollutants can be natural, like metals and polyaromatic hydrocarbons (PAHs), as well as synthetic biocides, medicines, flame retardants etc. Waste water treatment has shown itself capable of removing relatively high proportions of many of these substances, but often not



sufficiently to meet chemical standards requirements under the WFD (Gardner et al, 2013). Furthermore, concern about mixtures in the environment (EC, 2012; Posthuma et al, 2019) leads to calls for higher 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 UK showed that the most significant source of micropollutants to UWWTPs was our homes (Fig 2.8) (Comber et al, 2014).

**Figure 2-8 Pollutant sources to UWWTPs**



<sup>1</sup> [UK WIR Chemical Investigation Programme](#)

This finding should have 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 we use in our homes – substances with harmful characteristics such as carcinogenicity and endocrine disruption, as well as those directly harmful to aquatic life.

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 their impact on the environment (EC, 2020). In Switzerland, studies on impact of micropollutants on surface water status and on drinking water resources 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 Regulation on Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) (EU, 2006), the number of chemicals in everyday use has grown enormously in recent decades (EEA, 2019). Efforts are in place to break a cycle where restriction of one substance has merely led to its replacement by 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, 2020).

### **2.3.3 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 EC recommended a common approach to establish systematic surveillance of SARS-CoV-2 (EC, 2021) (EC, 2021)). 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 (eg 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 relatively low cost (~EUR 25 000 for one UWWTP per year) (JRC, 2021).

There is real concern around the risk represented by antimicrobial resistance (AMR), where antibiotics no longer are able to cure common infections (WHO, 2021). Intensively studied in the food and health sectors have not yet been matched in the environment (EFSA, 2021). UWWT 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, eg through exposure to antibiotic residues excreted by patients, and then transferred into the environment. Large scale understanding of the potential for transfer of resistance genes back into people is not yet available, but some smaller studies show contamination, eg surfers showed 3 times the level of antibiotic resistant *E. coli* compared to non-surfers (Leonard et al, 2018). If UWWTPs were found to be a significant cause of transfer of resistance genes, it is possible that disinfection would be more widely required. Research is on-going in this area.

## 2.4 Dwellings not connected to a sewer system

Dwellings which are not connected to UWWTPs can be a source of diffuse pollution if sewage is directly released to the environment without treatment, or when local sewage treatment is applied but is not well-maintained or operated (European Commission, 2007). Approximately 11 % of the EU population (55 million people) was not connected to waste water collection 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, 2021).

The UWWTD requires that waste water produced in urban settlements under 2000 p.e. must be collected or treated in Individual Appropriate Systems (IAS) (e.g. septic tanks, domestic waste water treatment plants) - which equate to “non-connected dwellings” under the WFD. These solutions can be used where building a collecting system is not justified owing to “no environmental benefit or because it would involve excessive cost”, and must be able to ensure that discharged waste water allows receiving waters to meet the relevant quality objectives and the relevant provisions of the UWWTD. Reporting on the implementation of the UWWTD in 2018 showed that about 9.9 million p.e.<sup>5</sup> was not collected nor received any treatment mainly among newer Member States (fig 2.9). It also indicated that 13.8 million p.e. of waste water was collected and treated via IAS, with some countries relying on this approach for a significant proportion of their sewage (fig 2.10).

Non-connected dwellings and small settlements can treat sewage effectively, such as through small treatment plants and constructed wetlands, though typically this requires strong oversight (Grebot et al, 2019). Owners of individual systems take care not to disrupt the process treatment process, e.g. avoiding the flushing of harmful substances (Mulder, 2019). 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 vacationers, applies extensive legislation regulating the operation of IAS (Grebot et al, 2019). However, more often regulation is relatively weak, not

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<sup>5</sup> EU27+IS+NO+UK



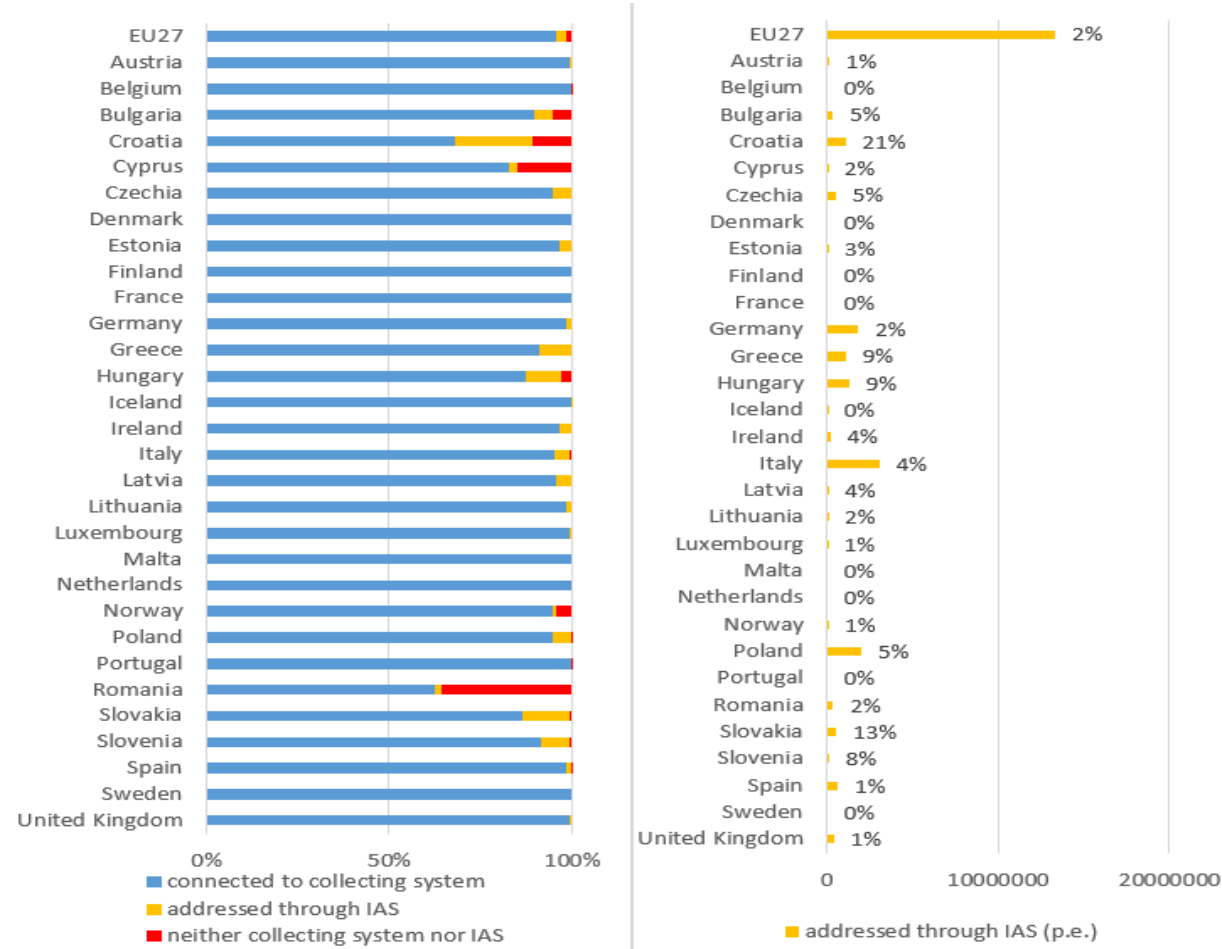
least because such facilities are usually on private land, and it can be a challenge to ensure effective treatment where financial resources as well as skilled personnel may be lacking (ibid).

**Figure 2-9 Percentage of waste water load collected in collecting systems, addressed through independent and other appropriate systems (IAS) or discharged without treatment in Europe, 2018**

**Figure 2-10 Actual load treated via IAS, 2018**

Fig 2.9

Fig 2.10



Source: UWWTD Waterbase 2020

## 2.5 Storm overflows

Rain and stormwater 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 landuse characteristics. Water falling on impervious surface, like highways, streets, parking lots, roofs, industrial and construction facilities, green areas, etc. is recognised as a major source of pollution (sediments, micropollutants, bacteria, oils) of water bodies originating in urban environment. Sewers collect urban runoff as well as sewage. In separated sewer systems, runoff is conveyed separately and



discharged without treatment into nearby waterway, whereas in combined sewers, it is collected together with waste water and travels to UWWTP. To prevent flooding of the UWWTP during heavy rainfall, sewerage systems are equipped with combined sewer overflows (CSO), allowing discharge of a mixture of runoff and urban waste water directly into surface waters. This may lead to pollution by organic matter, nutrients, micropollutants, bacteria and viruses, which can cause oxygen depletion, toxicity and health risks. Of particular importance is impact of CSO on the quality of bathing waters, owing to the increased concentrations of coliforms (JRC, 2019). Studies on micropollutants in CSO showed substantially elevated concentrations of some (caffeine, ibuprofen) occurring in urban streams following CSO discharges, which were higher than in treated effluents from WWTPs (Buerge et al, 2006).

To reduce the frequency of CSO discharges, some UWWTPs have temporary storage tanks which 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)

There are over 3 million kilometres of sewer systems across Europe, with at least 650,000 CSOs (Eureau, 2020). In the second reporting under WFD, 4% of surface water bodies were reported (by 18 MS) to be affected by pollution from storm overflows (EEA, 2021), though the actual proportion of water bodies affected may be higher, because quantification of discharges from CSOs is problematic (Ahm et al, 2016).

Studies into the implementation of the UWWTD found that full compliance with the Directive in relation to the management of CSOs and urban runoff would offer significant reduction of pollution load that ends up in environment (JRC, 2019).

In a pilot study for storm water management in northern France, Bézannes Joint Development Zone constructed a landscaped park instead of a traditional civil engineering solution (Oppla, 2021). This project had a number of aims, among them to reduce flood risk and the load to sewer systems, restoring ecosystems and their functions, increase biodiversity, improve water quality, increase accessibility to green open spaces and increase 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 Germany in summer 2021. Solutions include sustainable urban drainage systems and managing runoff, such as by harvesting rainfall, capturing runoff and allowing it to soak into the ground or treating it (e.g. through constructed wetlands) and then releasing runoff at a controlled rate (Grebott et al, 2019).

## 2.6 Industrial waste water

The focus of this study is urban waste water. Smaller scale manufacturing and food and drink production typically discharge to the sewer system, where the waste water is treated at the UWWTP. Member States must ensure that the discharge of industrial waste water to the sewer allows its effective treatment by the UWWTP, so that it does not damage equipment and the resulting sludge can be treated and disposed in an environmentally sound manner. In contrast, large industrial sources often have on-site treatment facilities, discharging directly into water. Typically such installations are regulated under the Industrial Emissions Directive (IED) (EC, 2010), such as pulp and paper, metals, energy supply and chemicals sectors (EEA, 2018). Quality of the effluent discharged by industry in both cases can be permitted by environmental regulators and waste water utilities. Regulation of industrial discharges to water has led to significant improvement in water quality since the 1970s.



Emissions to water from large UWWTPs are reported and publicly available under the IED and the [European Pollutant Release and Transfer Register](#) (E-PRTR) Regulation (EC, 2006; 2010). Minimum reporting thresholds apply, to limit the reporting burden, based on installation size and quantity released of a list of 91 substances. 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 in the EU27). Both the IED and the E-PRTR are currently under review, with UWWTP capacity thresholds one of the areas under consideration (EC, 2020).

Even with the limited reporting under E-PRTR, UWWTPs represent the major “point source” of pollution to water (EEA 2018; EEA, 2019). It must be remembered that the pollution does not derive from the UWWTP itself: rather, the many sources in the sewer network – homes, industry, schools, etc – are collected at the plant.

## 2.7 Sludges arising from urban waste water treatment

### 2.7.1 Sewage sludge

Treatment of sewage at UWWTPs produces sewage sludge, which is usually treated (e.g. dewatering, thickening, pasteurisation, sanitation, etc) 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:

- Primary sludge – settleable solids separated during primary treatment of waste water (physical separation such as screening)
- 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 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 Waste (EC, 2018a).

Following its extraction from the waste water treatment process, sewage sludge requires treatment to enable more efficient and safer transport and 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 (AD), composting with other organic waste. Final recovery and disposal include spreading of treated sludge on land and incineration. The application of sludge onto farmland is only allowed if the sludge content remains under thresholds established for a set of heavy metals, and after given time periods which should have passed between the production of the sludge and its application. Minimum durations are set in the Sewage Sludge Directive (SSD) (EEC, 1986).

However, because the sludge can contain pollutants which have been “cleaned out” of the water, there are concerns about the pollutant load in the sludge. Limits on metal loads to the soil are set in the SSD and some countries have set stricter limits than those in this old Directive (SSD evaluation; Ricardo 2021). Concerns in some Member States about the contaminant load potentially entering human food, or being released into the environment, have led to restrictions on sludge being put to land (e.g. DE, NL). 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 ([CROSS-REF to ch 3](#)).



### 2.7.2 Process waste

Every waste water treatment technology produces process waste that must be safely disposed of, as well as treated water and sludge. Processing, treatment and disposal of the process waste is subject to waste management legislation. Aims to minimise the amount of landfill waste by 2024 is likely to expand ways of treatment and disposal of process waste in terms of reuse and recycling.

Large items, sands, fats, grease and oils resulting from sewage screening, sieving, oil separation and fat extraction are usually considered as wastes requiring disposal. Other process wastes depend upon 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 amounts of waste produced by waste water treatment processes. The substrate for trickling filters, such as lava rock or plastic substrate, can last for decades so relatively insignificant. The amounts of sand used in sand filters are relatively small in comparison to e.g those used in construction. A study performed by UKWIR considered the use of activated carbon in micropollutant removal (UKWIR, 2020). Use of powdered activated carbon was found not to be a viable option, given the large increase in sludge produced that would need to be incinerated, with such capacity not being available in the UK where much sludge goes to land. The use of granular activated carbon to remove micropollutants was estimated at an additional 7-8% of the total produced by the UK water sector (4 million t/a), and an increase of 2% in total dry solids sludge production (UKWIR, 2020).

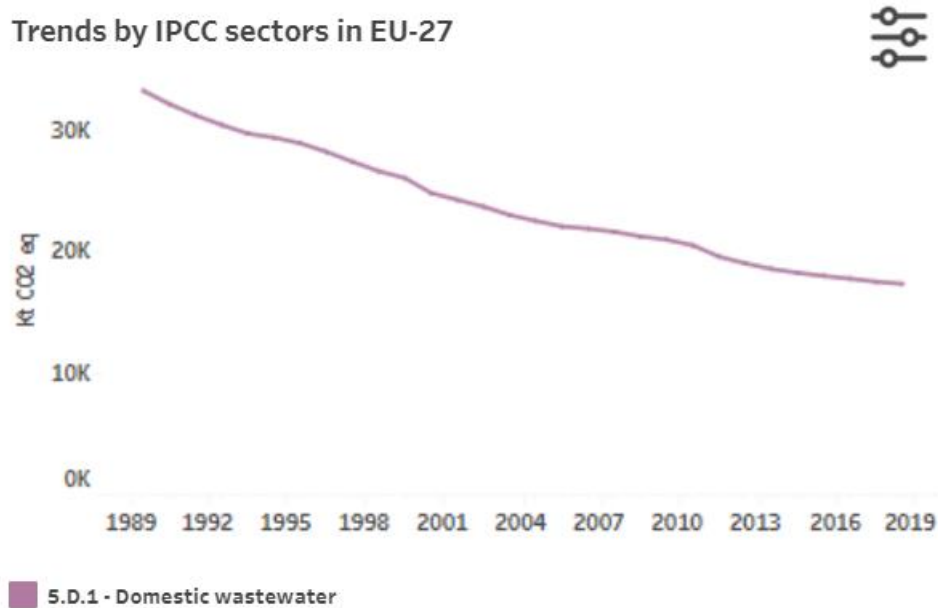
Recovery of resources from waste water treatment residues, as an alternative to traditional modes of disposal (landfilling, incineration) is the subject of numerous research projects, studying for example conversion of fats, oils and grease from sewage pre-treatment to biofuel using physicochemical processes, or recovery of resources from rejects from membrane-based technologies applied in advanced treatment.

## 2.8 Greenhouse gas emissions

Typically we consider water quality and sewage sludge when thinking of impacts of waste water treatment. However, direct emissions of greenhouse gases arise from biological treatment of organic material in urban waste water, principally methane ( $\text{CH}_4$ ), and nitrous oxide ( $\text{N}_2\text{O}$ ) (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 wastewater in efficient, centralised facilities (EC, 2020), with emissions steadily declining to 17 351 kt  $\text{CO}_2$  eq in 2019 (Fig 2.11). The decline has largely been in methane emissions, which more than halved since 1989, while those in nitrous oxides have changed little since the early 2000s, at about 6 100 kt  $\text{CO}_2$  eq per year (EEA, 2021).



Figure 2-11 CO<sub>2</sub>eq released by domestic waste water treatment



GHG emissions from domestic waste water treatment sector. Overall emission in CO<sub>2</sub> equivalents

Source: EEA, GHG emission data viewer

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 can lead to a high level of embedded greenhouse gases, with estimates suggesting infrastructure-related GHG emissions comprise about 50% of the total emitted by waste water treatment (JRC, ). Emissions arise from raw materials extraction, content in materials, such as concrete and steel in pipes and tanks, and those from construction. Scottish Water have developed a measure “investment intensity” to assess and control emissions of this nature (Scottish Water, 2021). They estimate that 60% of these emissions come from civil engineering, with infrastructure and mechanical and electrical work making up most of the remainder. They aim to choose low emissions 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.

Waste water treatment can reduce emissions of greenhouse gases through a range of methods, from optimising operation to modifying the plant. Emission of CO<sub>2</sub> can be reduced by enhancing energy efficiency of the treatment, minimising pumping and treatment of surface water runoff and by generating biogas from the anaerobic digestion of sewage sludge as a source of heat and energy in Combined Heat and Power production technology (CHP). Reductions in N<sub>2</sub>O can be achieved by application of control strategies to prevent incomplete nitrification/denitrification, while CH<sub>4</sub> emissions can be reduced by control measures to prevent gas leakages from sludge handling facilities and control of that formed in the sewers.

Additional demands for waste water treatment to remove micropollutants are likely to increase energy requirements, as their removal is currently based mostly on energy intensive methods



per unit of pollutant removed (Capodaglio and Oloffsson, 2019). Strategies that water utilities could adopt to mitigate the carbon impact of micropollutant removal include:

- **source control** so that treatment is not required,
- **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.



## 3 Energy and resources

### 3.1 Introduction

“Waste water treatment” is aimed at delivering clean water which is safe to be returned to the environment. It implies a linear process. However, our use of water is a transient stage of its natural cycle. Generation of sewage is largely predictable – a sustainable resource - allowing the infrastructure for its use and re-use to be established.

Waste water treatment currently uses at least 1% of total energy production in Europe (Ganora, 2019; Capodaglio and Olson, 2020). Pumping and treating water makes it the largest municipal use of energy. Energy efficiency can deliver savings on existing treatment costs, while demand for more intensive treatment is likely to drive up the energy requirement.

Meanwhile, sewage contains valuable resources. In waste water, this includes the water itself, but also heat, nutrients like nitrogen and phosphorus, and energy and other resources which can be derived from sewage sludge. Treated sewage sludge itself is valued for its nutrient and organic matter for agriculture in parts of Europe, but concern about mainly chemical contamination constrains its potential applications.

Taken together, the best-operating plants are able to meet environmental discharge limits and generate at least enough energy to power their own energy needs. The role of these “water resource factories” (Kehrein, 2020) can underpin a circular economy.

### 3.2 Energy use and efficiency

#### 3.2.1 Sustainable use of resources

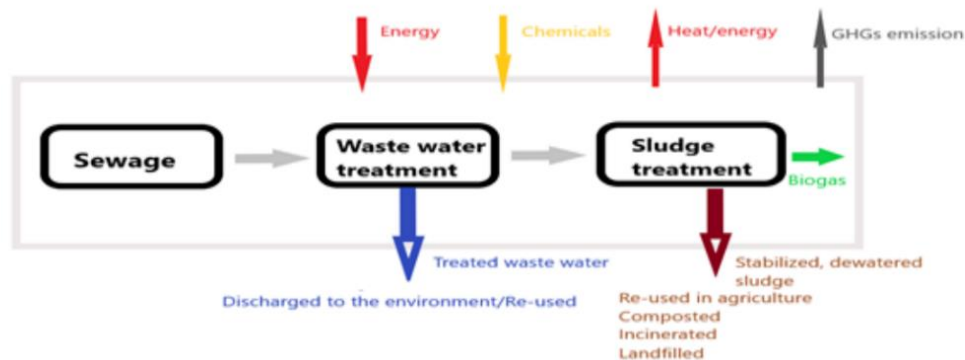
Minimising unnecessary use of resources is the first step towards sustainability, and often can provide monetary savings to operators. In the context of water, efficient use of this essential resource should be high priority, both because water can be in short supply, and because pumping and treatment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

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. 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 smaller scale approaches (b) is increasing in innovative towns and operators.

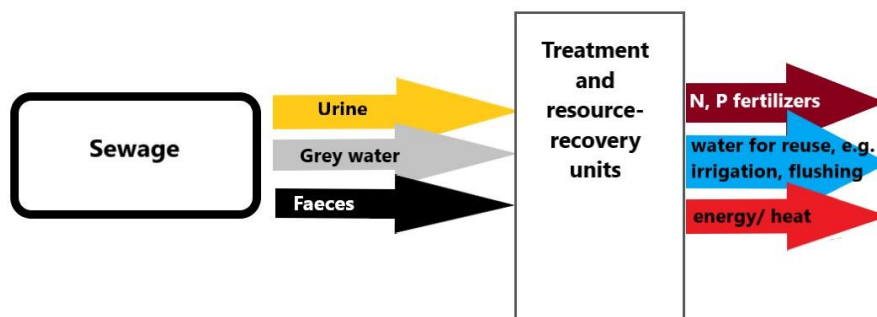


Figure 3-1 Inputs and outputs of sewage treatment

a)



b)



a) at WWTP, b) source separation sewage treatment

### 3.2.2 UWWTP energy use and efficiency

Energy use of an individual UWWTP is determined by the location, characteristics of sewage, treatment plant size, applied treatment technology and requirements on the quality of 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 larger volumes of sewage consume more energy, but typically have 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 – 74 % of the total energy used by UWWTPs (size ranging from below 2 000 p.e. to over 100 000 p.e.) (Longo et al, 2019).



Increasing energy costs, as well as pressure to reduce GHG emissions, have forced waste water treatment operators to look for ways to optimize energy consumption and navigate towards energy neutrality or even positivity, resulting in energy self-sufficiency or surplus (cross ref to 3.3.4). Reductions in energy consumption can be achieved through a variety of means. For example, the installation of energy-efficient aeration equipment in secondary treatment, improved process control, reduction of leakage, energy efficient approaches to sludge thickening/dewatering e.g. optimised sludge dewatering.

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

#### **Text box: Improvements in energy efficiency**

**Bulgaria.** The Sofia waste water treatment plant was commissioned in 1984 and historically consumed between 16 000 and 24 000 MWh electricity per year. Following the installation of combined heat and power (CHP) units in 2010, the energy produced annually on site rose from 15 288 MWh to 23 100 MWh in 2017. Measures implemented to reduce energy consumption included optimising the aeration process via air flow regulation, improving the anaerobic digestion process and utilising 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. 4 300 MWh).

Source CircE. [Energy production in Waste water treatment plant Kubratovo](#)

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 standardized methodology at European level has not been adopted. ENERWATER has developed a methodology for assessing and improving energy efficiency and labelling of WWTPs, enabling a rapid audit and assessment for decision support.

## **3.3 Extracting resources from sewage and sewage sludge**

### **3.3.1 Sewage sludge**

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, and humus which can help the soil structure. Long term experiments show fertility enhancement after sewage sludge application, resulting from lower soil bulk density and higher soil carbon concentration (Börjesson and Kätterer, 2018). Where lime has been used to treat the sludge, the sludge can also help reduce the acidity of agricultural soils. The Sewage Sludge Directive (EEC, 1986) sets minimum treatment and standards to protect against health and pollution risks from sludge application to land. This old Directive is currently under evaluation (autumn 2021) and is planned for revision under the Green Deal. However, concerns remain that the treated sludge has effectively collected many of the persistent pollutants present in waste water, which then may be dispersed on to the land and become a source of diffuse pollution. A study in Norway considered microplastics in sludge, concluding that they could be a major source to the environment though with no assessment of the risk that this might present (Lusher et al, 2017). Knowledge about the sources and presence of microplastics in water is still limited (EEA, in prep).



A study investigating concentrations of metals and several pharmaceuticals in the sludge itself, from 11 UWWTPs over a year, calculated that concentrations would be below soil 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 deadlines by 2032 for UWWTPs over 50 000 p.e., though sludge from smaller plants may still be used (Ricardo, 2021). In parallel, the ProgGress strategy requires the recovery of phosphorus from the sludge through mono-incineration (BMUB, 2016). Meanwhile, in Sweden, policy has shifted towards treated sludge going to land as part of a more circular approach (text box).

#### Text box: REVAQ-CERTIFIED WASTE WATER TREATMENT PLANTS IN SWEDEN

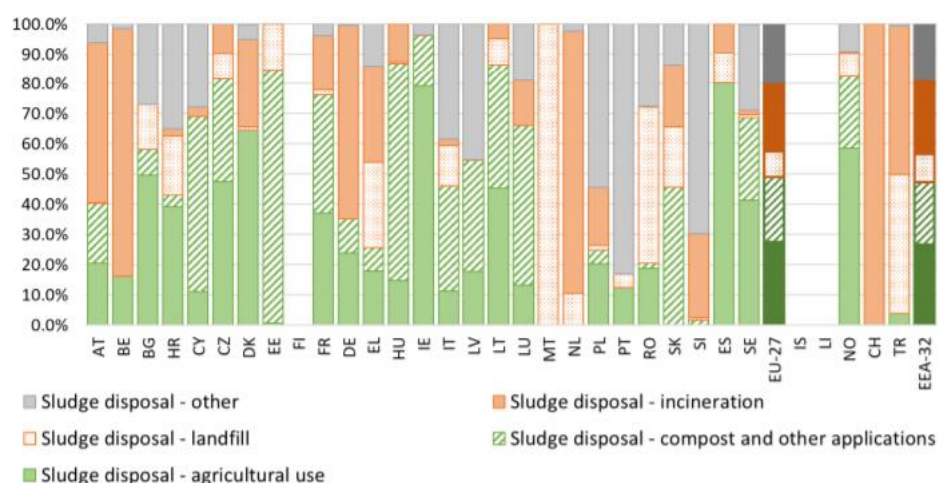
In Sweden, concerns about contaminants in sludge led to recommendations not to apply sludge to land during the early 2000s (Ricardo, 2021). However, in 2008 a collaboration between farmers, regulators and the water and food industries led to a certification scheme “REVAQ”, which assures the safety of sludge application to agricultural land, both in relation to the quality of soil and food and to water quality. This has led to an increase in the amount applied to land rising from 22 % in 2011 to 45 % in 2018 (Ricardo, 2021). Studies showed that “there is clear evidence that sludge fertiliser application supplies plant nutrients and humus that agriculture demands.” (Ministry of the Environment of Sweden, 2020).

### 3.3.2 Sewage sludge production

The annual production of sewage sludge in the EU-32 was about 11.1 million tonnes in 2018 – about 17 kg per person (Anderson et al, 2021). 94% of this sludge was “disposed”. According to the Eurostat data used in that report, 27 % of the sewage sludge was used in agriculture, 25 % was incinerated, 21 % in compost and other applications, 9 % landfilled, and 19 % is used in another way.

Fig 3.2 shows a wide variation in the destinations for sewage sludge. Some countries have a high reliance on sending treated sewage to land, others incineration. 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.

Figure 3-2 Sewage sludge management approaches in Europe



Notes: For data on sludge production and disposal, we used 2018 data for AT, HR, CY, CZ, HU, LV, LT, MT, NL, NO, PL, RO, SK, SI, SE, TR. For the countries for which the 2018 data was missing, data from the latest available year has been used as follows: 2017 (BE, BG, FR, IE, LU, CH), 2016 (EE, DE, EL, IT, PT, ES) and 2010 (DK).

Source: (Eurostat, 2020a)



The cost for treatment + disposal of sludge in European countries has been estimated to reach, on average, approximately 200 € per tonne of dry mass, according to the type of treatment and disposal.

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

- recovery of materials or energy from sludge, utilising its resource potential;
- reduction of the amount of sludge produced, minimising waste.

The increase of the solid content in sludge by dewatering significantly reduces the volume of wet sludge for disposal. The reduction of dry mass of sludge leads to the reduction of solid content and volume. Methods are based on physical, mechanical, chemical, thermal and biological treatments. Most of them are aimed at solids solubilisation and disintegration of bacterial cells in sludge.

### **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 potential secondary resource which can contribute to Europe's transition to a circular economy (Ricardo, 2021). A potential obstacle for promoting sludge reuse and recovery stems from two policy objectives which may be in conflict:

- Protection of the environment and human health, which require that sludge for reuse complies with specific quality standards
- Resource efficiency promoting the use of sludge in agriculture, ensuring the recycling and recovery of valuable and finite nutrients.

Prevention of contamination of sewage by persistent, hazardous pollutants would allow recycling of sewage sludge on land without concerns that this might lead to diffuse pollution of soils, plants and water.

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

Sludge could also contribute to renewable energy policy and targets as feedstock for energy generation, for example, through anaerobic digestion, incineration, pyrolysis and gasification. Estimations of additional energy potential (i.e. on top of that already recovered) has been subject to several studies assessing different sewage sludge options. Anderson et al (2021) estimated that the EU-27 could potentially recover between 1 800 GWh and 3 200 GWh of energy (net heat and electricity) through anaerobic digestion of the total generated sewage sludge currently intended for landfilling and composting, and 250 GWh (net electricity) through incineration of the total generated sewage sludge currently sent to landfill. This respectively represents 7 %, 13 % and 1 % of the total waste water sector energy needs in the EU-27 in 2018. Using an alternative approach to calculation, JRC (ref) estimated that up to an additional 3285 GWh could potentially be recovered through anaerobic digestion of the total sewage sludge applied directly on land (30%) and 850 GWh resulting from incineration of sludge currently sent to landfill.

Selection of the optimum sewage sludge option for energy recovery must consider additional energy demands and GHG losses that arise from sludge processing. Energy savings and burdens need to be summed to derive a net value for assessed energy recovery options. The JRC study concluded that across 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) GHG emissions.

#### *Phosphorus*

Phosphate rock has been identified as a critical raw material by the EC (EC, 2014). As an essential nutrient for the food system, reuse and recovery of phosphorus is of high priority. Policies under the Green Deal are addressing this: as part of the Circular Economy Action Plan, an integrated Nutrient Management Plan will be developed towards ensuring more sustainable application of nutrients and stimulating markets for recovered nutrients (EC, 2020). More broadly, the chemicals strategy for sustainability aims to promote the EU's resilience of supply and sustainability of critical chemicals (EC, 2020).

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 foresee already that phosphorus recovery from sewage sludge will become mandatory. Some incineration plants already store sludge ash to recover the phosphorus in future.

Significant efforts have been made toward phosphorus recovery from sewage sludge based on the precipitation of phosphorus minerals e.g. in the form of struvites. These recovery technologies have been developed and put into operation largely in the Japan and Netherlands. Global demand for fertiliser is expected to increase by 4% a year due to population growth, so it can be expected that fertiliser recovery from waste water will gain further importance in the future. As well as conventional fertiliser, manure from livestock production also competes with fertiliser recovered from wastewater. 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, 2020).

Other resources can be recovered from waste water and sewage sludge e.g. cellulose, bioplastics and alginic acid (Kehrein, 2020). 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). Blockers preventing wide-scale application of resource recovery is not the availability of technology, but the lack of a planning and design methodology to identify and deploy the most sustainable solutions in a given context.

Actions leading to a more circular and sustainable economy revolve around reduction, reuse and recycling. Bottlenecks which can hinder the successful implementation of these can be grouped into three categories – Economics and value chain, Environment and health; and Society and policy. Recovering the value from sewage sludge illustrates aspects of bottlenecks, such as process costs, resource quality, market value and competition, and utilisation and application in the value chain assessment. Societal acceptance of the reuse of treated sewage sludge and 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 10 times more chemical and thermal energy than needed for treatment. While only some of that energy can be recovered, it is possible for 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 sludge is typically similar to the energy content of low-grade coal (Stone et al. 2010). Energy can be generated from sewage sludge through pre-treatment by anaerobic digestion to produce biogas, and/or by incineration of the sludge. Biogas comprises of 60 – 70 % methane, and 30 – 40 % of carbon dioxide, trace amounts of other gases (e.g. hydrogen, hydrogen sulphide and nitrogen). Recovery of methane from biogas allows use in applications such as gas engines, 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.

In a study considering the potential for sludge currently landfilled in the EU-27, it was estimated that 7 - 13 % of UWWT energy needs (1 800 - 3 200 GWh<sup>6</sup>) could be met if that sludge were pre-treated by anaerobic digestion, although data were hard to come by (Anderson et al, 2021). This value represents an upper limit, as it would not be feasible to implement anaerobic digestion at all UWWTPs.

Most focus on energy generation from UWWT has been on anaerobic digestion and incineration, but operators may have other options. For instance, solar and wind energy generation, and heat recovered from the waste water itself. Solar panels installed on the roofs of Viikinmäki UWWTP in Finland generate c.210 MWh per year, or approximately 0.5 % of annual electricity use. Heat recovery from effluent waste water shows can be a much more significant source of energy, with potential heat energy recovery at up to 500 % of a plant's heat energy consumption (Heinonen, pers. comm.). Actual solutions for a particular plant depend on local circumstances. For instance, incineration facilities may not be available, while biogas generation may not be economic at some smaller sites.

### 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 use for other human activities, avoiding the abstraction from other, possibly non-renewable sources, such as groundwater.

The return of suitably-clean water is also important for aquatic life, ensuring there is 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 °C temperature rise scenario (EEA, 2021). The WFD and Biodiversity Strategy (EC, 2020) 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 early stages of implementation (EEA, 2021).

Water reuse has become a key part of water resources management in countries suffering highest water stress. Where water resources are abundant or less stressed (CSI 018), waste water reuse is driven by other factors, e.g. conservation of groundwater resources, reduction of costs; the precautionary principle. The primary use of reused water is in irrigation for agriculture, with the modelled potential for reuse shown in Figure 3.4. Other uses are in irrigation of urban space, groundwater recharge and river flow improvement.

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<sup>6</sup> Values for EEA-32 were 1 900 – 3 300 GWh



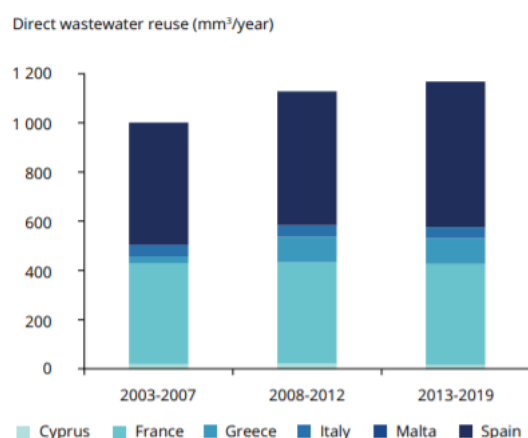
- Indirect reuse is the reuse of treated waste water which is placed into a water body such as a lake, river, or aquifer, and then some of it retrieved for later use.
- Direct reuse of treated waste water refers to the introduction of treated waste water via pipelines, storage tanks, and other infrastructure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

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

Implementation of water reuse is not widespread in the EU, though it is increasing in some Member States (Fig 3.x). It has been estimated that the potential for treated urban effluents in the EU is six times higher than current level of reuse (Pistocchi et al, 2017). In countries with significant problems of water stress or water scarcity, water reuse practice has been developed, facilitated by national guidelines providing regulatory reference on water reuse practices. Data are hard to come by but suggest that Cyprus reuse more than 90% of their waste water, followed by Greece, Malta, Portugal, Italy and Spain, where the share of reused urban effluent range between 1 and 12%. 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 was the protection of coastal water quality and conservation of groundwater resources.

**Figure 3-3 Water reuse in Mediterranean EU Member States**

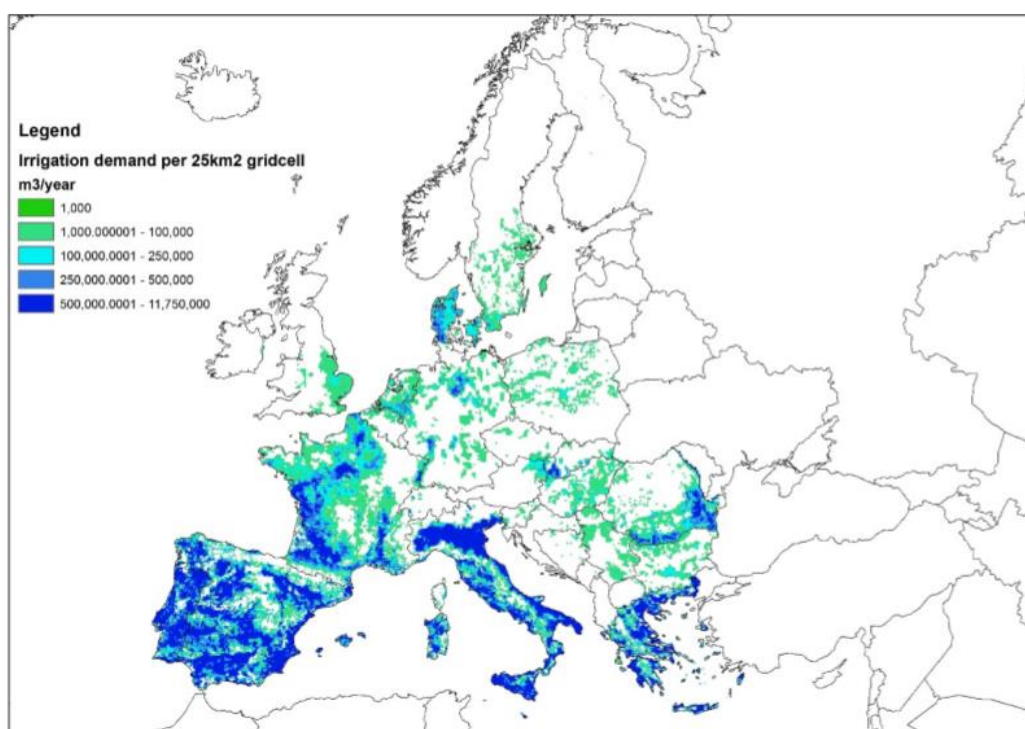
**Figure 3.29 Volume of direct wastewater reuse in the MED EU subregion (Mm<sup>3</sup>/year)**



Source: Computation based on FAO-AQUASTAT (2016).



**Figure 3-4 Modelled potential of water reuse for agricultural irrigation in the EU**



Source: Pistocchi et al, 2017

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

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

Despite the Water Reuse Regulation of 2020, which recognises that water reuse will become more necessary and so set standards for the agricultural reuse of waste water, numerous barriers to water reuse still exist in Europe. Drivers for reuse include population pressure and water scarcity. A coherent legislation framework (currently being established in the frame of Circular Economy Plan) is needed, which provides flexibility for treated water quality depending on destination uses, and allows for governance structures enabling interdependencies between waste water providers and users of reused water.

Text box /case studies: Waste water reuse

Case study – waste water reuse for irrigation - Milan, Italy

Reuse of wastewater for irrigation reduces the quantity of drinking water used for irrigation and guarantees supply of high-quality water for farmers in the Milan area. All the water treated by the Nosedo and San Rocco plants meets the limits applicable to reuse for irrigation purposes, as certified by ARPA, and is used to irrigate a substantial portion of farmland with a surface area of over 100 km<sup>2</sup>. This practice for irrigating the rural areas outside the city, has its roots in the past and reflects the historical and cultural heritage of the area.



Case study – beer brewed using recycled waste water - Čížová microbrewery – Czechia

To raise public awareness of the importance of preserving water, together with Veolia, Čížová microbrewery in the Czech Republic 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, where ultra-fine synthetic membranes serve as a filter that lets water pass through and retains suspended solids and other substances, such as micro-organisms 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 new types of membranes have low energy consumption. The treated water is then transported to Čížová microbrewery, where it is used to brew ERKO beer. 15 hectoliters of lager were produced in May 2019 and more continue to be produced as the interest in supporting recycling schemes grows.

### 3.4 Low input sewage treatment

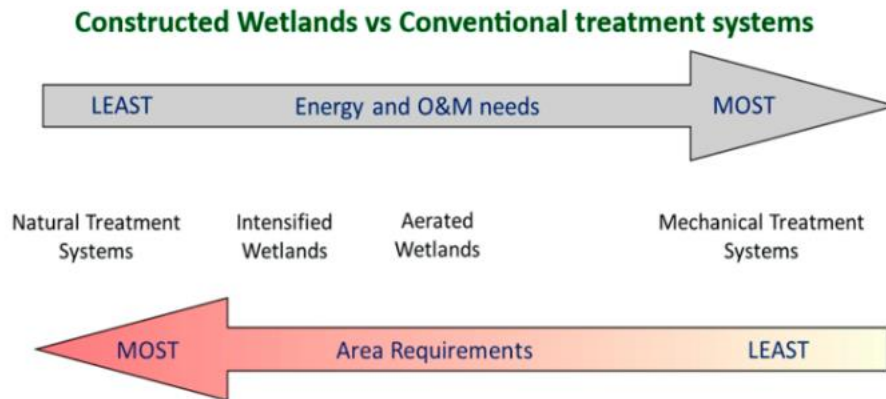
Options for waste water treatment are constrained by local factors. A densely populated city, with many industries and limited land availability presents one extreme, while sparsely populated, rural areas represent another. Construction of waste water treatment plant can involve greenhouse gas-intensive 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 (Water Projects online, 2019).

A focus on nature-based solutions under the EU's Biodiversity Strategy (EC, 2020) brings attention to small-scale solutions to sewage treatment. Natural wetland systems are able to transform and/or remove various pollutants through a series of physical, biological, and chemical processes, and therefore improve water quality. These processes are mimicked in so-called "constructed" wetlands. These treat waste water near its source, without high demands on infrastructure and operational costs, while enabling recovery and use of resources from waste water and increasing green space in rural or peri-urban areas. In a study on Slovenia, the JRC compared various solutions in terms of cost-effectiveness and socioeconomic acceptability. They found that nature-based solutions were a preferred option for areas with a predominance of rural, scattered dwellings and small settlements. The concept was proposed as a mainstream solution for the less urbanized areas of the Lower Danube region (Pistocchi et al, 2020).

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



**Figure 3-5 Comparison of needs for land, energy and maintenance between constructed wetlands and conventional urban waste water treatment**



**Figure 2.** Qualitative comparison of constructed wetlands and mechanical treatment systems in terms of energy, operation and maintenance demands and area requirements.

Source Stefanakis, 2019

Recent technological advances have managed to significantly close the gap with 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 wastewater treatment and urban runoff 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).

#### Text Box: Waste water purification in villages in Spain

In Spain, the challenge for administrations to implement waste water purification systems in towns with less than 1 000 inhabitants stood out in the search for balance between the elimination of pollution and the economic sustainability of treatment plants. The cost of operation and maintenance of a conventional treatment plant in municipalities with more than 10,000 inhabitants could be around 10 euros per inhabitant per year, while in a town where fewer than 100 people live it would increase to 345 euros. Use of alternative technologies with lower maintenance costs, adapted to the local situation was expected to significantly reduce this economic gap. Analysis was carried out on the presence of emerging pollutants in the waters of the treatment plants of the Badajo province, such as drugs and herbicides. This highlighted analgesics as being the emerging pollutants with the highest concentration in the water entering the treatment plants, although in 90 percent of the cases, residues were eliminated during the purification process.



## 4 Systemic change: Zero pollution, circular economy

### 4.1 Introduction

Treatment to clean our sewage is essential to protect human health and the environment. Waste water treatment is also expensive, 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 more waste and emissions. In our focus towards ensuring the water cycle is respected, we have developed a linear solution – missing the circularity which 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 which are harmful to the environment, traces of which can enter the water system from our homes, schools and workplaces. Some of these substances are essential and alternatives may not be available. But for others, achieving the aims of the Chemicals for Sustainability Strategy provide for a long term solution. Transitioning to a society where chemicals and products no longer contain substances of concern<sup>7</sup> both advances zero pollution and also allows circularity, within the product as well as the “waste water” chain. In advance of achieving that ambition, we will nevertheless have to manage pollutants already in use and circulation.

Historically, we have left it to water managers to solve society’s waste problem, at the end of the pipe. But already more sustainable solutions are being trialled by innovative utilities, villages and cities. By recognising the central role that waste water treatment can play in a circular, zero pollution economy, full power can be applied to achieve systemic change.

### 4.2 Re-thinking “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 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 – financial, in pollutants to water and greenhouse gas emissions, and, as we look ahead to a changing climate, with new challenges. More intense rainfall in parts of Europe is leading to more frequent surface water flooding and discharge or runoff 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 UWWTPs, reducing their efficiency.

Practically, we have built a system which requires dilution of a nutrient and energy-rich natural resource by 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 for politically-acceptable and economically-viable routes. This linear

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<sup>7</sup> i.e. those with persistent, toxic, bioaccumulative and mobile characteristics



approach focuses on water quality, giving much lower priority to other environmental dimensions.

There are other ways to manage our sewage safely and with much less infrastructure. Keeping the sewage from toilets separate from other contaminated “grey” water, such as that from washing, allows alternative, water-less treatment to kill pathogens and recover the nutrients and or energy (Zeeman and Kujawa-Roeleveld, 2011). Meanwhile, less intensive treatment, or no 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 waste water treatment plants. Experiments with building-focused sewage treatment and water reuse have already shown the problems associated with construction mistakes, where effluents from other non-drinking water systems in buildings have been introduced into the drinking water distribution system, compromising human health (EC, 2021). Less immediate, environmental harm may be caused if the waste from ourselves and our houses continues to be contaminated with micropollutants (Zintz et al, 2021; Comber et al, 2014). However, households with individual treatment systems such as septic tanks tend to be careful not to poison those systems (Mulder, 2019). Realising the ambitions of the Chemicals Sustainability Strategy over the longer term is key to reduce harmful micropollutants at source. “Hybrid grey and green” water infrastructure combines centralised and decentralised water treatment, leading to reduced water loss, increased water reuse, optimising the exploitation of alternative water sources in a circular economy, and strengthening resilience against climate change events (WE, 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 that is still lacking, and to develop skills and capabilities in “new” technologies (or rather, re-learning traditional recycling). New developments in urban areas, such as the brownfield site at Buiksloterham (see text box), can provide opportunities in purpose-built, decentralised treatment approaches.

**Text box: Case study – Collaboration, city level - Amsterdam, the Netherlands.**

In Buiksloterham, a collaboration between the water board, municipality and housing corporation is piloting a study on separation of waste water at source, to test the sustainability of decentralized sewage treatment. An innovative vacuum sewer and floating treatment plant has been built with a capacity of 1550 p.e., with vacuum toilets installed in 47 floating homes.

The traditional waste water sewer system is replaced by a multiple sewer system, which consists of a vacuum pipe with a small diameter for the concentrated collection of 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 through avoidance of pumping 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.



### 4.3 Zero pollution and waste water treatment

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. Cleaning, washing and runoff introduce these into the waste water stream. Such societal and sectoral issues are beyond the capacity of water managers to resolve, but rather, require wholesale review of what substances we choose or allow to be used. Such is the role for the Chemicals for Sustainability Strategy, launched by the EC in 2020 (EC, 2020). Among its ambitions, the Strategy aims to ban the most harmful chemicals in consumer products and allow use of such substances only where essential. This is key to reducing the load of harmful chemicals into waste water. The ambition to boost the production and use of chemicals that are safe and sustainable by design should lead to lower chemical pollution over the longer term. In turn, lowered pollution loads in waste water will reduce the need for intensive treatment i.e. turning 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 the JRC has examined the costs and benefits of micropollutant removal, considering ca. 1200 chemicals assumed as a proxy of the total pollution conveyed by raw wastewater. This has shown that advanced treatment for micropollutants at all plants in Europe with a capacity of 100 000 p.e. or more could reduce the overall toxicity of discharged effluents by about 40% (JRC, 202x).

The decisions taken to addressing sewage treatment through any particular approach are necessarily local. Water managers aim to optimise according to local requirements and possibilities: ensuring and enabling circularity principles form part of those considerations is the role of policymakers. Where trade-offs come into play, ensuring the protection of human health and the environment should take primacy.

### 4.4 Circular economy – from “waste water treatment” to resource recovery

The goal of a circular economy is to manage natural resources efficiently and sustainably (EEA, 2016). Respecting planetary boundaries through increasing the share of renewable resources while reducing the consumption of raw materials and energy, and at the same time cutting emissions and material losses, meets goals set both for sustainability and business efficiency. The Circular Economy Action Plan under the Green Deal seeks to accelerate the transition towards a regenerative growth model and move towards keeping resource consumption within planetary boundaries, thereby reducing Europe’s consumption footprint (EC, 2020). Three principles underpin the detail for a circular economy:

- Eliminate waste and pollution
- Circulate products and materials
- Regenerate nature

Source: Ellen MacArthur Foundation, n.d.

Water in the environment follows a natural cycle that secures water resources by regulating water flow and ensuring water quality. On the other hand, in systems created by people that

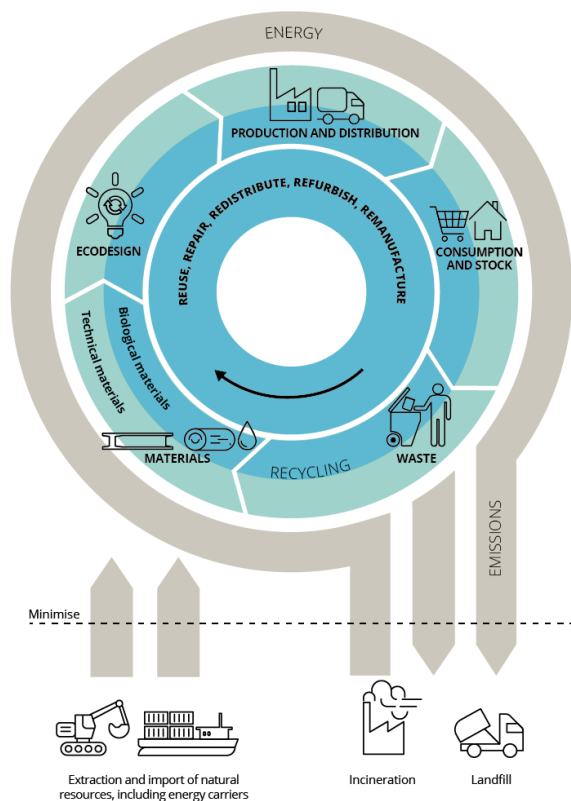


follow a linear model of economic growth “take-make-consume-dispose”, the quality of water is reduced, becoming unfit for further use both by humans and ecosystems (Stuchtey, 2015).

From one perspective, sewage and waste water are the waste products from human life. However, these also form part of natural cycles that urban waste water treatment is at least already partly successful in recreating, such as returning cleaner water to the environment and sludge to land. However, the approach to date has neglected some areas, such as greenhouse gas emissions, and been unable to fully address others, such as micropollutants in urban waste water. The transition of UWWTPs from “pollutant removal facilities” to resource recovery facilities has been foreseen by the sector, with a wide range of technologies for water reuse, energy and resources recovery, despite limited, full-scale application (Kehrein, 2020; Veolia, n.d.).

Whilst some progress has been made in water utilities transitioning to a circular economy, there remain two significant drawbacks: a difficult regulatory environment and opaque market conditions. The complexity of the “landscape” for implementation of circularity becomes clearer (Fig 4.1).

**Figure 4-1 Challenges in shifting from a linear to a circular system**



Source, EEA 2020

Implementing circularity more fully in the UWWT sector will extend the context of supply and demand in which water utilities operate, as well as the regulatory framework, since single sector approaches will not be able to deliver the desired outcomes. Challenges to the waste hierarchy are already arising, with some innovative operators presenting mono-incineration of sewage sludge with phosphorus recovery, as circular practice. Circularity will result in an increased range of products, such as reused water, energy, nutrients and other resources. Quality will need to be regulated, while reflecting use which is fit for purpose - already the Waste Water Reuse



Regulation (2020) has taken steps in this direction. Customers across different economic sectors e.g. energy, agriculture and industry, need to play an active role in defining the quality of products. Specific value chains, embedded in local or regional economies, may need to be established for specific products or services. Taken together, delivering circularity will require adaptation of existing institutions and regulatory practices. Holistic, integrated water management is required which does not necessarily follow conventional administrative, sectoral, political and geographical boundaries. It will need to build on broad-based engagement and partnership ( [Stuchtey, 2015](#); [IWA, 2016](#); [Arup et al., 2018](#)).

## 4.5 Accelerating the transition

Sewage treatment is an essential service which can provide clean water, nutrients and renewable energy. However, in its current operation it uses significant amounts of energy, leads to significant emissions of greenhouse gases and produces sewage sludge in large quantities which may represent disposal problem for utilities. The shift from “waste water management” to “resource hubs” is already happening in some forward-thinking towns and utilities (text boxes).

### **Text box: Case study – Net zero emissions - Scottish Water, UK**

Scottish Water have a target to reach net zero GHG emissions by 2040. Some actions are directly in their control, such as improving energy efficiency and hosting renewable energy. But others require efforts to influence customers and supply chains, such as the amount of water people use, removing surface water from sewers, and reducing emissions in the cement they buy (Scottish Water, 2021). They have identified areas for innovation, such as low energy treatment methods; ammonia and methane recovery; the need for digital and analytical tools; low/zero emissions materials for investment and operations.

### **Text box: Case study – 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 of 17 smaller facilities. The Danish water sector aims to be climate and energy neutral by 2030.

Marselisborg UWWTP has increased plant efficiency and reduced energy consumption by optimising its processes. It now produces 50 % more electricity than it needs for UWWT and 2.9 GW 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 saving approximately 1 GWh/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.

While solutions adapted to the local situation are necessary for sewage treatment, the characteristics which are necessary to achieve a transition to more sustainable approaches can be set out. Innovation can play major role in enabling circularity. More efficient technologies, which eg reduce energy costs of resource recovery and increase recovery rates are perhaps obvious, but innovation also applies to new partnerships extending across public administration, research, industry and citizens, with new business models and new forms of water governance



(Martins et al, 2013; Moore et al, 2014; EWA, 2014). Sustainability, nature-protection ideas and citizens can contribute to the exploration of alternative domestic, communal, and public approaches. The Strategic Implementation Plan for EIP Water identifies several areas, such as water re-use 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 (European Commission, 2012a). Digitalisation can help in the delivery of improved efficiency and productivity, and faster monitoring to inform decision-making (Mbavavira and Grimm 2021; EC, 2021). Connecting to Stakeholders beyond Traditional Boundaries provide mechanisms to promote a shift towards markets for recovered resources and sustainable technologies, using perhaps Integrated Resource Management as a process to bring together all the resource groups. This allows optimisation of the supply and demand for resources, and for opportunities and synergies to be taken into account, helping to place recovered resources in appropriate value chains. Practically, achieving circular practice can require intense efforts by all players, not least in the area of enabling legislation (text box).

#### **Text box: Case study – Legislative barriers to urban phosphorus recovery - NL**

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 (where the sludge is not mixed with other wastes). In the Netherlands, experiments to recover struvite from UWWTPs at full scale started in 2006, but introduction to the fertiliser market was hindered by the classification of struvite as a waste, with the Fertilisers Act prohibiting use of wastes. A change in legislation was supported by extensive studies examining struvite use as a fertiliser and various initiatives of the Dutch Nutrient Platform, in particular 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, 2021). Use of struvite and other two recovered phosphates as fertilisers was eventually approved from 2015.

#### **4.5.1 De-centralised solutions for circularity**

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

Decentralised waste water management is used to treat and dispose, 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. 3–5 km) and not served by a central sewer system connecting them to a regional UWWTP. While still needing a local collection system, this is likely to be much smaller and less expensive than those used for conventional, centralized treatment, especially when the greywater components have been separated human waste (Capodaglio, 2017). Decentralised systems focus on the on-site treatment of waste water and on local recycling and reuse 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, capacity can be added incrementally and quickly. As such they can serve as alternatives to conventional expansion/refurbishment of the sewer network and thus could help to save funds in the short and long terms. Remote control and monitoring contributed to operation and management improvement and resolved problem with lack of skilled personnel. Decentralised solutions enable introducing source separation between urine and faeces, and possibly grey water through toilet systems or other water saving systems which can further enhance resources and energy recovery.



Decentralised solutions in general will tend to be compatible with local water use and reuse requirements where locally treated water could support agricultural productivity or (in more urban areas) be used as a substitute for drinking water for uses which do not require such high quality (e.g. landscaping, surface storage, recreation, groundwater recharge, industrial application/ cooling) (Capodaglio, 2017).

The decision to implement a decentralised solution to waste water treatment needs is usually made or discussed at the local level, and local stakeholders are usually more proactive when considering these systems. Stakeholder involvement can help in establishing closed loops for local reuse of recovered resources and thus contribute to establishing viable value chain for recovered resources as a part of local economy. As such they can serve as sources of valuable novel approaches, and testing laboratories for new concepts that can be extrapolated at larger scales.

#### **4.5.2 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 UWWT might seem somewhat remote. But we all have a part to play.

- i) Water efficiency. Using water more efficiently not only saves water, but also the energy put into treating it and pumping it to the tap, and then the resources to take it through the UWWT process.
- ii) Avoid putting harmful pollutants down the sink and drain. Then they do not need to be removed from the water - if indeed, it is possible to remove them. Safe disposal of pollutants is usually offered by local councils. Leftover medicines can be taken back to pharmacies.
- iii) When replacing clothes, textiles and furniture, consider those which are made of environmentally-friendly materials if possible. This helps avoid pollutants in such products being washed out and then eventually reaching the sewer system.

#### **4.6 What needs to change**

With no change to current direction, the trajectory for UWWT in Europe is for 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 using sewage sludge in application to land, leading to increased demand for incineration and problems for regions lacking such capacity. Infrastructure investment costs will continue to increase, along with the GHG emissions embedded in concrete, plastics and steel for sewer networks and treatment plants.

Water managers are skilled at optimising processes within their remit. UWWTP processes can be optimised to improve energy efficiency. GHGs released during treatment are being reduced and more energy recovered from the UWWT cycle, such as in biogas and through heat recovery. Nutrient recovery, particularly of phosphorus, is driving innovative utilities towards solutions such as mono-incineration and finding applications for reuse of remaining ash.

Accepting this situation with no change risks accepting an unsustainable lock-in (EEA, 2020).

Addressing long-term sustainability in this area means fundamentally reviewing the purpose of sewage treatment. In the long term, protecting human health and the environment from sewage and waste water does not necessarily require the major infrastructure programme that we have developed. Decentralised and nature-based solutions, such as constructed wetlands and source separation schemes, allow for low input, effective sewage treatment, while at the same time



1526 producing local environmental benefits such as green space. The treatment solution at any  
1527 particular place has to reflect the local situation, but more sustainable approaches should be  
1528 enabled.

1529 Achieving a circular economy in sewage treatment is a long term project and is dependent on  
1530 many contributors. From realising the Chemicals Strategy for Sustainability to prevent  
1531 micropollutants reaching sewage from our homes, to enabling legislation at all levels, to  
1532 establishing viable markets for recycled products. Such are the needs to transition to the  
1533 sustainability envisaged by the Green Deal.



## List of abbreviations -to be added

Abbreviation	Name	Reference
EEA	European Environment Agency	<a href="http://www.eea.europa.eu">www.eea.europa.eu</a>



1545

## Glossary – to be added

Word	Meaning
Eutrophication	

1546

1547

1548



## References – to be added

- For print references use the following format:
  - Author's surname, author's initial(s)., year of publication, *Title of reference work* (where appropriate include edition number), publisher, place of publication, relevant page numbers if necessary.
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