CHAPTER 4

Mitigation measures in drinking water and sanitation services

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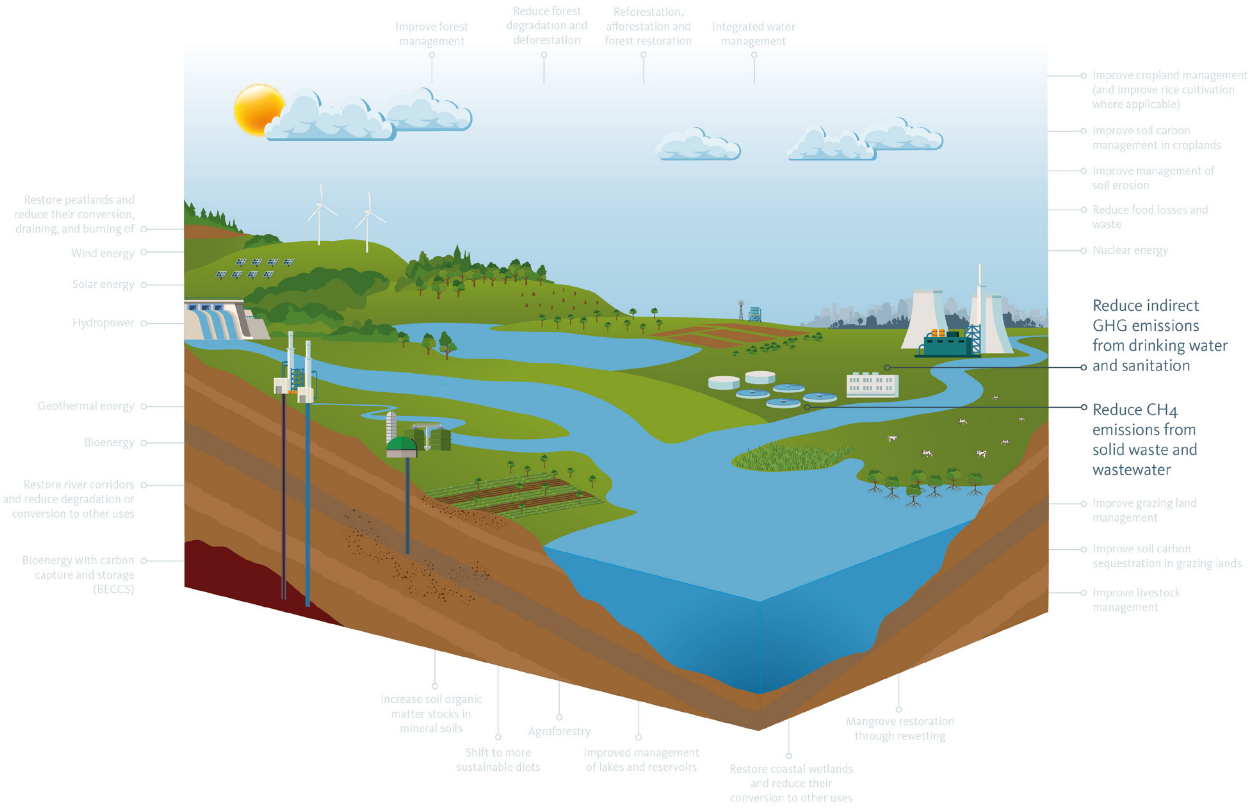

Figure 4.0. Mitigation measures in drinking water and sanitation services. Source: SIWI.

Highlights

- Wastewater treatment and discharge account directly for 12 per cent and 4 per cent of global methane and nitrous oxide emissions, respectively. In addition, drinking water and wastewater management are responsible for approximately 4 per cent of global electricity consumption, often associated with indirect carbon emissions. It is expected that, by 2030, the amount of energy consumed will increase by 50 per cent.
- Reducing the release of these greenhouse gases (GHGs) is a major opportunity for climate change mitigation. Release of GHGs from wastewater and faecal sludge can be reduced through the improved design, management, and adjustment of operating conditions of wastewater treatment plants (WWTPs). Similarly, energy efficiency measures and other solutions (e.g., increased use of renewable energies) can be implemented to decrease energy consumption and reduce carbon dioxide (CO_2) emissions.
- A significant proportion of the wastewater generated in cities and rural areas remains untreated or only partially treated, with the emissions from untreated wastewater being three times higher than emissions from conventional WWTPs. In addition, millions of people currently have limited or no access to sanitation, and the mitigation potential of providing them with access to safely managed sanitation services cannot be underestimated. The extension of wastewater collection and treatment systems, including decentralized solutions, emerges as a win-win for development and climate mitigation.
- Water utilities are increasingly measuring and reporting their GHG emissions and savings as part of national GHG inventories, using tools such as the publicly available Energy Performance and Carbon Emissions Assessment and Monitoring (ECAM) tool. However, there is a need to strengthen assessment, monitoring, and reporting of GHG emissions from water and wastewater handling, including on-site sanitation. The actual mitigation potential is largely unknown because data on GHG emissions is limited and has high levels of uncertainty.
- This data and knowledge gap hampers effective integration of water, sanitation, and hygiene (WASH) in climate policies and mitigation strategies. It also presents a challenge to making climate finance available.

4.1 Introduction

Improvements in the delivery of drinking water and sanitation services can contribute significantly to climate mitigation solutions. The collection, treatment, and discharge of wastewater and faecal sludge result in the direct emissions of significant amounts of methane and nitrous oxide from the decomposition of organic matter. Similarly, the management of water and wastewater systems involves energy-intensive processes and, depending on the source of energy used, contributes indirectly to emissions of CO_2 and other GHGs (Maktabifard et al. 2020). From another angle, water supply efficiency can reduce global emissions through the reduction and control of unaccounted-for water, for example.

The emissions from water and sanitation systems arise from different stages of the value and service chain. They result from either fugitive emissions from biological treatment facilities (direct emissions), or management activities and the demand for resources to run such systems, such as energy and transportation of sludge; the production of chemicals for water treatment and distribution; or processes associated with abstracting, supplying, and treating drinking water (indirect emissions). The magnitude and characteristics of emissions from a given system are highly dependent on its technological configuration and operational arrangements. Other important factors include the features of the water, wastewater, and sludge, and environmental conditions, such as the average seasonal temperatures of a country.

This chapter describes the mitigation measures for various potential adverse impacts resulting from the management of water and wastewater systems. In the next section, global and regional data on GHG emissions from water and sanitation services are presented and discussed. Section 4.3 covers the mitigation options to reduce the direct release of GHGs from wastewater and faecal sludge treatment and discharge. It also addresses the emissions from decentralized sanitation systems. Section 4.4 presents solutions to mitigate the GHGs emitted indirectly through energy-intensive processes related to water and wastewater management. Sections 4.5 and 4.6 present the gaps in climate policy and financing, and in data and knowledge on GHG emissions from water supply and sanitation. Section 4.7 concludes with a list of key action points suggesting the way forward.

4.2 GHG emissions from drinking water and sanitation

4.2.1 Direct GHG emissions from wastewater and faecal sludge management

Wastewater treatment and discharge processes are sources of anthropogenic emissions of GHGs such as CO_2, methane, and nitrous oxide.[1] In coherence with the trends observed during the past decades, these emissions are projected to increase steadily in the future (US EPA 2013). Lu et al. (2018) estimated that direct GHG emissions at WWTPs account for approximately 1.6 per cent of global GHG emissions, stating that wastewater treatment is responsible for roughly 5 per cent of the total global non-CO_2 GHG emissions (e.g., methane and nitrous oxide). In another study, Crippa et al. (2019) showed that in 2018 the sanitation and wastewater sector[2] was responsible for 11.84 per cent of global methane emissions and 4.28 per cent of global nitrous oxide emissions (Figures 4.1 and 4.2). In this same year, wastewater treatment and discharge alone accounted for 57.21 per cent of methane and nitrous oxide combined global emissions from the waste sector. Of those, the share of methane and nitrous oxide emissions corresponded to 51.76 per cent and 5.45 per cent, respectively (Crippa et al. 2019). Figure 4.2 also shows that within emissions of nitrous oxide from the waste sector, wastewater accounted for almost 94 per cent of these emissions (Crippa et al. 2019). According to the Intergovernmental Panel on Climate Change (IPCC) Working Group (IPCC 2014), between 1970 and 2010, the domestic/commercial sector was responsible for close to 80 per cent of the methane emissions from the wastewater category.

More detailed inventories in the United States of America (USA) and European Union (EU) indicate regional disparities. In the USA, GHG emissions from wastewater accounted for approximately 2.8 per cent and 6.2 per cent of total methane and nitrous oxide emissions, respectively (US EPA 2018). A similar EU inventory (EEA 2021) showed that methane emissions accounted for approximately 4 per cent of the total emissions, while nitrous oxide emissions were significantly lower, i.e., 3 per cent of the total emissions. Moreover, in both regions, the trends for the two gases have been different over the last 30 years. In the USA, methane emissions remained stable from 1990 to 2005, and in the last 15 years have decreased by almost 20 per cent. This reduction was attributed to decreasing amounts of wastewater being treated in anaerobic systems. Nitrous oxide emissions were gradually increasing from 1990 until 2015 (altogether by 35 per cent) and then stabilized. The increase was explained by an increasing USA population and protein consumption. However, in the EU, methane emissions decreased by over 50 per cent, while nitrous oxide emissions decreased by almost 17 per cent. These reductions were attributed to the implementation of new wastewater treatment technologies (EEA 2021).

Although relatively small compared with GHG emissions that are released directly from WWTPs, the mitigation impact of decentralized sanitation also requires consideration in planning for sanitation and wastewater systems. More specifically, it is estimated that 1.6 billion people use pit latrines on a daily basis (WHO 2021), roughly accounting for 1 to 2 per cent of current methane emissions (Dickin et al. 2020; van Eekert et al. 2019; Reid et al. 2014). Pit latrines are therefore a significant source of methane in sanitation, as already suggested by Kulak et al. (2017), which states

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[1] The IPCC guidelines suggest that only methane and nitrous oxide emissions are accounted for in WWTPs, while CO_2 emissions are not included as being derived from natural biological sources (IPCC 2014).

[2] The sanitation and wastewater sector includes industrial and domestic categories, comprehending different treatment systems such as latrines, septic tanks, lagoons, and aerobic and anaerobic plants, among others (Crippa et al. 2019).

that closing the sanitation gap through pit latrines would be expected to cause large increases in India's annual GHG emissions, equivalent to 7 per cent of current levels. Along this same line, another study suggests that providing basic services such as pit latrines to 1.69 billion people who lack access to sanitation could double the GHG emissions from this source (van Eekert et al. 2019). These estimates are, however, relatively uncertain, since GHG emissions depend on the type of on-site infrastructure (e.g., pit latrine versus septic tank), the individual use of the system (e.g., poor flush latrines versus dry latrines), the quality and efficiency of faecal sludge management, and the existence and type of faecal sludge treatment, including operational issues and the propensity for anaerobic conditions (Saunois et al. 2016; GIZ et al. 2020).

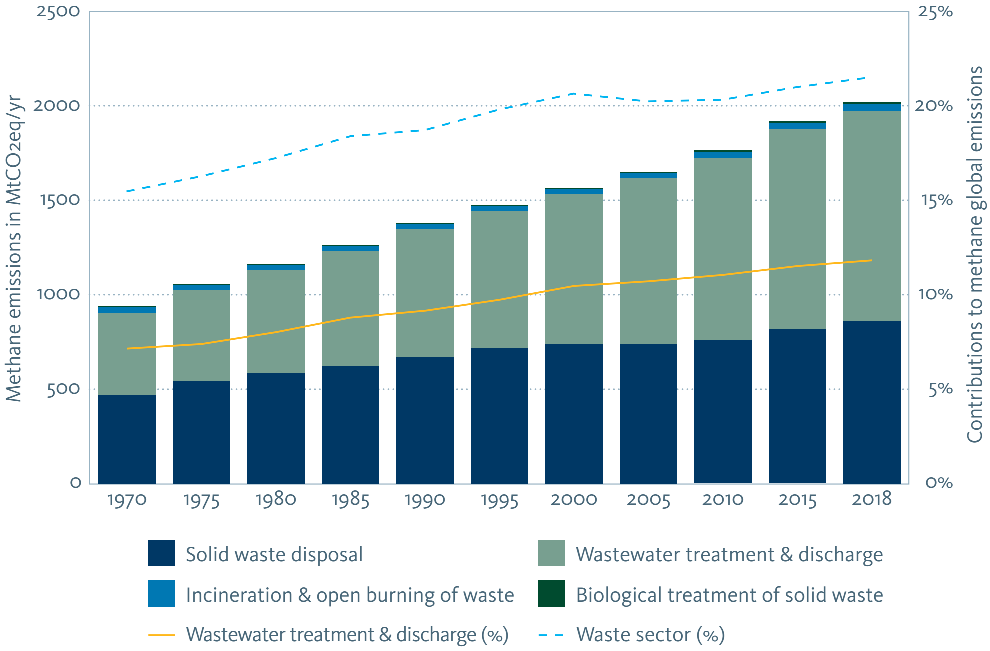

Figure 4.1. Global methane emissions from waste, by activity in the water sector, and percentage contribution to global emissions. Source: adapted from Crippa et al. (2019). Graphs were elaborated based on EDGARv6.0 inventory, which makes use of IPCC 1996 and 2006 codes for specification of the sectors. The 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 5: Waste was used as a reference for defining the codes included in the waste sector, i.e., Solid waste disposal; Biological treatment of solid waste; Incineration and open burning of waste; and Wastewater treatment and discharge (domestic and industrial).

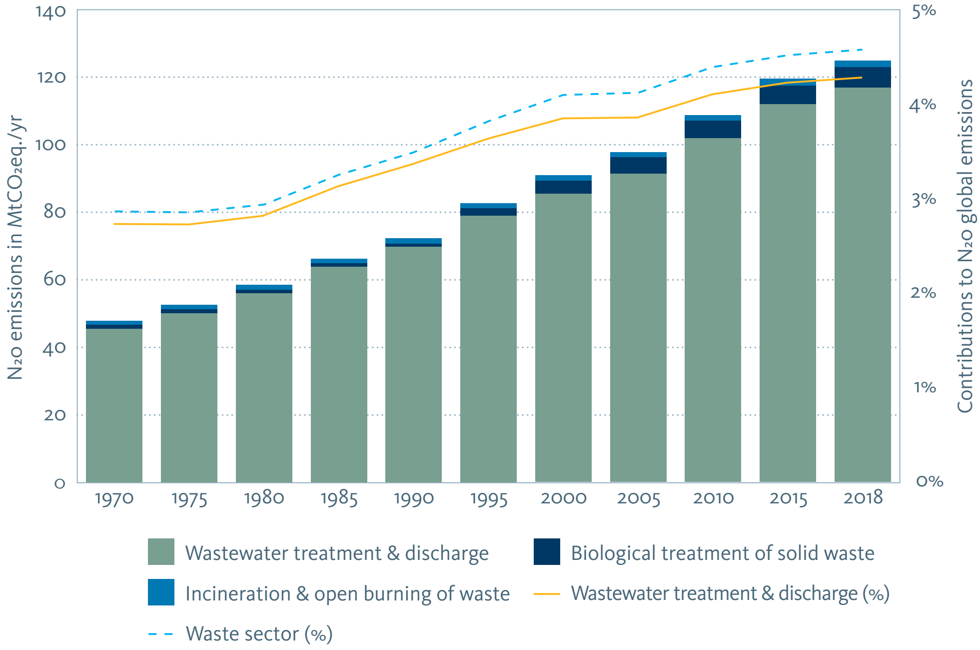

Figure 4.2. Global nitrous oxide emissions from waste, by activity in the water sector, and percentage contribution to global emissions. Source: adapted from Crippa et al. (2019).

4.2.2 Indirect GHG emissions from drinking water and sanitation

The extraction, distribution, and treatment of water and wastewater use vast amounts of energy. It is estimated that the sector[3] globally uses roughly 120 million tons of oil equivalent (Mtoe) per year (IEA 2018), making the proper management of water and wastewater essential to reduce energy usage and associated GHG emissions (Nair et al. 2014). More than half of this energy is in the form of electricity, accounting for 4 per cent of global electricity consumption. About 40 per cent of this electricity is used for water supply, including the extraction of ground and surface water, while wastewater treatment and water distribution account for about 14 and 13 per cent, respectively. About 26 per cent is used for desalination and re-use, and the remainder for long distance water transfers (5 per cent) (IEA 2018). However, as noted by IWA (2022), there is a big difference between high-income and low-income countries. In high-income countries, wastewater treatment makes up about 42 per cent of electricity consumption, whereas in low-income countries, this figure is substantially lower since a large portion of wastewater is neither collected nor treated.

In consequence, for many municipal governments, drinking water supply and wastewater treatment are typically the largest public energy consumers, often accounting for 30 to 50 per cent of total energy consumed (Copeland and Carter 2017; IEA 2018), also representing a significant fraction of municipal energy bills (Capodaglio and Olsson 2019).

By 2030, it is expected that the amount of energy consumed by the water sector will increase by 50 per cent, with upward pressure coming from several sources: a) increased reliance on desalination to bridge the water supply gap in water-scarce regions; b) large-scale water transfer projects; and c) wastewater treatment expansion in developing and emerging economies (IEA 2018).

4.3 Mitigation actions to reduce direct GHG emissions from wastewater and faecal sludge management

In WWTPs, mitigation strategies to measure, reduce, and report direct emissions of GHGs are increasingly common. As shown in Table 4.1, they can focus on both selecting an appropriate process configuration and adjusting operational conditions. However, much of the wastewater generated in cities and rural areas remains untreated or only partially treated, with the emissions from untreated wastewater being three times higher than those of conventional WWTPs (IEA 2018). Therefore, there is an urgent need to expand and improve wastewater collection and treatment, with a special emphasis on low-cost decentralized systems.

Modern urban wastewater treatment plant. Source: Shutterstock.

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[3] Includes water extraction, long-distance water transport, water treatment, desalination, water distribution, wastewater collection, wastewater treatment, and water reuse (IEA, 2018)

Table 4.1. Overview of potential mitigation action to reduce direct GHG emissions (methane, nitrous oxide and CO_2) from drinking water and sanitation

★★★★ High mitigation potential due to efficient reduction of direct GHG emissions and high level of scalability;
★★★ Medium to high mitigation potential due to efficient reduction of direct GHG emissions but not easy to scale-up;
★★ Medium mitigation potential due to less efficient reduction of direct GHG emissions;
★ Low mitigation potential due to low reduction of direct GHG emissions.

MITIGATION ACTION	PROS, CONS, AND CAVEATS	MITIGATION POTENTIAL (MP)
Modify the operational conditions (minimization).	In terms of costs, the most efficient way to reduce GHG emissions is to modify and control the operational conditions of WWTP units (Campos et al. 2016). However, this is not always possible due to the operational limitations of the installed units.	MP: ★★★★ Marinelli et al. (2021) determined direct and indirect emissions from WWTPs in the Treviso region of Italy. The study included five plants of different treatment capacities, ranging from 3,000 to 73,000 population equivalent (PE). The authors prioritized the following systematic GHG mitigation strategies: • Acquire external renewable energy sources to reduce the indirect emissions • Optimize aeration efficiency to reduce dissolved GHGs in the final effluent • Avoid uncontrolled transitory phases in the reactors to reduce direct emissions • Promote low- impact sludge disposal, e.g., farmland distribution. • Use chemical reagents characterized by lower emission factors.
Apply new treatment configurations and processes (prevention).	The configuration of new WWTPs should maximize the anaerobic pathway for organic matter removal and the use of microalgae. Land requirements, however, might hamper the implementation of these solutions in specific contexts (microalgae systems to remove nitrogen would require about ten times the area necessary for activated sludge systems).	MP: ★★★★ One study quantified the potential reduction of GHG emissions due to the implementation of new processes in WWTPs (Campos et al. 2016). Results obtained indicate that systems using microalgae to remove nitrogen are the most suitable systems to decrease GHG emissions during wastewater treatment.
Introduce biogas capture and valorization.	Biogas capture and valorization through a cogeneration system, directly reducing methane emissions and providing renewable energy, which can be used in the WWTP. Emissions and their reductions need to be measured frequently.	MP: ★★★★ In 2014, the water utility in the city of Cusco, Perú (SEDACUSCO), supported by the Ministry of Housing, Construction and Sanitation, and the German Agency for International Cooperation (GIZ), started operating an anaerobic digester for treating sludge and producing biogas on a continuous basis. In this way, SEDACUSCO attained a steady reduction in the amount of untreated sludge it disposed of. In 2021, SEDACUSCO avoided about 8,200 tons of CO_2 equivalent per year, but with the biogas being flared and released into the atmosphere without valorization. In 2021, SEDACUSCO inaugurated a biogas-powered clean energy production system, turning biogas into thermal and electrical energy. It is expected that this new system will help SEDACUSCO to save EUR 260,000 in annual electricity costs and avoid 544 tons of CO_2 equivalent per year in addition to the emissions avoided by the sludge treatment.

MITIGATION ACTION	PROS, CONS, AND CAVEATS	MITIGATION POTENTIAL (MP)
Capture and treat the gaseous streams containing GHGs (treatment).	Various technologies exist to destroy or capture nitrous oxide, methane, and CO_2 from industrial gaseous streams. For instance, traditional technologies, such as selective catalytic reduction and selective noncatalytic reduction, are currently used to control and remove nitrous oxide emissions. Similarly, biological technologies based on biofilter systems have been studied to remove methane from waste gas emissions. However, efficient low-cost mitigation technologies to treat gaseous streams from WWTPs are not yet fully developed. In addition, the capital costs required to cover the different tanks and capture GHG emissions are relatively high (Campos et al. 2016).	MP: ★★ Chou and Cheng (2005) evaluated control methods for volatile organic compounds (VOCs) from WWTPs in Taiwan, and recommended use of a system of sealed covers connected by suction to a purification facility as the optimal technology for controlling VOC emissions in parts per million volume (ppmv) as methane. Cost analysis results indicate that incinerators with regenerative heat recovery are optimal for treating high VOC concentrations exceeding 10,000 ppmv as methane; the resulting cost for abatement VOC emissions is around USD 165 per ton of methane. For a low concentration of 1,000 ppmv as methane, thermal incineration is not recommended as its cost exceeds USD 2,560 per ton methane. Collecting the exhaust from the neutralization and biotreatment stages and then injecting the collected stream into the activated sludge basin via existing blowers is recommended when treating varying VOC concentrations (100–1,000 ppmv as methane). Treatment costs increase from USD 49 to 490 per ton methane as concentration reduces from 1,000 to 100 ppmv. New blowers for injecting exhaust into an activated sludge basin, at a cost of USD 810 per ton methane, are only recommended for concentrations exceeding 1,000 ppmv as methane.
Improve design of decentralized sanitation solutions with specific focus on composting toilets.	Reasons to promote composting toilets have traditionally been unrelated to GHG mitigation. These refer to avoided groundwater pollution and the opportunity for nutrient recycling by reconceiving excreta as a resource. The recognition of the mitigation potential of this solution adds to its existing advantages. However, before scaling up this sanitation solution, better characterization of both methane and nitrous oxide emissions is needed. In addition, the adoption of composting toilets may be limited in some contexts due to socio-cultural barriers relating to reuse and handling of excreta, such as religious practices.	MP: ★★★ Reid et al. (2014) discusses the potential methane mitigation costs of composting toilets, showing that they are competitive with some other measures in the waste management sector like source separation of municipal food waste or upgrading WWTPs to anaerobic treatment with biogas recovery. By computing the marginal abatement costs (MACs), authors show that MACs for composting toilets range from USD 57 to 944 per ton CO_2 equivalent in Africa and USD 46 to 97 per ton CO_2 equivalent in Asia, while averaging USD 134 per ton CO_2 equivalent and USD 193 per ton CO_2 equivalent for solid waste separation and anaerobic wastewater treatment, respectively.
Composting toilet at Airlie Beach, Queensland, Australia. Source: Shutterstock.		

MITIGATION ACTION	PROS, CONS, AND CAVEATS	MITIGATION POTENTIAL (MP)
Promote off-site composting of human waste.	Composting is a waste treatment technology used in circular sanitation designs that may mitigate GHG emissions relative to other waste fates, such as anaerobic pit latrines. Off-site composting presents a range of operational decisions that can impact GHG emissions. Specifically, pile management options that alter drainage, aeration or the use of bulking materials may reduce methane emissions or may increase nitrous oxide emissions (i.e., emissions swapping). The production of compost that can be sold as an agricultural organic amendment to enhance crop growth and soil fertility may represent another advantage (McNicol et al. 2020). On the other hand, in low-resource settings, human pathogen hazards can constrain management options.	MP: ★★★ One recent study shows that methane emissions during off-site composting of human waste are one to two orders of magnitude smaller than IPCC values for other excreta collection, treatment, and disposal processes (McNicol et al, 2020). This study also shows that, at local scales, the climate change mitigation potential is 126 kg CO_2 equivalent per capita per year for slum residents whose waste is composted. If scaled to cover all slum populations in the world, composting could mitigate 3.97 teragrammes of methane per year, representing 13-44% of sanitation sector methane emissions (McNicol et al. 2020).
Enhance the capture of methane from on-site sanitation through household biogas digesters.	Biogas produced from human excreta provides a renewable and clean-burning energy source. However, there is a high risk of significant leakage from poorly maintained systems, which may negate the mitigation potential (Bruun et al. 2014). Adoption of biogas may also be limited by the lack of a reliable supply of manure to feed the system, and possible failure in cold climates (Hou et al. 2017). Other barriers include the need for technical improvements, lack of social acceptance, and high investment costs (Garfí et al. 2016).	MP: ★★ Small-scale biogas digesters can help reduce global warming impacts if used appropriately. For instance, one study shows that when the biogas is used as a fuel for cooking, the mitigation potential will be reduced by 83% compared with the traditional wood biomass cooking system. In addition, the digestate can be used as a nutrient-rich fertilizer substituting more costly inorganic fertilizers, with no global warming potential impact (Rahman et al. 2017). However, if used inappropriately, the proliferation of biogas digesters could contribute significantly to global emissions of methane. More specifically, Bruun et al (2014) shows that methane emissions from the inlets and outlets of small-scale biogas digesters, from leaks and from intentional releases, are likely to be substantial because of poor maintenance and poor biogas handling. In many cases, the global warming impact of this methane could be greater than the impacts avoided by the replacement of other fuels for cooking and other purposes.

4.3.1 Mitigation of GHG emissions through optimized process selection and operational conditions of wastewater and faecal sludge treatment and discharge

In wastewater and sludge treatment, nitrous oxide is produced primarily during nitrogen removal processes (nitrification-denitrification). The dominant production (90 per cent) occurs in the biological stage while the remaining portion is produced in grit chambers and sludge storage tanks (Campos et al. 2016). The produced liquid nitrous oxide is typically stripped, i.e., transferred from the liquid stream to the air in aerated parts of the treatment process. Stripping also occurs in non-aerated zones, but at much lower rates compared with the aerated compartments (US EPA, 2021).

Some identified operational conditions leading to increased nitrous oxide production include: a) low dissolved oxygen concentration in aerobic compartments and the presence of oxygen in anoxic compartments; b) occurrence of transient anoxic and aerobic conditions, and shifts in dissolved oxygen concentrations; c) high nitrite concentrations in both aerobic and anoxic compartments; d) low chemical oxygen demand (COD)[4] to nitrogen ratio in the anoxic compartments; and e) sudden shifts of pH and ammonia concentrations (Campos et al. 2016).

Regarding methane, approximately 1 per cent of the inflowing COD can be transformed to methane (Daelman et al. 2013). In the absence of oxygen, methane is released in sewers (Liu et al. 2015), in particular in case of long detention times of wastewater (Foley et al. 2010). However, most of the methane emissions in WWTPs are attributed to sludge handling processes. The sludge line with anaerobic digestion may be responsible for over 70 per cent of methane emissions from WWTPs, while the remaining portion originates from bioreactors in the main treatment line (Campos et al. 2016).

Campos et al. (2016) identified three possible approaches to reduce direct GHG emissions: a) minimization through the modification of operational conditions; b) prevention by applying new configurations and processes; and c) capture and treatment of the gaseous streams containing GHGs. Currently, the last approach does not appear feasible due to high capital costs.

In existing WWTPs, changing the operational conditions appears to be the most economical approach to mitigate GHG emissions without deterioration of the required effluent quality. This is carried out mainly by aeration control, feed scheme optimization, or process optimization (Duan et al. 2021). For instance, the direct nitrous oxide emissions can be reduced by adjusting the conditions in the biological stage of WWTPs. Specific measures include the variable (step) aeration mode, the distribution of the return activated sludge between different compartments, controlling the dissolved oxygen concentrations in aerobic compartments and mixed liquor recirculations, and changing the operational mode (length of phases) in a sequencing batch reactor (Zaborowska et al. 2019). Even though nitrous oxide mitigation alternatives have been well recognized, Duan et al. (2021) identified five critical challenges for wider implementation of nitrous oxide mitigation strategies, including quantification methods of nitrous oxide emissions, reliable prediction models, risk assessment for WWTPs, the role of decentralized systems, and novel strategies promoting nitrous oxide reduction pathways (especially full denitrification). Regarding methane, emissions can be minimized effectively by covering sludge thickeners and other tanks storing sewage sludges. Then, the captured methane, instead of being cleaned, can be burned together with the biogas generated in the sludge anaerobic digester.

Despite being the most efficient in terms of cost, a change of operational conditions of WWTPs to reduce GHG emissions is not always possible due to the operational limitations of the installed units (e.g., the type of treatment technology, the volume of the reactor, effluent requirements, etc.). In consequence, most of the efforts to improve WWTP performance are being focused currently on prevention strategies, including aspects related to reduction of energy consumption, minimization of sludge production, and maximization of the amount and quality of biogas generated (Campos et al. 2016). More specifically, the energy consumption goal could be achieved by maximizing the anaerobic pathway for organic matter removal and using process alternatives for nitrification-denitrification (e.g., microalgae reactors or anammox-based systems). The drawbacks of this solution include the large area required for the microalgae reactors, the potential instability of the anammox process in the main treatment line, and the increased risk of high GHG emissions during the de-ammonification (partial nitrification + anammox) process (Vasilaki et al. 2019; Li et al. 2020).

4.3.2 Mitigation of GHG emissions through expanding wastewater collection and treatment, including decentralized sanitation solutions

As previously mentioned, a significant proportion of the wastewater produced globally is not treated. Available estimates are highly uncertain. On one hand, among the 42 countries and territories reporting on total wastewater generation and treatment in 2015, only 32 per cent of wastewater flows were subject to some form of treatment. On the other hand, an estimated 56 per cent of wastewater generated by households in 2020 was safely treated, according to data from 128 countries and territories (UN Habitat and WHO, 2021). These values are consistent with those reported by Jones et al. (2021), which indicate that approximately 63 per cent of globally produced wastewater is collected, with approximately 84 per cent of the collected wastewater undergoing a treatment process. These data, however,

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4. The chemical oxygen demand (COD) is the amount of oxygen needed to oxidise the organic matter present in water. The biochemical oxygen demand (BOD) represents the amount of dissolved oxygen consumed by biological organisms when they decompose organic matter in water.

mask significant regional disparities. On average, high-income countries treat about 70 per cent of the municipal and industrial wastewater they generate (Sato et al. 2013). In the EU, approximately 95 per cent of urban wastewater is collected, with more than 85 per cent meeting the stringent treatment requirements of the Urban Wastewater Directive (EEC 91/271/). However, the wastewater treatment ratio drops to 38 per cent in upper-middle-income countries and to 8 per cent in low-income countries (Sato et al. 2013).

In the absence of wastewater collection and treatment services, the expansion of decentralized sanitation solutions is imperative for the 1.69 billion people who currently lack basic sanitation services (WHO 2021). In this regard, Sustainable Development Goal (SDG) targets 6.2 and 6.3 represent an urgent call for action by all countries to provide adequate and equitable sanitation and hygiene for all, also ending open defecation, and to halve the proportion of untreated wastewater discharged into water bodies (United Nations General Assembly, 2015). The extension of wastewater and faecal sludge treatment through WWTPs and decentralized sanitation solutions to meet these targets should be viewed as an opportunity to significantly reduce direct GHG emissions. However, more evidence is needed to understand which low-cost sanitation solutions enable the most effective approaches to mitigating climate change, with a view to optimizing the entire faecal sludge management service chain, from the collection and transport of sludge to the final end-use or disposal of treated sludge.

Therefore, simpler mitigation measures to improve how sanitation services are designed, planned, and managed should be explored and implemented, such as enhanced design for septic tanks or lined pits, or appropriate operational or management solutions with a focus on the energy use and GHG production (WHO 2019). For instance, in on-site sanitation systems, long detention times for faecal sludge increase methane formation. In this regard, Reid et al (2014) found that methane emissions can be reduced by using aerobic decomposition, which can be achieved most simply by digging shallow pits that remain above the water table (which is also preferable for limiting groundwater pollution), or through the use of well-maintained composting toilets. Composting toilets separate liquid and solid waste and, with proper maintenance, the solids decompose aerobically to a nutrient-rich compost within a few months (also providing an opportunity for nutrient recycling). Small-scale biogas digesters that capture anaerobically produced methane before it is released to the atmosphere are another potential mitigation option (Reid et al. 2014). They generate biogas from human excreta and manure, and burn it as an energy source for household use, which can also serve as an alternative to collecting wood for burning (and reduce deforestation). As alerted by Bruun et al (2014) however, poor maintenance and poor biogas handling can partially or totally negate this mitigation potential. The International Energy Agency (IEA) estimates that the conversion of uncollected and untreated waste into cooking fuel for all people without access to clean sanitation would be enough to supply 60–180 million households (IEA 2018).

The future contribution of pit latrine and other decentralized sanitation solutions to methane emissions depends on the spread of these solutions in underserved areas, particularly in South Asia and sub-Saharan Africa. Recent statistics show that pit latrine users are expected to increase, mainly due to population growth (WHO 2021). It is therefore important to recognize both the global climate impact of pit latrine emissions and the availability of appropriate on-site mitigation measures. This would highlight potential synergies between water and sanitation development and GHG mitigation efforts. Before recommending specific mitigation actions, however, it is critical to characterize the climate change mitigation potential of decentralized sanitation systems with greater certainty (Reid et al. 2014).

4.4 Mitigation actions to reduce indirect GHG emissions from drinking water and sanitation

The withdrawal, treatment, and distribution of water as well as the collection, treatment, and disposal of faecal sludge and wastewater require a large amount of energy, which is associated with carbon emissions. Table 4.2 lists a number of mitigation actions to reduce, measure, and report indirect GHG emissions from drinking water and sanitation. Improved energy efficiency and the use of renewable energy, among others, can significantly decrease indirect CO_2 emissions from water and wastewater management, as well as reducing energy costs. In addition, it is crucial to measure and report emission reductions from these actions to contribute formally to mitigation objectives.

Table 4.2. Overview of potential mitigation action to reduce indirect GHG release from drinking water and sanitation systems (by reducing energy use)

★★★★ High mitigation potential due to highly efficient energy-saving measure and high level of scalability;
★★★ Medium to high mitigation potential due to highly efficient energy-saving measure but not easy to scale-up;
★★ Medium mitigation potential due to less efficient energy-saving measure;
★ Low mitigation potential due to low energy savings.

MITIGATION ACTION	PROS, CONS, AND CAVEATS	MITIGATION POTENTIAL (MP)
Conduct energy audits or life-cycle assessments (LCAs).	Energy audits allow for systematic identification of areas of inefficiency, also providing direction for energy-saving opportunities or energy conservation measures. LCAs enable the selection and prioritization of the best technologies and management models available.	MP: ★★★ In Western Australia, an LCA concluded that GHG emissions from electrodialysis desalination water treatment plants were more than six times higher than groundwater or surface water treatment plants due to energy-intensive treatment processes (Biswas and Yek 2016).
Introduce advanced aeration control systems.	Increased aeration efficiency refers to the improved oxygen transfer or to the decreased energy consumption per transferred unit of oxygen in the aerobic biological reactor. Aeration control systems can save considerable amounts of energy by quickly adjusting the operational conditions within the reactor. However, low oxygen levels through decreased aeration intensity may increase nitrous oxide production (Sweetapple et al. 2014)	MP: ★★★★ One case study from a Swedish WWTP showed that energy consumption decreased by 15% in the aeration process by improving aeration control strategy. It also helped deliver a better oxygen distribution, which led to higher sludge quality (Jonasson 2007).
Enhance pumping operations.	Pump stations upgrades, together with variable speed systems, can represent significant energy savings and reduction of GHG emissions. In addition, variable speed pumps can lower operation and maintenance requirements, if applied correctly.	MP: ★★★★ The Miyahuna utility in Madaba, Jordan, reduced GHG emissions in a water supply system by more than one third through the exchange of pumps and use of variable frequency drives. The utility also experienced a significant reduction in energy costs (Kerres et al. 2022).
Improve faecal sludge management.	The optimization of the entire faecal sludge management service chain (collection, transport, treatment, and disposal of sludge) provides a range of opportunities to reduce energy consumption. It also enhances resource recovery options. However, lack of accurate data often prevents the identification of the most efficient solutions.	MP: ★★★ A case study examining emissions across the entire sanitation chain in Kampala, Uganda, showed large emissions associated with long periods of storage of faecal waste in sealed anaerobic tanks (49%), discharge from tanks and pits direct to open drains (4%), illegal dumping of faecal waste (2%), leakage from sewers (6%), wastewater bypassing treatment (7%) and uncollected methane emissions at treatment plants (31%). Overall sanitation produced 189 kilotons CO_2 equivalent per year, which may constitute more than half of the total city-level emissions in Kampala (Johnson et al. 2022). This demonstrates high potential for mitigation through better management of pits and tanks storing faecal sludge.

MITIGATION ACTION	PROS, CONS, AND CAVEATS	MITIGATION POTENTIAL (MP)
Implement Nature-based Solutions (NbS).	Besides improvement of water quality, other possible co-benefits of NbS include increasing biodiversity, providing recreational areas and social well-being through green spaces; improving urban microclimates; flood and storm peak mitigation; biomass production; and enabling water reuse. NbS can therefore tackle the climate and biodiversity crisis while also contributing to sustainable development. On the other hand, NbS generally require more land than conventional systems (e.g., activated sludge). In addition, scaling up NbS first requires accurate assessment of GHG emissions.	MP: ★★★ In a compilation of case studies, Cross et al. (2021) provides evidence on the use of NbS for improved sanitation, with an emphasis on the co-benefits that these technologies can provide to both people and ecosystems, such as high treatment performance, high water reuse, or reduction of potent GHGs such as methane and nitrous oxide. Reciprocating (tidal-flow) treatment wetlands create aerobic, anoxic, and anaerobic environments within a treatment unit. The sequential aerobic/anoxic environments significantly improve removal of BOD_5, suspended solids, turbidity, ammonia, nitrate, and methane. Specifically, methane emissions can be consistently reduced by an average of 95% compared with adjacent anaerobic lagoon treatment. In addition, reciprocation has demonstrated energy efficiency and significant reductions in noxious odours such as hydrogen sulphide (Cross et al. 2021).
Reduce non-revenue water (i.e., water that has been produced and is “lost” before it reaches the customer).	It has been estimated that reducing the current level of non-revenue water in low-income countries by half appears a realistic target (Kingdom et al. 2006). This reduction could generate additional financial resources for the sector while significantly improving the energy efficiency and overall performance of water utilities. However, utilities often lack the governance, autonomy, accountability, and technical and managerial skills to effectively manage water losses.	MP: ★★★★ In Christchurch, New Zealand, significant efforts have been made since 1996 to manage non-revenue water with the aim to protect aquifers and thereby avoid the need to access different sources of water that require different types of treatment to meet acceptable quality standards. Initial work established techniques for surveying the losses in the system, and designed and constructed structures that would measure flow rates at night (when water consumption is lowest). To measure minimum night flows and non-revenue water, Christchurch’s reticulation network was temporarily isolated into approximately 200 sub-zones by closing valves so there was only one single feed into a zone at which point the night flow was measured. The council surveyed approximately 40 zones per year using night flow testing and then carried out leak detection work. It took approximately five years to survey the entire city. This programme needs to be ongoing as water loss reduction work is a continuous effort, with the next step being the creation of permanent district metering areas.
Achieve energy neutrality through energy recovery.	Many possible solutions can be implemented for both reducing energy consumption and increasing renewable energy production in the WWTPs.	MP: ★★★ The As-Samra Wastewater Treatment Plant in Jordan has been developed in phases to increase energy recovery and water reuse. Since Phase 1, completed in 2008, the generation of renewable energy from the sludge treatment process provides 80% of the plant’s power.

MITIGATION ACTION	PROS, CONS, AND CAVEATS	MITIGATION POTENTIAL (MP)
Increase use of renewable energy.	Besides the positive impact on climate change, increased use of renewable energy helps address two major challenges in the water and sanitation sector: the cost of maintaining operations and the degree to which delivery of water services depends on a steady supply of energy from utility companies. As an added bonus, solar power is also instrumental in solar irradiation, a water treatment method that eliminates a wide selection of chemicals and microorganisms, without producing harmful by-products.	MP: ★★★★ Biswas and Yek (2016) carried out a life-cycle assessment to calculate the carbon footprint associated with different drinking water production options and to identify areas of production with high levels of GHG emissions. They found that by using 100% renewable energy, 97, 92 and 89% of GHG emissions could be reduced via wind turbines, photovoltaic, and biomass, respectively. Although solar and biomass were found to be less promising than wind for providing electricity for reducing GHG emissions, the consideration of 100% electricity generation from wind is challenging given its intermittent nature and potential availability.
Enhance desalination processes.	It is expected that more water will come from desalination in the future, especially in areas where no other natural supply of potable water exists or when there are long periods of drought. However, in addition to the high upfront investment costs, once operational, plants require huge amounts of energy. Energy costs account for one third to one half of the total cost of producing desalinated water. Therefore, the cost of producing water is greatly affected by changes in the price of energy. Brine disposal is another environmental problem that should be considered when installing a desalination plant.	MP: ★★ Elsaid et al (2020) conducted a study to discuss the mitigation and control strategies of the different environmental impacts of desalination processes, i.e., brine loaded with chemicals being discharged back to the environment, and GHGs being released to the atmosphere. Feed water source and quality, desalination technology, and energy source were found to have a substantial effect on the overall desalination environmental impact. Specifically, hybrid and emerging desalination systems, and utilization of renewable energies were found to substantially reduce the negative impacts of desalination. However, the study also found that incorporation of renewable energies is still at laboratory or pilot scales, and can only be used for small communities in remote locations. Therefore, use of clean or renewable energy sources need to be combined with high energy-efficiency desalination processes.

4.4.1 Mitigation of GHG emissions through energy efficiency improvement measures

IEA sees a huge potential for energy savings in the water and sanitation sector (IEA 2018). Opportunities for efficient energy use can be detected through an energy audit, while other techniques such as life-cycle assessments (LCA) can help identify the best water technology available. In this regard, mitigation options include:

- Enhance efficiency of aeration in aerobic wastewater treatment
- Improve pumping operations, including pump upgrades
- Implement sound faecal sludge management modalities
- Substitute energy-intensive treatment technologies with nature-based solutions.

In WWTPs, since aeration holds the biggest share of the total energy consumption (in most cases >50 per cent), novel aeration control strategies are the most promising operational measure for energy saving (Maktabifard et al. 2018). The improved aeration efficiency has significant potential for reducing emissions of GHGs. However, the trade-off between the cost of aeration and nitrous oxide emissions should be monitored carefully (Maktabifard et al. 2020; Sweetapple et al. 2014), with aeration control systems focusing on avoiding over-aeration while ensuring sufficient dissolved oxygen concentrations.

After aeration, pumping operations represent the second most important energy consumption at WWTPs (Saghafi et al. 2016). It has been estimated that electric motors can account for 90 per cent of the electric energy consumption of mechanical devices in a WWTP (Water Environment Federation 2010). Similarly, pumps are often the largest consumers of energy in a drinking water system, with groundwater pumping requiring about seven times as much energy as withdrawal from surface water (IEA 2018). In total, for either surface or groundwater systems, pumping typically accounts for 90–99 per cent of energy consumption at a water system (US EPA 2013). Variable speed operation is often the most energy-efficient flow control method for pumping systems, as it can result in better process control, smoother operation, and reduced maintenance costs for the pumping station (Ahonen et al. 2015).

Several other measures can be undertaken to improve the energy balance of water and wastewater treatment and transportation, including reduction of physical water losses and maintenance of pipes, technological upgrades of sludge management, digitalization, sensors, process controls, etc. (Kerres et al, 2022). Previous solutions to reduce energy consumption and foster energy efficiency, however, have been designed for and in high-income countries, and low-income countries might require customized, different, or new solutions (Larsen et al. 2016). For instance, faecal sludge management offers a huge potential for mitigation, such as the optimization of energy and fuel consumption for the emptying of septic tanks and pit latrines by an upgrade of the vacuum pumps, improved transport routes and shorter distances to the treatment plant, and a more efficient organization of emptying services. Nature-based solutions, such as constructed wetlands, can also offer the potential to substitute energy-intensive treatment technologies. Yet, the mitigation potential of nature-based solutions has yet to be unleashed and, for their wider implementation, better and more accurate assessment of GHG emissions will be needed (Cross et al. 2021).

4.4.2 Mitigation of GHG emissions through water efficiency improvement measures

Linked to energy efficiency, another area with significant mitigation potential relates to water efficiency through reduction of water losses and unnecessary water consumption. In this regard, one key performance indicator to measure efficient operation of water utilities refers to non-revenue water (NRW), which can occur through physical losses from leaking and broken pipes, commercial losses caused by inaccurate metering, poor data gathering, illegal connections and theft, or unbilled authorized consumption (e.g., water used for firefighting and water provided for free to certain consumer groups).

NRW is one of the most persistent problems in municipal water systems. In a recent study, the global volume of NRW has been estimated at 346 million cubic metres per day or 126 billion cubic metres per year (Liemberger and Wyatt, 2018). This is equivalent to 30 per cent of water system input volumes across the world, and the total cost of such losses can be up to USD 39 billion per year. The problem varies by region. The lowest NRW levels (36 litres per capita per day) can be found in Australia and New Zealand, due to the extensive water loss reduction efforts made to cope with the long droughts that have occurred in Australia during the past decade. The average level of NRW in Latin America and the Caribbean is 121 litres per capita per day, while in Europe and the United States it is 50 and 119 litres per capita per day, respectively (Liemberger and Wyatt 2018). Another study assessing the performance of urban water utilities in Africa estimates that NRW losses can range between 20 and 40 per cent (van den Berg and Danilenko 2017).

Important drivers are pushing for NRW reduction besides the reduction of GHG emissions. These are related mainly to: a) promoting utilities' financial sustainability through cost recovery; b) securing water availability; and c) managing water stress. Therefore, the benefits of addressing NRW relate not only to environmental benefits through reduced impact on the environment and less energy consumption, but also to important economic and financial benefits that result from the reduction of the volume of water treated and/or the reduction of costs related to operation and maintenance (O&M).

4.4.3 Mitigation of GHG emissions through deployment of renewable energy

The replacement of fossil energy sources with renewable energy can significantly reduce emissions in water and wastewater management, while also lowering energy costs and reducing dependence on fuel availability. Options include energy generated by photovoltaics and wind, and small hydropower solutions (Olsson 2018).

In addition, as they are usually connected to an existing electricity grid, utilities that generate energy from renewable sources can feed excess energy into that grid. Facilities not connected to an electricity grid can make use of standalone renewable solutions as an alternative to carbon-intensive options such as diesel. This might be the case in remote rural areas, where most water pumping is currently powered by diesel.

4.4.4 Mitigation of GHG emissions through enhanced desalination processes

Desalinated seawater and brackish water contribute to less than 1 per cent of the international water supply. However, the share of electricity for desalination was estimated at about 26 per cent of the water sector's electricity use in 2016 (IEA 2018). In the Middle East, where almost half of the global desalination is installed, more than a quarter of the sector's energy consumption is used for desalination, mostly through natural gas and oil, with consequent implications for CO_2 emissions.

Desalination is an energy-intensive process, although the amount of energy required depends on the technology used, the capacity of the desalination plant (small, medium, or large), and the type of feed water (the desalination of brackish water requires only about one tenth of the energy needed for seawater desalination). In addition, the use of renewable energies can significantly decrease energy consumption and related GHG emissions. While research in desalination and renewables is ongoing, it seems that membrane-based facilities connected to the electricity grid might be able to use excess electricity from renewable energies. Studies also suggest that renewables are currently working better with small-scale desalination schemes (Ahmadi et al. 2020).

4.4.5 Mitigation of GHG emissions through energy recovery

For the carbon embodied in the water and wastewater supply chains to become net zero, all key infrastructure and provisioning systems will need to be decarbonized (Seto et al. 2013). However, it has become increasingly evident that WWTPs worldwide have the potential to be energy-neutral or energy-positive facilities, where the energy needs of a treatment facility are satisfied entirely by self-generation, with the potential to produce more energy than needed through energy recovery improvements. Wastewater contains a significant amount of chemical, thermal, and hydrodynamic energy, which can be partially recovered. With the best available techniques, it is estimated that utilities can generate 50 per cent more electricity than they need (IEA 2018).[5] Wastewater is then valorized, enabling WWTPs to sell clean energy and recover the costs of treatment (IEA 2018). In turn, conversion of wastewater into bioenergy sources can reduce emissions if they replace certain sources, including fossil fuels. A few success stories have already been documented (Gu et al. 2017, Maktabifard et al. 2018, see Box 4.1).

The chemical energy, bound primarily in organic compounds (approximately 1–4 kilowatt hours per kilogramme COD), has the highest potential for efficient recovery by applying anaerobic digestion and biogas production coupled with combined heat and power engines or boilers. Different sludge pre-treatment methods (thermal hydrolysis, chemical pre-treatment, ultrasound/microwave, and hydrodynamic disintegration) can be used to increase the biogas production rate and efficiency.

The remaining electricity demand for complete energy neutrality could be covered mainly by organic waste co-digestion and application of renewable energy and heat recovery systems, although it is questionable whether external organic waste streams can account wholly for the WWTP energy balance. In addition, despite the high potential for increasing biogas production through co-digestion (up to 200 per cent), its possible negative

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5. This potential does not apply only to large, centralized treatment plants.

Wind turbines providing electricity for the desalination plant at Costa Teguise, Lanzarote, Spain. Source: Shutterstock.

Box 4.1. Achieving energy neutrality in watstewater treatment plants in Europe

Gu et al. (2017) listed the full-scale energy-neutral and energy-positive WWTPs worldwide. Among the European case studies, two Austrian plants (Wolfgangsee-Ischl and Strass) are energy neutral. Wolfgangsee-Ischl WWTP produced on average approximately 21 kilowatt hours per population equivalent (kWh/PE) of electrical energy through biogas from anaerobic digesters and the number of the digesters exceeded the plant's electricity demand. Therefore, surplus electricity was sold to the grid. The total electricity consumed in Wolfgangsee-Ischl was 19 kWh/PE, of which 11 kWh/PE was consumed for aeration and mixing of the aeration tank, and the remaining 8 kWh/PE was consumed by other treatment processes.

The other successful case study in Austria is Strass WWTP. In that plant, 21 kWh/PE of electric energy was produced through biogas from anaerobic digestion of sludge. 'Combined heat and power', a system using the anaerobic digestion of sludge, is the technology most widely adopted in the existing energy self-sufficient WWTPs, including the Austrian case studies. The total electricity consumed in the Strass WWTP was 20 kWh/PE, of which 9 kWh/PE was consumed for aeration and mixing of the aeration tank, and the remaining 11 kWh/PE was consumed by other treatment processes. Together with the enhanced on-site electricity production, the WWTP reduced its energy consumption by 12 per cent after switching the previous conventional nitrification/denitrification process to a full-scale novel process of deammonification (partial nitration – anammox).

impact should not be ignored. While energy recovery via biogas production can decrease indirect GHG emissions, there may be additional GHG losses during anaerobic digestion and release with incomplete biogas combustion (Maktabifard et al. 2020). The CO_2 emitted indirectly due to the energy consumed by wastewater and sludge processes (if renewable energies are not in place) can also be reduced by improving the energy efficiency of those processes.

IEA (2018) projects that if current typically centralized urban wastewater treatment technologies are expanded to meet SDG targets 6.2 and 6.3, the required electricity demands would increase by over an additional 680 terawatt hours (TWh) by 2030. This typical scenario would recover 6 per cent of electricity demand from energy production using wastewater. The range for improved performance is thus significant. If adopting more viable technologies (e.g., deployment of variable speed drives, more efficient compressors, better sludge management, etc.) energy efficiency could increase by 10 per cent, and energy generation could recover 30 per cent of the demand. Using the best available emerging technologies for all new wastewater facilities, the electricity demand could be reduced by approximately 30 per cent (to 480 TWh by 2030) and, as mentioned above, energy recovery from wastewater could be increased to 150 per cent. Depending on the source of energy, the reduction in energy use can translate into the reduction of GHG emissions and significant financial benefits through decreased operation and maintenance costs.

4.5 Gaps in global climate policy and financing

4.5.1 WASH is not well represented in national climate policies and strategies

Despite the importance of drinking water and sanitation for climate action, the sanitation sector continues to be poorly represented in climate policy and climate finance. One key policy instrument where this lack is evident is within the Nationally Determined Contributions (NDCs). The NDCs outline the steps or commitments countries are taking to reduce emissions, as well as their adaptation actions. A detailed analysis of the first round of SDG 6-related NDCs (approximately 2015–2018), showed that only 2 per cent of concrete activities included in these NDCs deal with sanitation access, while for wastewater, only 3 per cent of SDG-related NDC activities were identified (see Figure 4.3, Dickin et al. 2020). These included activities in both adaptation and mitigation sections, but mainly in adaptation. This analysis also found that no sanitation-related mitigation activities are included in the NDCs by China, India, Indonesia, or USA, all of which are making large contributions to emissions from wastewater. Instead, identified activities were

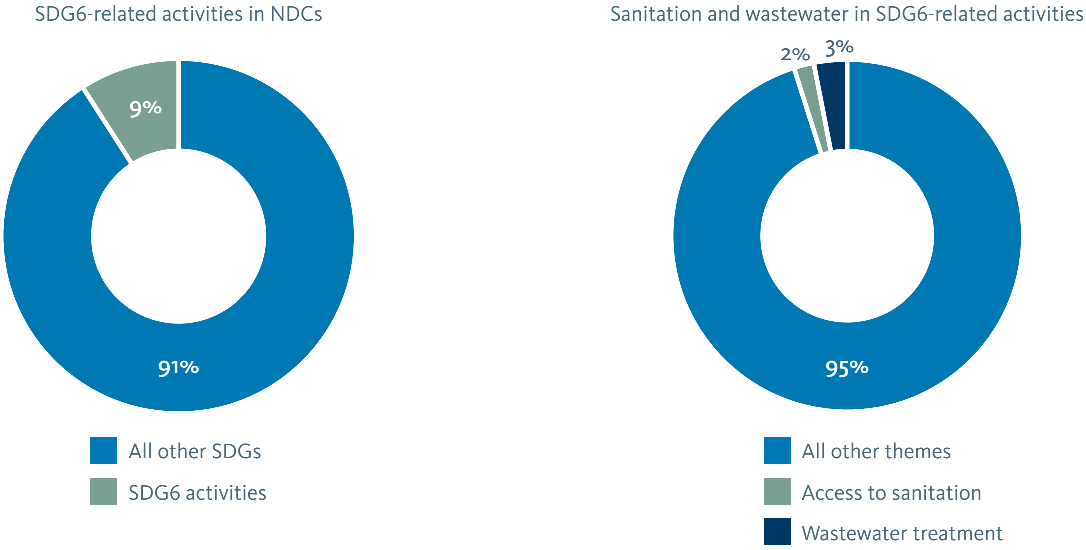

Figure 4.3. SDG-NDC connections: a) 630 out of 6,900 activities (9 per cent) were related to SDG 6 in the first round of NDCs; b) within SDG 6-related activities, 2 per cent were linked to access to sanitation and 3 per cent to wastewater treatment. Source: Dickin et al. (2020).

mostly from low- to middle-income countries in the Middle East and North Africa, and sub-Saharan Africa regions. Recent analysis of enhanced NDCs prepared by non-Annex 1 parties released in the two years prior to the beginning of 2022 noted an increase in the inclusion of water supply, sanitation, and hygiene measures in adaptation sections (SIWI/GIZ NDC study (forthcoming). For example, 43 per cent of non-Annex 1 countries included sanitation measures in adaptation sections, but direct water mitigation measures in WASH remain limited.

4.5.2 Climate finance offers an opportunity for WASH-related climate action

The Climate Policy Initiative has been compiling global estimates of climate finance for mitigation and adaptation since 2011, disaggregating data by sector and type of finance instrument (public and private, domestic and international). These estimates show that the water sector (including sanitation) receives a substantial share of committed adaptation-related finance (43 per cent of the annual total since 2011, on average) with funding standing at USD 19 billion in 2020 for water and wastewater management. Water and sanitation-focused mitigation-related finance is growing but is more modest at USD 1 billion in 2020 for water and wastewater combined, representing only 0.1 per cent of the total global climate finance for mitigation. An additional USD 2 billion goes to both adaptation and mitigation combined. Since the total global climate finance amount allocated to mitigation is far greater than that allocated to adaptation, the total share of climate finance for water and sanitation overall is approximately 3.5 per cent (CPI 2021). Complementary climate finance data is provided by the OECD (see Box 4.2).

However, these aggregates mask sharp disparities between water supply and sanitation, and between centralized and decentralized systems. Dickin et al (2020) shows, for instance, that projects related to water supply and sanitation with climate change as a main objective often fail to incorporate a specific sanitation or wastewater element, with only 3 per cent of climate-related finance for the water supply and sanitation sector targeting mitigation and adaptation related to sanitation.

4.6 Gaps in global data and knowledge

Data and information on GHG emissions from water supply and sanitation is limited and associated with high levels of uncertainty. In part, this knowledge gap hampers effective integration of WASH in climate policies and mitigation strategies and, in turn, presents a challenge to the availability of climate finance, as already mentioned above.

Box 4.2. Climate-related development finance in the water and sanitation sector, based on development finance data

Examining climate-related official development assistance (ODA) data for water and sanitation, as tracked by the Organisation for Economic Co-operation and Development (OECD) DAC, shows that 13.7 per cent of all development finance flows tagged as climate related from 2000 to 2019 was allocated to water- and sanitation-related fields. This specifically comprises 9.7 per cent of the total in the case of adaptation-related flows, and 4 per cent of the total in the case of mitigation-related flows (Figure 4.4).

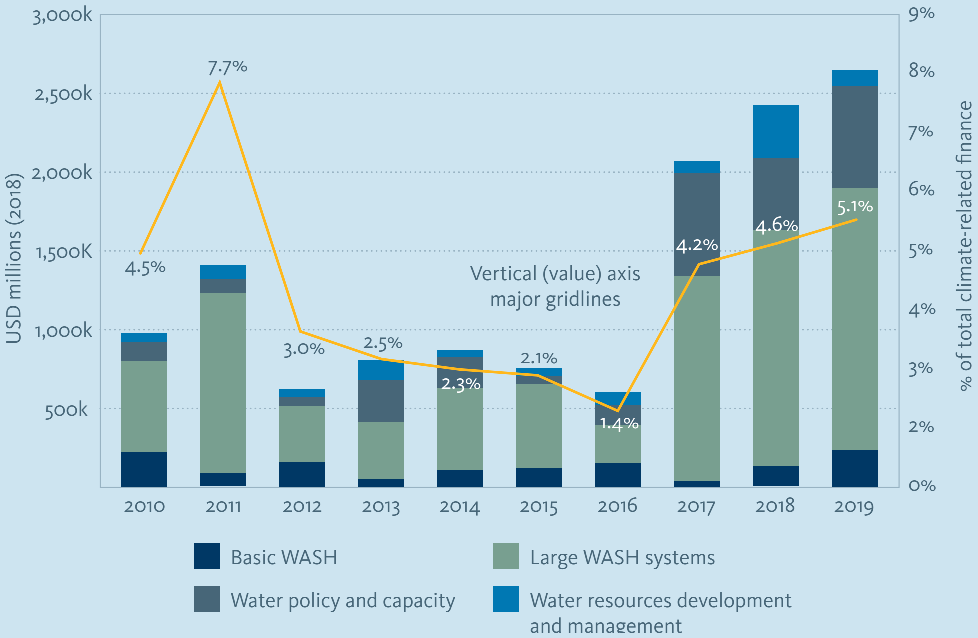

Figure 4.4. Climate-related development finance for mitigation to water subsectors (2000–2019). Source: OECD (2022).

OECD tracks 11 sub-sectors under the WASH sector. To aid interpretation, however, the data has been grouped into four main categories: basic WASH systems, large WASH systems, water policy and capacity, and water resources development and management. Focusing on mitigation, Figure 4.4 shows the proportion of climate-related finance allocated to these categories between 2010 and 2019 (yellow line). The share tagged as climate related for mitigation decreased from 2011 to 2016, to a low of 1.4 per cent, then increased to 5.1 per cent in 2019.

The figure also illustrates the amount of climate-related development finance dedicated to each category. Large WASH systems historically represent the largest share (2.3 per cent of all climate-related finance for mitigation between 2010 and 2019), with water policy and capacity coming second at 0.7 per cent. Basic WASH has received the lowest share, at 0.4 per cent in total during the time period, decreasing from an average of 2.1 per cent in 2000–2009. As previously discussed, the global warming potential of providing safely managed sanitation for all cannot be neglected, and more resources should be mobilized based on GHG mitigation opportunities. Combined, basic WASH and large WASH systems have represented just 2.6 per cent of all climate-related finance for mitigation over the period 2010–2019. It is noted, however, that projects tagged as climate related can have multiple objectives, and that there is no discernible pattern of mitigation-focused finance going to sanitation as opposed to water supply (Calow et al. 2020).

Water utilities in many countries neither measure nor report their emissions, and Saunois et al. (2016) suggests that inventories for anthropogenic sources of methane in the waste sector might miss the mark by 20 to 30 per cent. This is due to the complexity of the processes influencing emissions, and inadequate reporting and accounting of contributions by type of source, as well as the absence of consistent measurements from different systems. Similarly, McNicol et al. (2020) states that GHG inventories and mitigation opportunities in water and sanitation are largely unknown due to the scarcity and variability of the data available from different water supply and sanitation systems. In this regard, data gaps and limitations in GHG accounting are not specific to a particular water supply or sanitation system, although knowledge has advanced more slowly regarding on-site sanitation, such as those associated with ecological sanitation.

If data collection is set as a priority in the international agenda, systems can include, by design, features to provide consistent measurement of emissions, making GHG accounting stronger across water supply and sanitation systems. In addition, water utilities can apply specific tools to strengthen assessment, monitoring, and reporting of GHG emissions, such as energy audits or the ECAM tool (Kerres et al, 2022, see Box 4.3). GHG emissions from water and wastewater management can then be regularly reported to the respective authorities based on the IPCC guidelines, as a necessary step to promote their inclusion in national GHG inventories. In this regard, the IPCC guidelines, which have been continuously updated (Eggleston et al. 2006; IPCC, 2019), provide an important mechanism in standardizing and guiding accounting throughout different sectors and allowing for comparison.[6] However, constraints to the advancement of knowledge related to different dimensions of sanitation system emissions and accounting can downplay the applicability of results in mitigation action.

For example, in the case of decentralized systems, there are uncertainties due to high levels of inadequate or missing data from local sources (Ryals et al. 2019; Huynh et al. 2021), the ways in which such information is organized in databases, and the application of emissions factors (González et al. 2019). This is primarily the case in low- and middle-income countries, where the informal nature of sanitation services delivery often hampers regular data collection and reporting. For on-site sanitation, direct measurements are scarce, not only in relation to containment but also to other steps of the sanitation chain, i.e., collection and emptying of faecal sludge, transportation, treatment, and end-use and disposal, making estimations from emissions factors even more limited (Mills et al. 2020; Reid et al. 2014). Therefore, understanding the quantity of GHG emissions from on-site sanitation and other decentralized solutions, and how these may vary with alternative design and management strategies, is crucial, also given the increasing number of people accessing these facilities in low- and middle-income countries.

Similarly, data gaps for centralized systems include lack of consideration of the organic fraction in different wastewater flows (Falk et al. 2013), methodological issues for estimation of nitrous oxide emissions, lack of consideration of operational conditions in relation to potential higher production and release of gases, and the application of emissions factors that are not always confirmed by direct measurements (Lahmouri et al. 2019). Another limitation refers to the inclusion of CO_2 from wastewater in the assessment. The IPCC guidelines have always considered these to be null, given they are usually derived from modern (biogenic) organic matter in human excreta or food waste, not accounting for the transfer of carbon to the atmosphere. However, recent work has contested such a premise, alleging the presence of fossil organic carbon in sewage, originating from cosmetics and pharmaceuticals for example. This has been recognized in the 2019 refinement of the guidelines, but not yet incorporated in its methodology. Similarly, the latest IPCC guidelines have produced other significant improvements, e.g., in relation to the measurement mechanisms concerning nitrous oxide emissions from domestic wastewater, even though large uncertainties are still associated with the provided default factors and assumptions.

Therefore, data collection and adequate reporting and accounting are still some of the biggest challenges for mitigation in the sector, hampering appropriate understanding of how emissions occur throughout different systems and processes.

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[6] The IPCC guidelines for GHG emissions inventories do not include a water chapter. Instead, emissions from water and wastewater management are reported in volumes 2 (Energy) and 5 (Waste).

Box 4.3. User-friendly tools for analysis and continuous monitoring enable sustainable mitigation efforts

Accurate reporting on GHG emissions is becoming increasingly important and mandatory. To meet this demand, gain greater insight into the current emissions status, and identify areas where GHG emissions can be reduced, the **Energy Performance and Carbon Emissions Assessment and Monitoring** (ECAM) tool was developed by the Catalan Institute for Water Research within the scope of the Water and Wastewater Companies for Climate Mitigation (WaCCliM) project. WaCCliM is a joint initiative between the German Agency for International Cooperation and the International Water Association as part of the International Climate Initiative, financed by the German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection.

Using ECAM, water and wastewater utilities are assessing their energy use and GHG emissions by considering all components of the urban water cycle, from water supply to wastewater treatment, sludge management, and water reuse. ECAM follows the 2019 IPCC guidelines and requires data that are typically available from utilities in developing and emerging economies. Where data is not available, the tool generates estimates using information from international databases and examples of good practice. The results also allow utilities to identify priority areas for reducing emissions and seeking climate finance.

4.7 Conclusions, outlook, and recommendations

4.7.1 Conclusions

To respond to the question: Are we on the right track to mitigate the climate change effects of drinking water and sanitation? – the answer is: we are not yet making enough progress. A basic vicious cycle needs to be broken. First, there is a need to reduce uncertainty levels around GHG emissions and develop solid climate evidence, combining the best available data and information generated from enhanced monitoring and reporting processes with local knowledge and context. Second, climate evidence needs to be part of water and sanitation policy-making, strengthening the alignment of WASH and climate priorities in national policies. In turn, a demonstrated climate narrative should help position WASH to attract climate financing and new investments.

Therefore, although improved management of water and sanitation services represents a major opportunity for climate mitigation, several obstacles and bottlenecks discourage climate decision-makers from prioritizing and investing in WASH. These include the following:

Lack of data hampers evidence-based climate action. Critical information and reporting gaps lead to probable underestimation of the GHGs released in the water supply and sanitation chain. Various challenges hamper data collection and adequate accounting of these emissions, including limited water quality monitoring, inadequate emission measurements by type of source (particularly from on-site and decentralized sanitation systems), limited GHG measurements in water and wastewater facilities despite available digital tools, and certain ambiguities in the IPCC guidelines for estimating emissions. Global data reporting gaps result in these emissions not being included in national GHG accounting, and actions to reduce GHG emissions are not adequately incentivized.

At the policy level, **poor representation of WASH in the climate policy debate** suggests that national policy-makers involved in setting climate goals do not appreciate the role of WASH, particularly sanitation, in climate action. At the same time, WASH actors have often been reluctant to develop a narrative that describes how climate change affects service provision and to disseminate this narrative beyond the WASH domain. Neither have they sufficiently documented the potential contribution of GHG from water and sanitation systems to climate change.

In terms of finance, **WASH projects rarely estimate their potential for emissions reduction** by, for example, outlining how GHG emissions will be cut and energy efficiency enhanced. A demonstrated climate narrative should be the basis for identifying climate opportunities and promoting WASH interventions that not only consider adaptation solutions but also better integrate the mitigation potential.

4.7.2 Recommendations

Against these challenges, the recommendations below suggest the way forward.

Increase evidence: More and better data and reporting of actual GHG emissions from water and sanitation infrastructure needs to be prioritized by mobilizing political will at the institutional level. Different pathways should be explored. Available guidance and accounting tools for monitoring and reporting of GHG emissions from water utilities such as ECAM need to be scaled up via capacity-building and training as a necessary step to advocate for their inclusion in national GHG inventories. In addition, reporting guidelines for water utilities should be standardized and, in the best case, backed by an international authority such as IPCC, including the choice of a functional unit for this assessment. Carbon footprint assessment studies and energy audits can also provide new and better evidence to enhance accounting and reduce uncertainty levels of GHG emissions across different water supply and sanitation systems and, in turn, improve the reporting guidelines. Finally, research studies can provide new evidence on the actual contribution of different decentralized solutions in terms of GHG emissions, e.g., including emissions not only at the point of delivery but also along the whole water supply and sanitation chain.

Enhance policy-making: Apart from documenting the potential contribution of water and sanitation systems to climate change through GHG emissions, context-specific evidence of the impact of climate on the delivery of WASH services needs to be strengthened. Available knowledge and evidence need to inform climate policies and strategies, thus linking to the broader climate debate beyond WASH. The formulation of response plans and interventions should be promoted, clearly showing the mitigation potential. Then, the actual implementation of policies, plans, and strategies needs to be regularly monitored, identifying bottlenecks that constrain progress.

Incentivize investment: Climate finance provides an opportunity to expand and enhance drinking water and sanitation management at a large scale through climate-resilient WASH solutions. A significant proportion of wastewater globally is currently not treated or only partially treated and would emit much less GHG if proper collection and treatment systems were in place. Similarly, mitigation efforts should be aligned with the provision of safely managed sanitation for the millions of people who currently lack this service. With an urgency to enhance delivery of WASH services while reducing emissions, there is a need to promote greater opportunities for climate finance to complement development finance, particularly in the sanitation sector. In addition, one recent study suggests that much of the climate-related finance fails to align with critical needs (WaterAid 2021). A shift in financing priorities could therefore be recommended from a human rights and climate justice perspective to ensure that the most efficient, effective, and equitable measures within the water and sanitation sector are identified and implemented. In this regard, the priority in low-income contexts should be to secure access to basic services, with mitigation opportunities considered in the context of win-win solutions.

Gather momentum: To achieve impact at scale, the establishment of climate platforms is the key to strengthening cooperation among climate and WASH stakeholders and enhancing action on mitigation solutions. These platforms should provide access and stimulate exchange of information, evidence, and guidance intended to inform the development of climate mitigation strategies and plans at the local, national, and international scales. At the same time, although knowledge, technologies, and infrastructure exist for energy-efficient and low climate impact water and wastewater processes, more guidance and improved design standards are needed to promote low GHG interventions that can be scaled up through investment, capacity building, and training.

4.8 References

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