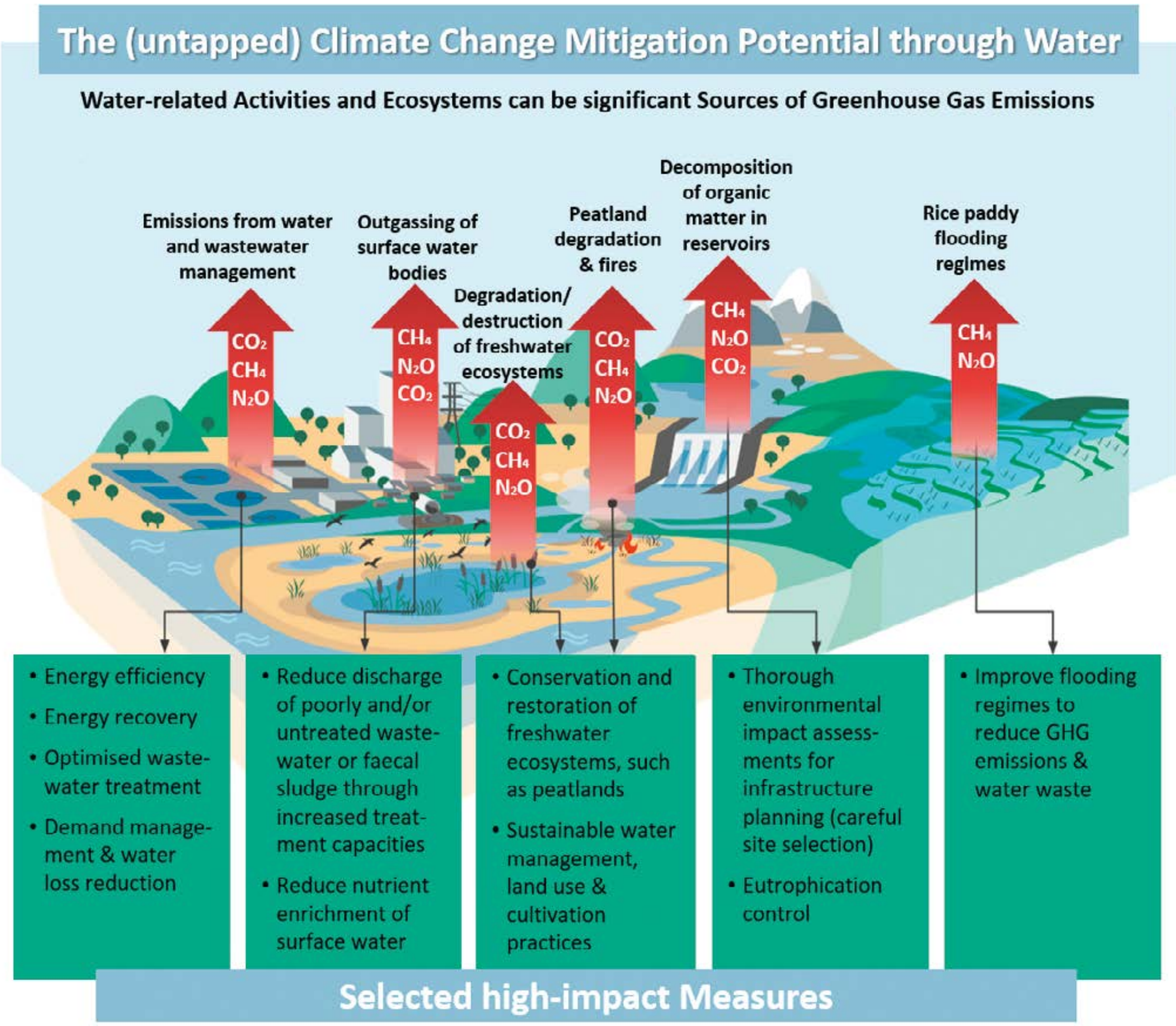
7. Mitigation of greenhouse gases through water

The relevance of water for safeguarding climate resilience is undisputed. However, the water sector itself, as well as water-related activities in other sectors, contribute to climate change by emitting different GHG – in parts highly potential ones. To consider the full mitigation potential of water-related activities, this chapter discusses GHG associated with:

- Energy-intensive processes for purifying, supplying and treating water and wastewater.
- Methane and nitrous oxide emissions from wastewater and faecal sludge management and discharge.
- Emission of GHG from surface water bodies.
- Decomposition of organic material in reservoirs.
- Degradation and destruction of wetlands, in particular peatlands; and
- Different flooding regimes for rice paddy irrigation.

Collectively, GHG emissions from these six categories might cause more than 10% of global anthropogenic GHG emissions, rendering water security a potentially vital element of global climate mitigation activities and strategies. However, this study argues that, despite its significance as a key ingredient in reducing GHG emissions, water security across sectors is widely overlooked.

Figure 34: **Water management – the potential for climate change mitigation**



Key Messages of Chapter 7

- **A significant amount of energy and its respective carbon emissions (depending on the source of energy) is required to abstract, supply and treat water and wastewater. Depending on the sanitation system and its management, wastewater and faecal sludge management can cause additional emissions before, during and after treatment. User-friendly tools can help utilities in emerging and developing countries to reduce emissions and save energy costs.**

- **Untreated and improperly treated wastewater and (faecal) sludge as well as the (over-) use of agricultural fertiliser can contribute to global warming by facilitating the formation of highly potent GHG in surface waters, namely, methane (CH_4) and nitrous oxide (N_2O). Reducing inflows of poorly treated wastewater and faecal sludge, i.e. of organic matter and nutrients, into surface waters can significantly contribute to climate change mitigation.**

- **Freshwater ecosystems, such as inland wetlands, can absorb and store substantial amounts of carbon. For instance, though covering only 3% of global land surface, peatlands alone store twice as much carbon as all of the planet's forests combined – making them carbon pools of global significance. In consequence, it is especially their carbon storage function that renders healthy natural wetlands an important asset to global mitigation efforts, although they are important GHG sinks, as well.**

- **Safeguarding the integrity of natural wetlands through conservation and restoration/rewetting measures is a low-hanging fruit for fostering climate ambitions through Ecosystem-based Mitigation (EbM) approaches. These activities can potentially create various co-benefits in the field of biodiversity conservation and human well-being. The sustainable management of water resources is a key element in safeguarding inland wetlands' climate regulation ecosystem services.**

- **Rice paddies have a significant water footprint. Globally, however, they also are major GHG sources. Water sector measures aimed at rice paddies' flooding regimes bear the potential to foster both water efficiency and climate mitigation.**

7.1 GHG emissions from water and wastewater management

The management of water and wastewater involves processes with a high energy demand and, depending on the source of energy used, respective emissions of GHG. In 2014, energy-intensive processes associated with abstracting, supplying and treating water and wastewater accounted for around 4% of global electricity consumption (IEA, 2016). In the US, energy consumption of water and wastewater utilities can represent 30-40% of a municipality's total energy costs (Copeland and Carter 2017). Of the electricity consumed in the water sector, around 40% was used to extract water, 25% for wastewater treatment and 20% for water distribution.

➔ *Water and wastewater management accounts for around 4% of global electricity consumption. Energy consumption in the sector could double by 2040.*

Growing water demand, higher regulatory standards for treating wastewater and the uptake of desalination are projected to more than double energy consumption in the water sector by 2040 (IEA, 2016). This applies especially to developing countries, where large population segments still lack access to drinking water supply and sanitation services. Moreover, where water and wastewater utilities facilitate access, they often rely on inefficient pumps, leaky distribution lines and dated treatment technologies.

Data and knowledge on GHG emissions from water supply and sanitation at the global level is limited. In the US, water-related use of energy alone was responsible for almost 5% of national GHG emissions (Rothausen and Conway, 2011). Thus, energy-efficient technologies and management approaches can significantly reduce GHG emissions in the water sector.

Municipal wastewater treatment requires energy for the different treatment stages, for instance for pumps, blowers, mixers and screens. The aeration process is often the most energy- intensive part of wastewater treatment. In addition, wastewater collection and treatment processes entail the release of significant amounts of methane (CH_4) and nitrous oxide (N_2O). Although this emission amount is lower than CO_2, its adverse effects on climate are much stronger. The IPCC has estimated the global warming potential of CH_4 at 28-34 times the effect of CO_2 over a timespan of 100 years. Concerning N_2O, global warming potential is

Definition of terms

The Carbon cycle is used to describe the flow of carbon in various forms, e.g. as CO_2, carbon in biomass and carbon dissolved in the ocean as carbonate and bicarbonate through the atmosphere, hydrosphere, terrestrial and marine biosphere and lithosphere.

Adapted from IPCC (2018) p. 544

Carbon sequestration is the uptake (e.g. the addition of a substance of concern to a reservoir) of carbon-containing substances, in particular CO_2, in terrestrial or marine reservoirs. Biological sequestration includes direct removal of CO_2 from the atmosphere through land-use change (LUC), afforestation, reforestation, revegetation, carbon storage in landfills and practices that enhance soil carbon in agriculture (cropland management, grazing land management). In parts of academic literature, but not in this report, (carbon) sequestration is used to refer to Carbon Dioxide Capture and Storage (CCS).

Adapted from IPCC (2018) p. 544, 560

Carbon Dioxide Removal refers to anthropogenic activities removing CO_2 from the atmosphere and durably storing it in geological, terrestrial or ocean reservoirs, or in products. It includes existing and potential anthropogenic enhancement of biological or geochemical sinks and direct air capture and storage, but excludes natural CO_2 uptake not directly caused by human activities.

IPCC (2018) p. 544

Mitigation (of climate change) describes a human intervention to reduce the sources or enhance the sinks of GHG.

Adapted from IPCC (2018) p. 554

Pools are reservoirs in the earth system in which elements, such as carbon, reside in various chemical forms for a period of time.

Adapted from IPCC (2014) p. 216

Sink denotes a reservoir (natural or human, in soil, ocean and plants) in which a GHG, an aerosol or a precursor of a GHG is stored. Note that UNFCCC Article 1.8 refers to a sink as any process, activity or mechanism which removes a GHG, an aerosol or a precursor of a GHG from the atmosphere.

Adapted from Ramsar Convention Secretariat (2018) p. 2

Stock is the total carbon stored in an ecosystem, regardless of the time it took to build up this stock.

Adapted from Ramsar Convention Secretariat (2018) p. 2

indicated at 265-298 times the effect of CO_2 for the same timespan (IPCC, 2013).

Moreover, in the absence of oxygen, CH_4 can be released in sewers, in particular in case of long detention times of wastewater (Foley et al., 2010). Another possible source of CH_4 are onsite sanitation systems. Here, long detention times of faecal sludge, for instance, can also increase CH_4 formation. During treatment, CH_4 can be released during anaerobic digestion (if biogas is not or incompletely flared or collected). Depending on the specific treatment and conditions, a share of CH_4 might also remain dissolved in already treated wastewater, thus, gases potentially escape at a later stage. Furthermore, CH_4 emissions can arise during activated sludge management, sludge storage and through leaking biogas. N_2O can be released through the removal of biological nitrogen during wastewater treatment. Uncontrolled sludge disposal is also a source of CH_4 and N_2O (*see Chapter 7.2*).

In the absence of wastewater collection and treatment services, communities often rely on onsite sanitation systems, such as septic tanks or pit latrines. In this case, GHG emissions depend on the individual use of the system, e.g. poor flush latrines vs. dry latrines, the quality and efficiency of faecal sludge management and the type of faecal sludge treatment.

The registration of emissions from wastewater and faecal sludge was included by the IPCC task force on National Greenhouse Gas Inventories in its 2006 guidelines and 2019 refinement in a specific sub-section of the waste sector (IPCC, 2019). Emissions resulting from the influx of untreated or poorly treated wastewater and faecal sludge into surface waters are addressed in *Chapter 7.2*.

Trends and regional differences in GHG emissions from water supply and treatment

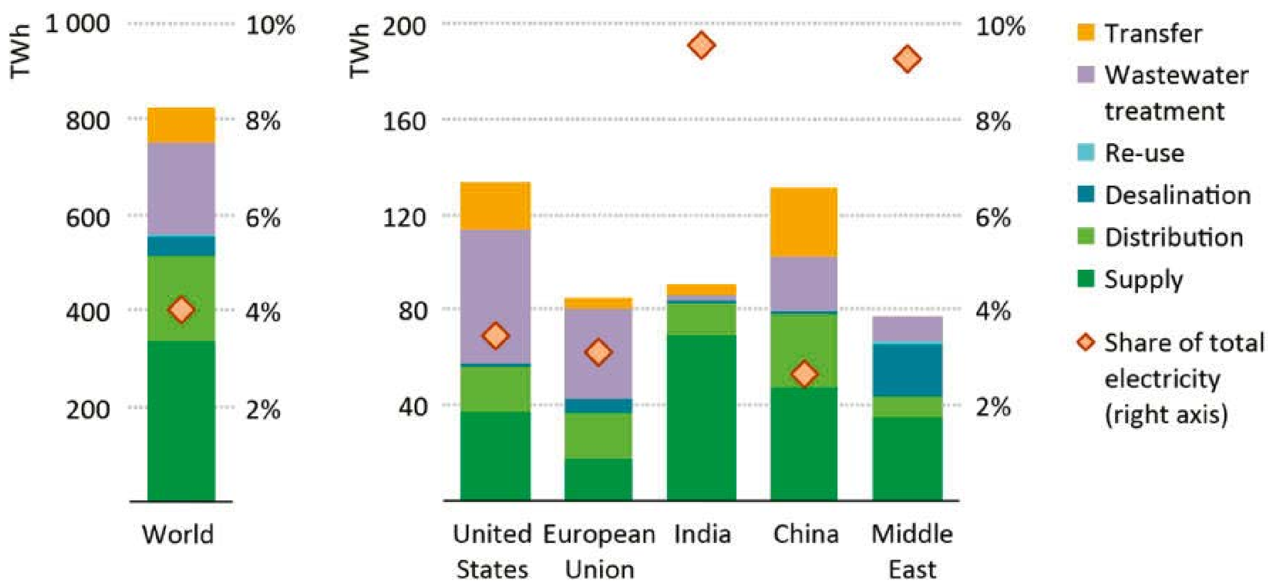
Global electricity consumption in the water sector is projected to increase by 2.3% per year, until it reaches a total of 1470 TWh in 2040 (IEA, 2016). However, the amount of energy used in the water sector varies widely across regions, depending on climate conditions, topography, existing infrastructure and other factors. Furthermore, when displaying water sector energy trends and comparing its energy use in different regions, it is important to be aware of different reference values, such as total energy consumption, as well as the share of electricity and energy consumption based on fossil fuels.

In developed countries, by far the greatest share of water-related energy consumption is used for wastewater treatment and end-use (Rothausen and Conway, 2011). The comparative lack of wastewater treatment plants in developing countries suggests that less CO_2, CH_4 and N_2O is emitted from energy-intensive and often fossil fuel-based wastewater treatment processes. However, this does not necessarily mean that GHG emissions caused by wastewater treatment processes are generally lower in developing countries, since CH_4 and N_2O not only emerge from wastewater treatment, but also, and in a much more uncontrolled way, from wastewater and faecal sludge, which is discharged into the environment without any kind of treatment (*see Chapter 7.2*). In addition, the extraction of groundwater for irrigation can account for high GHG emissions, in particular in more arid regions and countries in which rain-fed agriculture cannot be performed throughout the year. For instance, groundwater depletion and pumping for irrigation, often using diesel pumps, accounts for 2-7% of India's total annual CO_2 emissions (Mishra et al., 2018).

Alternative water resources, such as desalination, can also be associated with high energy use. Roughly 0.7% of global water needs are met by water from desalination and water reuse (*see Chapter 6.3* for climate resilience and environmental aspects of these approaches). However, these processes account for almost a quarter of total energy consumption by the water sector (IEA, 2016). It is projected that desalination will account for the largest increase in electric energy consumption, as production of freshwater from seawater desalination might increase nine-fold and brackish water desalination five-fold. Today, desalination accounts for about 5% of global water sector electricity consumption. In 2040, it is estimated that desalination will account for more than 20% of water-related global electricity demand by the water sector (IEA, 2016).

In terms of regional distribution, desalination technologies are mainly prevalent in North Africa and the Middle East (*Figure 35*). In 2016, desalination accounted for just 3% of the Middle East's water supply, but 5% of its total energy consumption. Moreover, the production of desalinated seawater is projected to increase almost fourteen-fold in the Middle East by 2040 (IEA, 2018).

Figure 35: Electricity consumption in the water sector by process and region, 2014, Source: IEA, 2016.



One challenge concerning the quantification of GHG emissions is the limited availability of comprehensive assessments on the water sector's energy profile. In parts, that can result in major shortcomings in terms of demonstrating the water sector's mitigation potential in the field of supply and treatment, as well as promoting informed water decision-making on water-climate policies. In addition, existing studies deploy different methodologies and delineate water sector boundaries in different ways.

Strategies to reduce GHG emissions in water, wastewater and faecal sludge management

The decarbonisation of energy-intensive processes in the water sector has gained currency over recent decades. Energy-related measures have taken on an increasing role in new strategies for designing and managing water systems (Hering et al., 2013). Solutions are versatile, ranging from the promotion of energy-efficient technologies to onsite renewable energy production. For instance, the GHG-saving potential of water treatment processes can be quite high, since sewage and sludge treatment offers the possibility of producing low-GHG fertiliser from recovered nutrients or renewable energy from organic matter (Wang et al., 2018).

The International Energy Agency (IEA) estimates that if economically available energy efficiency and energy recovery potentials in the water sector are utilised, the sector could reduce its energy consumption by 15% in 2040. Therefore, wastewater treatment, desalination and water supply offer the largest potential for savings (IEA, 2016).

➔ ***Water and wastewater utilities can substantially contribute to national GHG mitigation targets.***

However, most of this energy reduction potential is being squandered (Li et al., 2015). For instance, only a few water and wastewater utilities in Europe and the US have become energy-neutral by deploying energy-optimising measures (Rothausen and Conway, 2011). Wastewater treatment processes hold additional potential for reducing GHG emissions. Through analysing, monitoring, reporting and reducing these emissions, water and wastewater utilities can contribute a substantial share to national GHG mitigation targets. Some measures aimed at mitigating GHG emissions associated with energy consumption as well as wastewater and faecal sludge management are listed below:

- **Energy efficiency:** Addressing unnecessary water consumption and water losses are sustainable and cost-efficient ways to prevent GHG emissions, since the energy associated with the treatment and supply of water can simply be reduced. Water losses in distribution networks can be high, even in some water-scarce countries. For instance, an estimated 48% of water is lost in India, including through leakage, theft or inaccurate metering (IEA, 2016). Active leakage control, including sounding techniques, is an efficient way to find unreported leaks. Pressure management, on the other hand, is a cost-effective water loss strategy, reducing the number of bursts and leaks.

- **Reuse:** The reuse of water from wastewater and faecal sludge treatment for purposes with less strict water quality requirements than for potable water also holds significant water and energy-saving potential (Grant et al., 2012). Moreover, water-use efficiency can enhance water security and climate resilience, while significantly reducing processing costs. Energy efficiency in water, wastewater and faecal sludge management can further be increased by deploying adequate technologies and management processes. The optimisation of pumping systems might include updating or replacing pumps, but also improving control, operation and data acquisition. Energy demand during wastewater treatment can be reduced through the installation of efficient aerators and diffusers, as well as optimised aeration control.

- **Renewable energy:** There is significant potential to reduce GHG emissions by deploying renewable energy during water, wastewater and faecal sludge management. For instance, the organic matter in wastewater and faecal sludge contains more energy than is needed to treat it (Li et al., 2015). Treating sludge in anaerobic digesters allows treatment plants to capture biogas, which can be further processed into biofuels, heat and electricity. Using anaerobic treatment approaches, a plant can cover 50-75% of its own energy consumption. Additional modifications, such as technologies that turn biogas into biomethane, can further optimise the energy performance of treatment plants (McCarty et al., 2011). Apart from gaining energy through treatment processes, the extended use of renewable energy, such as solar and wind power, can further lower the carbon footprint of water and wastewater utilities.

- **Optimised wastewater treatment:** The mere extension of wastewater and faecal sludge treatment coverage reduces emissions from untreated wastewater in surface water, as further discussed in *Chapter 7.2*. Anaerobic wastewater treatment can improve energy conservation and reduce GHG, if the methane produced during the process is not released into the environment. Nature-based Solutions, such as constructed wetlands, also have the potential to substitute energy-intensive treatment technologies. Besides the use of biogas for generating energy, approaches to avoid CH_4 emissions include biogas flaring and avoiding biogas leakage (Paolini et al., 2018).

The benefits of tapping into the mitigation potential of the water sector stretch beyond saving GHG emissions. Lowering energy consumption can substantially **reduce operational costs of water and wastewater utilities**, which can be as high as 40% in developing countries (Liu et al., 2012). If well-planned and, depending on local conditions, inclusive of energy-pricing systems, investments into energy efficiency can pay off within a few years (Ballard et al., 2018).

However, an extensive implementation of the aforementioned measures to address GHG emissions bears inherent challenges. For instance, traditional wastewater treatment infrastructures were not developed to pursue multiple purposes in parallel, such as the removal of pollutants, energy recovery and nutrient recycling (Wang et al. 2018). In addition, several solutions to foster energy efficiency in the water sector have been designed for and in developed countries. Individual needs and (economic) realities in low-income countries might require customised, different or new solutions to reduce energy consumption in water supply and treatment (Larsen et al., 2016).

Adverse impacts of renewable energies on water-related ecosystems

Global demand for electricity is expected to grow by roughly 70% by 2035 (WWAP, 2014). Renewable energies play a growing role in energy production. However, while it involves much lower CO_2 emissions, renewable energy production also entails adverse environmental impacts. These have also come to affect water security and water-related ecosystems through pollution or high levels of water use. It is strongly recommended to account for and mitigate these impacts.

Hydropower accounts for 16% of global electricity production and is, therefore, the largest source of renewable energy (WWAP, 2014). Dams built to generate hydro-electricity and store water resources bring multiple benefits, like flood protection, reliable water supply and energy security. But they also have negative consequences for river ecosystems and the people that depend on them (Vörösmarty, 2010). The negative externalities of dams, such as loss of biodiversity, declining fisheries and relocation of local communities, might exceed the benefits of job creation and energy supply (Ziv et al., 2012; Winemiller et al., 2016). Moreover, water is lost through evaporation and seepage from reservoirs (Gerbens-Leenes et al., 2009). Reservoirs can also emit large quantities of CH_4, corresponding to 1.3% of global CO_2-equivalent emissions (Deemer et al., 2016).

Wind and solar power do not require large quantities of water resources for energy production. The water footprint of these two energy forms is among the smallest per produced kWh, compared to other renewable energies (Mekonnen et al., 2015). However, wind and solar power have less visible negative impacts on water security and water-related ecosystems. Advanced lithium batteries, which have high-energy storage capacity to balance out the supply-demand gap, require large amounts of chemical-containing water to extract the ore (Izquierdo et al., 2015). Without proper treatment and disposal, the wastewater pollutes ecosystems and can precipitate water conflicts among local water users.

Biofuel often has a large water footprint, especially when crops are cultivated in semi-arid and arid areas (Gerbens-Leenes et al., 2009). The cultivation of energy crops, such as corn, sugar cane or palm oil, and the cooling processes in power plants to burn biofuels, require a lot of water (Raptis et al., 2016). In addition, ecosystems, like wetlands or forests, have been drained or converted to expand the production of bioenergy. By causing the loss of these natural carbon pools, in particular peatlands (see Chapter 7.3), the industry is responsible for significant GHG emissions. Moreover, the rise of energy crops has starkly increased competition for arable land, thereby indirectly causing land use change (including the loss of wetlands, for example).

The cultivation of energy crops also necessitates large quantities of **fertiliser and manure**. Washed out by the rain or carried away by winds, significant amounts of nutrients enter wetlands, lakes and rivers. Once there, they cause high levels of eutrophication, which is a main threat to freshwater ecosystems and biodiversity. Furthermore, the enrichment of nutrients in an ecosystem can have a positive correlation with the increased emission of GHG. Converting forests or other natural environments to cultivate energy crops often fosters soil erosion. Consequently, sedimentation can pollute rivers, wetlands and lakes (Croitoru and Sarraf, 2010).

Good practice example

Helping countries towards a climate-smart water sector: Water and Wastewater Companies for Climate Mitigation (WaCCliM)

In order to reach the goal of the 2015 Paris Agreement to limit global warming to well below 2°C, all sectors need to contribute and increase their GHG mitigation ambitions. As exposed in this chapter, the urban water sector is a notable source of emissions. These will most likely increase due to growing water demand and increasing service coverage, in particular in emerging and developing countries. Since 2014, the project **Water and Wastewater Companies for Climate Mitigation (WaCCliM)**, financed by the Federal Ministry of the Environment, Nature Conservation and Nuclear Safety of Germany (BMU) and implemented by GIZ and the International Water Association (IWA), has been working with selected countries and utilities to prove that in the urban water sector, climate mitigation action can be achieved, alongside and in harmony with climate-resilient sustainable development.

WaCCliM's experience has shown that the flow of water into, through and out of cities connects NDC and SDG commitments of developing and emerging countries. The project has introduced a roadmap of systematic steps and measures towards low-carbon water and wastewater utilities that can also plan for climate risks and improve their services. Helping utilities on this path is the project's **Energy Performance and Carbon Emissions Assessment and Monitoring Tool (ECAM)**, which any utility can use to assess its GHG emissions and pinpoint opportunities to use less energy – or even generate its own energy. ECAM also functions as an important tool providing data for Measurement, Reporting and Verification (MRV) systems for the sector and helps to monitor compliance with NDCs. ECAM has been used beyond the project: The Zambian water programme Climate-friendly sanitation in peri-urban areas of Lusaka, financed by the German Federal Ministry for Economic Cooperation and Development (BMZ) and implemented by GIZ, developed an additional module for faecal sludge management for ECAM and calculated a baseline of GHG emissions for the whole urban water cycle of Lusaka.

WaCCliM has piloted mitigation solutions, ranging from energy-efficient pumps to technologies for generating power with biodigesters, with utilities in Jordan, Mexico, Peru and Thailand. Prioritized measures in these pilot utilities have led to an annual mitigation equivalent to more than 10,000 tons carbon dioxide – or planting about 50,000 trees per year. The water and wastewater utilities using WaCCliM tools to pioneer GHG benchmarking and climate-smart planning are becoming national sector leaders, and they are providing evidence for an increased consideration of water as a sector for combined mitigation and adaptation action in the next round of NDCs. The WaCCliM vision on climate-smart urban water systems has to be achieved on a local, national and global scale. So, while WaCCliM works with national and international partners to enable local action, it does this with a larger transformation in mind. The toolbox of both mitigation and adaptation planning measures will be available to utilities everywhere on the **knowledge platform Climate Smart Water:** www.climatesmartwater.org

7.2 GHG emissions from organic matter and nutrient inputs into surface waters

Alongside the energy consumption of water supply and treatment processes, there are other major sources of GHG emissions related to water sector procedures as well as on environmental standards and their enforcement. Surface water bodies, such as artificial reservoirs, rivers, canals, open drains, lakes or wetlands, naturally produce considerable amounts of GHG (Bastviken et al., 2011). For instance, GHG formation in surface waters stimulated by the influx of poorly treated or untreated wastewater and faecal sludge can become a major cause for increased GHG emissions, since such influx comes along with the enrichment of nutrients and organic matter. Globally, over 80% of the wastewater is not collected or improperly treated. Particularly in developing countries, the release of untreated wastewater remains an ordinary practice, due to a lack of infrastructure, technical and institutional capacity, and financing (WWAP, 2017).

The enrichment process of water bodies with dissolved nutrients is also called eutrophication. Higher amounts of nutrients, such as nitrogen (N) and phosphorus (P), as well as organic matter added to water systems, also reinforce the production of CH_4 and N_2O. An increased formation of these gases in receiving waters, associated with unmitigated nutrient and organic carbon influx, correlates with the amount of GHG being emitted eventually. In addition, from a climate mitigation perspective, CH_4 and N_2O are distinctly problematic, due to their high global warming potential. Furthermore, the resultant emissions are generally higher in countries with warmer climates, because higher temperatures potentially stimulate the microbial transformation processes linked to GHG production. Also, higher temperatures decrease gas solubility further exacerbating gasification rates.

Agricultural run-off can also carry significant amounts of P and N into water systems, both from inorganic fertiliser and livestock manure. While the mass of fertiliser applied was relatively lower in most developing countries during the 20th century, it is set to grow strongly in the future. Therefore, it is likely that such trend results in an overall nutrient surplus. In Africa, for instance, the quantities of N and P that are applied to land but are not taken up by crops or are removed during harvests will increase significantly by 49% (N) and 236% (P) between 2000 and 2050 (Bouwman et al., 2013).

Reservoirs, lakes and other lentic waters are major sources of GHG as well. Eutrophication of lentic waters under scenarios of future nutrient loading to surface waters show that enhanced eutrophication of lakes and reservoirs will significantly increase CH_4 emissions from these systems (+30-90%) over the next century. Thereby, changes in CH_4 emissions could have an atmospheric impact equivalent to 18-33% of that from current fossil fuel CO_2 emissions (Beaulieu et al., 2019). In addition, the distinct conditions of reservoirs created by dams – characterised by fluctuating water tables and a high occurrence of organic material – produce considerably more CH_4 than natural lakes or other surface waters. Dam reservoirs, therefore, contribute approximately 1.3% of anthropogenic GHG emissions (Deemer et al., 2016).

➔ ***A growing scientific consensus links nutrient influx into surface water bodies and GHG emissions from them – primarily CH_4 and N_2O.***

Finally, there is now emerging scientific consensus on the link and positive correlation between excessive nutrient loadings into receiving surface water bodies and GHG emissions from them – primarily CH_4 and N_2O (Beaulieu et al., 2019; Deemer et al., 2016; DelSontro et al. 2018; Fernandez et al., 2019; Murray et al., 2019; Prairie et al., 2018; Sanches et al., 2019). In consequence of this consensus, enhanced wastewater treatment and sanitation efforts not only contribute to improved water quality, but also potentially lower degrees of CH_4 and N_2O emissions.

Challenges to estimate actual GHG fluxes from surface waters

The emission of GHG from surface waters, such as CH_4 and N_2O, does not automatically equal the amount of gases being formed in them. Consequently, the amount of gases being transferred from the liquid phase – hence, the actual GHG emission – is often hard to estimate without complex direct measurements within a certain study area. In this connection, the broad absence of real-time gas emission flux data form surface waters constitutes one of the major challenges, when estimating their actual adverse climate impact. Not least because of above challenges concerning the quantification of emissions (using consistent or institutionally accepted protocols) and a resulting lack of sufficient data, global estimates on total GHG emissions from surface waters are not available until now.

➔ ***Severe organic pollution already affects one seventh of all river stretches in Africa, Asia and Latin America.***

However, given the low wastewater treatment rates in many developing countries, it is likely that untreated wastewater has a significant climate impact (Bogner et al., 2007). This assumption can be substantiated through studies showing that severe organic pollution already affects one-seventh of all river stretches in Africa, Asia, and Latin America, and that figure has been steadily increasing (UNEP, 2016). Furthermore, an absence of global estimates does not mean that GHG emission from surface are not being quantified at all. GHG emissions can be estimated for a certain region by using an emission factor approach, as described by the IPCC and the EPA (IPCC, 2006; USEPA, 2019). However, this approach needs to make use of several assumptions and simplifications. For instance, N_2O emissions from surface water bodies are described by a point emission factor, which suggests that 0.5% of the total nitrogen loading is emitted as N_2O, without accounting for regional specifics or nitrogenous substrate differences (ibid.). Furthermore, there is no corresponding measure for CH_4 emissions introduced up to now.

Strategies to reduce GHG production in and emission from surface waters

There are different solutions to prevent lakes, reservoirs and other surface waters from becoming even greater sources of GHG. These solutions seek to lower the quantities of nutrient and organic matter that enter water systems by different means:

- **Control of GHG from insufficiently treated wastewater and faecal sludge:** A low wastewater collection and treatment coverage as well as the absence of formalised faecal sludge management for decentralised sanitation in the majority of urban poor settlements in several developing countries renders this field of action a top climate priority. Thereby, a reduction of CH_4 and N_2O emissions from surface waters can be achieved by enhancing proper wastewater and faecal sludge management. This explicitly includes the appropriate processing and disposal of sludge, as in the foreseeable future the majority of the global urban population will depend on decentralised sanitation systems, since only 41% of the global population is connected to centralized sanitation systems in 2017 (WHO, UNICEF, 2019; *see Chapter 7.1*).

- **Watershed management to reduce nutrient and organic matter inputs:** To lower the GHG emissions associated with the nutrient enrichment of water bodies, watershed management strategies with a focus on nutrient reduction need to be put in place (e.g. management practices including the reduction of nutrient-laden soils through excessive fertiliser use, vegetated filter strips and proper handling of animal manures).

- **Reservoirs created by dams:** With the current support for hydropower in many countries, strategic and careful site selection of new reservoirs will be important (e.g. upstream of nutrient pollution sources). Furthermore, improving the design and management of existing ones is another measure that can help to reduce GHG emissions (Deemer et al., 2016). GHG fluxes from reservoirs strongly depend on various environmental conditions, such as soil characteristics or prior vegetation cover. In consequence, the use of other renewable energy sources than hydropower might be advisable from a climate mitigation angle in some cases.

- **Indirect positive mitigation effects through nutrient recovery:** Fertiliser production (mostly fossil-fuelled) accounts for a significant amount of global GHG emissions. Fossil fuel consumption could be reduced by using wastewater N and P for fertiliser directly through recovering those nutrients. However, it often remains a challenge to fully capture the nutrient recovery potential in an energy- and cost-efficient manner (McCarty et al., 2011), in particular concerning conventional wastewater, which usually has a lower share of N and P compared to more concentrated fluids. Still, an expected increase of nutrient demand might create further economic incentives for nutrient recovery in the future (Cordell et al., 2009). Another forward looking process is to produce bio-char or “terra preta” from faecal sludge and to create a carbon sink, when adding this bio-char to agricultural land, where it can increase the fertility of soils (Biederman et al., 2013; Woldetsadik et al., 2017).

7.3 GHG emissions from peatlands

Wetlands constitute the largest carbon stocks among terrestrial ecosystems. Their conservation depends on water security together with environmental protection, resources management and land use. Peatlands – one type of wetlands – are important as global carbon pools. Measures using wetlands for climate change mitigation involve a) avoiding the destruction of natural wetlands through conservation efforts, including the safeguarding of their carbon sink function and the prevention of significant GHG emissions coming along with their degradation; and b) restoring already degraded wetlands to recover their ability to remove and store CO_2. This grants wetlands a particularly powerful role among **Ecosystem-based Mitigation (EbM)** measures as few other systems can address both elements of climate change mitigation – reducing the sources and enhance the sinks of GHG. However, the potential to store carbon varies by wetland type, which range from floodplain swamps and alpine mires to seagrass meadows and mangroves. Common to all of them is that their plant communities remove CO_2 from the atmosphere through photosynthesis and build it into their biomass. When wetland plants die, dead plant material (carbon-rich organic matter) sinks to the wetland's ground. There it cannot fully decompose due to a lack of oxygen (*see Figure 36 on the next page*). In this way, wetlands accumulate more and more carbon over time, eventually, forming thick organic layers respectively carbon pools. The associated uptake process of carbon from the atmosphere in terrestrial reservoirs is called **carbon sequestration.**

➔ ***Peatlands store twice as much carbon than all global forests.***

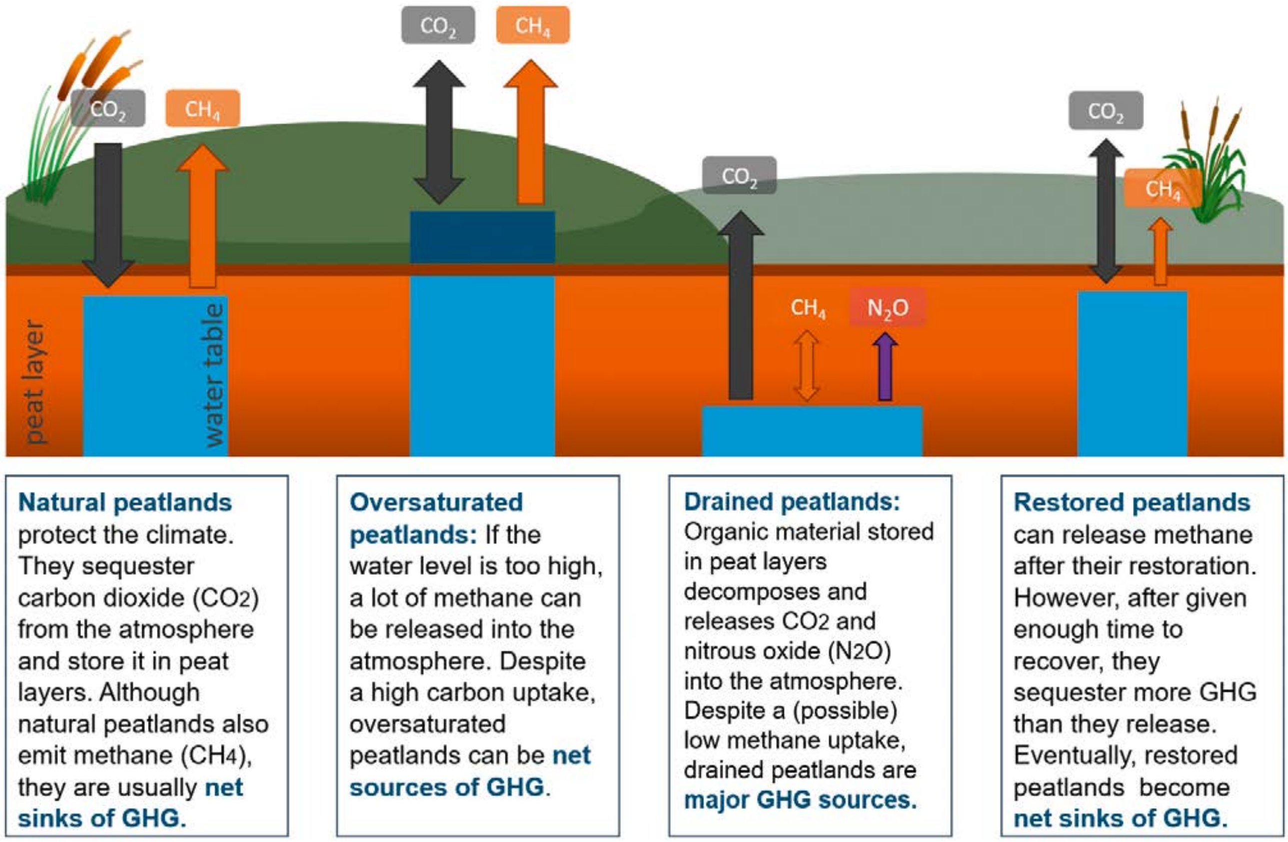
Although only covering 3% of the earth's land surface, peatlands contain nearly one-third of the land-based carbon. This equates to double the amount of carbon locked in the biomass of global forests (Crump, 2017). Peatlands form thick layers of peat, sometimes over thousands of years, allowing them to store more carbon than any other wetland type. A slow formation process of these peat layers – thus a slow creation of carbon pools – makes it imperative to avoid the loss of peatlands in the first place. Furthermore, the amount of carbon stored in peatlands depends on different factors, such as the water table and the vegetation cover. In general, tropical peatlands – almost exclusively located in developing countries – store much more carbon per area unit than those in boreal climates (*see Table 8*). For the sake of completeness, it needs to be noted that also other types of wetlands store high amounts of carbon, such as forested inland wetlands, salt marshes and mangroves. Even though peatlands constitute bigger carbon stocks on a global scale, other types of wetlands can have higher carbon sequestration rates rendering them promising subjects of interests for advanced climate action as well.

Climate	Total peatland	CL[a]	GL[a]	FL[a]	N/A[a]	Degrading peatland	Actual emissions[b]	Peat C	Degrading Peat C
	Area (Mha)						$Gt\ CO_2$ eq.	Gt C	
Tropical	58.7	8.5	11.3	34.6	4.3	24.2	1.48 (0.04–2.79)	119.2	49.1
Temperate	18.5	3.5	5.0	8.9	1.3	10.6	0.16 (0.10–0.21)	21.9	12.5
Boreal	360.9	6.8	85.6	249.5	19	15.5	0.26 (0.16–0.36)	427.0	18.3
Polar	25.0	0.1	14.9	9.7	0.4	0.7	0.01 (0–0.02)	29.6	0.8
Oceanic	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0 (0–0)	<0.1	<0.1
Total	**463.2**					**50.9**	**1.91 (0.31–3.38)**	**597.8**	**80.8**

a) Peatland area according to land use classes (CL), grassland (GL) and forest land (FL). N/A means that no distinct land use type could be identified
b) Annual mean values for CO_2, CH_4, N_2O, and DOC; values in parentheses show the lower and upper range of emissions

Table 8: Area and emission overview of global peatlands (adopted from Leifeld and Menichetti, 2018)

Figure 36: The key role of water for optimising the climate-regulating function of peatlands (Adopted from Umweltbundesamt, 2019)



The GHG footprint of wetlands, in particular in connection to methane emission has been subject to discussions. Wetlands are the largest contributor to natural CH_4 emissions (more than 75%) (Zhu et al., 2016). Therefore, some have argued that draining natural wetlands could be an effective strategy to reduce CH_4 emissions (Muller, 2019). However, this doesn't reflect the whole picture of GHG fluxes: While CH_4 emissions tend to decline after the drainage of a wetland, the subsequent release of CO_2 and the loss of potential prospective sequestration services eventually turn drained wetlands into net sources of GHG emissions (Petrescu et al., 2015). Indeed, almost all wetlands are net carbon sinks, when carbon sequestration and CH_4 emissions are examined over an appropriate time period that also accounts for the decay of CH_4 in the atmosphere (IPCC, 2014; Joosten et al., 2016, Mitsch et al. 2011). In this connection, peatlands have a particularly high mitigation potential, since they cause less than a quarter of all CH_4 emissions emitted by wetlands, while being carbon pools of global significance (Turetsky et al., 2014).

Geographical distribution of peatlands and (potential) GHG emission hotspots

Around 75% of the current GHG gas emissions from degrading peatlands is caused in the tropics; those from boreal peatlands are trivial in comparison (*see Table 8 on the previous page*). Actual emissions from tropical peatlands mainly stem from Southeast Asia as *Figure 37* shows. Yet, *Figure 38* also shows that peatlands in Africa and Amazonia – that are still mostly in an intact natural condition – are likely to emerge as future emission hotspots unless adequate safeguards and conservation efforts are established. However, when estimating future potential emissions from peatlands and the resultant global warming potential, it is critical to acknowledge that the known extent and size of global peatland carbon stocks are still highly uncertain (Leifeld and Menichetti, 2018). In 2011, scientists discovered the largest peatland in the Amazonas, the Pastaza-Marañon Foreland Basin in Peru (Lähteenoja and Page, 2011; Draper et al., 2014), and a few years later the largest tropical peatland, the Cuvette Central in Africa's Congo Basin (Dargie et al., 2017).

Figure 37: Global peatland distribution and annual actual emissions from peatland degradation: The colored area shows the worldwide distribution of peatlands and the GHG emissions currently released from them. The different legend colors indicate the amount of GHG emissions per hectare (Source: Leinfeld and Menichetti 2018).

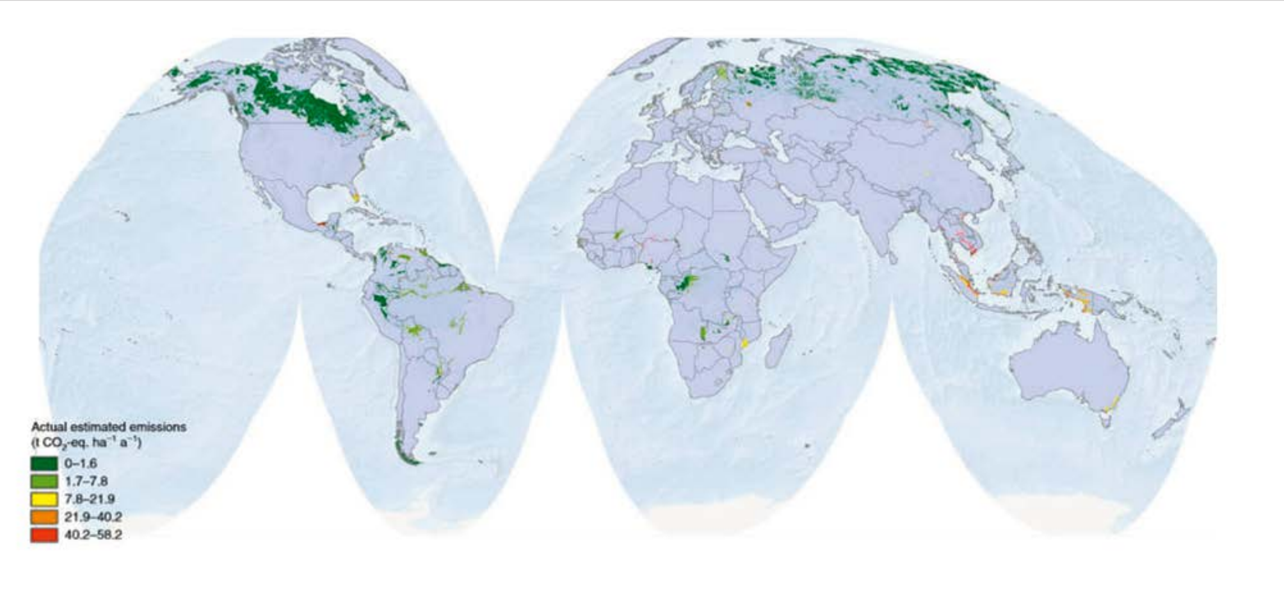
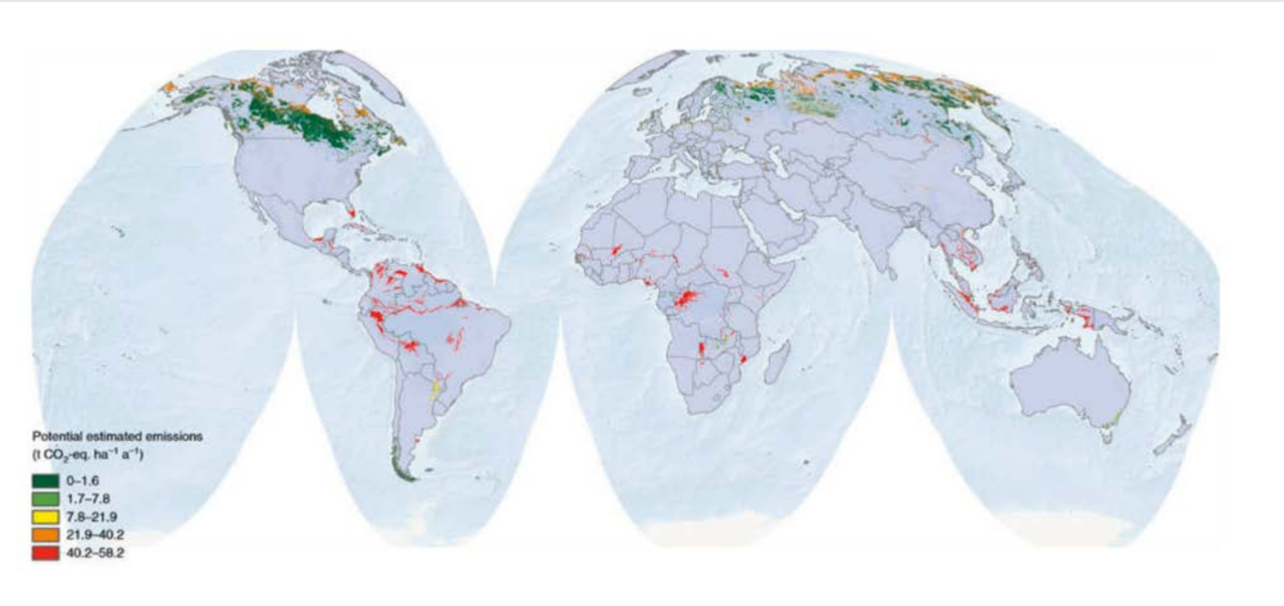


Figure 38: Global peatland distribution and annual potential emissions from peatland degradation: The colored area shows the worldwide distribution of peatlands and the potential annual GHG emissions per hectare if those peatlands would be drained. The map shows that peatlands across the tropics would become emission hotspots while emissions from boreal areas would also increase (Source: Leinfeld and Menichetti 2018).



➔ ***Comprehensive global mapping efforts of wetlands are urgently required.***

Recent discoveries of the large peatlands, as mentioned above, have far-reaching implications for global peatland conservation and restoration. First, they illustrate that tropical peatlands may be much larger than estimated and are undervalued in current global assessments (Leinfeld and Menichetti, 2018). Their extent and volume may be three times greater than in previous estimates (Gumbricht et al., 2017). Comprehensive global mappings of wetlands – in particular peatlands – are urgently required to foster mitigation and conservation efforts through informing decision-making and reducing uncertainties. This can help to prevent the further degradation of (unknown) peatlands, including their vast carbon stocks (*see boxes below* on peatland mapping initiatives and the Nile basin peatland assessment). Second, these discoveries have revealed that the carbon pools contained by African and South American peatlands may be as large as or even larger than those in Southeast Asia. The African Cuvette Centrale peatlands alone are estimated to contribute as much as 29% to the global peat stock. As a result, the Democratic Republic of Congo and the Republic of Central Africa, over whose territories the Cuvette Central spreads, were upgraded to the second and third most important countries in the tropics for peat areas and carbon stocks (Dargie et al., 2017). This not only underpins the essential role peatlands play in climate mitigation, it also implies that much of the future peatland conservation efforts need to go beyond Southeast Asia by accounting also for potential future emission hotspots in Africa and Latin America.

Initiatives involved in mapping global peatlands

The latest discovery of the Cuvette Centrale is just one example highlighting the poorly investigated extent and condition of peatlands around the world. There are several initiatives underway to improve the data availability on peatlands. One is the 🌐 Global Peatland Database (GPD). Started in the 1990s by the International Mire Conservation Group, it collects and integrates data on the location, extent, and ecological status of peatlands and organic soils worldwide and for 268 individual countries and regions. The database contains analogue and Geographic Information System (GIS) maps, reports, observations, pictures, and is supported by the Peatland and Nature Conservation International Library (PeNCIL). The GPD regularly produces comprehensive analyses including worldwide overviews on peatland status and resultant emissions. Its spatial information on peatlands is used to inform peatland conservation in areas of climate change mitigation and adaptation, biodiversity conservation and restoration, and sustainable land use planning.

The 🌐 Global Peatland Initiative is another effort by leading experts and institutions that collaborate to improve the conservation, restoration, and sustainable management of peatlands. One of the outputs of the Global Peatlands Initiative will be an assessment that seeks to discern the status of peatlands worldwide and their importance in the global carbon cycle. It will also examine the monetary value of peatlands for national economies. The Global Peatlands Initiative has carried out a peer-reviewed rapid response assessment for peatlands (Crump, 2017) based on existing data and studies. This rapid assessment looks at the location and extent of peatlands, key threats affecting them, existing conservation policies and their effectiveness, and it suggests future interventions.

Good practice example

Nile Basin Peatlands: Assessment of soil carbon, CO_2 emissions, and mitigation potential

The total peatland area in the Nile Basin is estimated to be 30,445 km^2. That is approximately a fifth of the largest peatland complex in the tropics, the Cuvette Central in the Congo Basin, and comparable to the largest described peatland complex in Amazonia with 35,600 km^2 (Draper et al., 2014). About 40% of the total peatland area estimated for the entire Nile Basin is found in the Nile Equatorial Lakes (NEL) countries (Uganda, Tanzania, Rwanda, Burundi, Kenya). Unfortunately, land-use change in the Nile Basin continues to accelerate and an increasing area of peatlands is being impacted directly (burning and clearing for agriculture, peat extraction for energy) or indirectly (drainage for infrastructure, surrounding plantations causing groundwater drawdown). Other threats to peatlands in the Nile Basin include changing rainfall patterns and fire hazards. The consequences are increased CO_2 emissions through the loss of carbon stocks and productive land.

Recently, the Nile Basin Initiative (NBI) with support from GIZ, on behalf of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) under the International Climate Initiative (ICI), commissioned the study: "Assessment of Carbon (CO_2) Emissions Avoidance Potential from the Nile Basin Peatlands". The objective of the study was to contribute to the discussion on CO_2 emissions' mitigation potential in the Nile Basin, by calculating the current carbon stocks in the Nile region. The study estimated the peat soil carbon stocks in the Nile Basin to be between 4.2 and 10 Gt of organic carbon (GtC). Within these parameters, the country with the highest carbon stock is South Sudan (1.5–3.59 GtC), followed by Uganda (1.3–3.1 GtC). Peat carbon stock losses and mitigation potential within the NEL region were explored with a model assuming that in 2015 25% of all peatlands were drained and that from 2015 until 2050 the drained area will increase annually by 1 %. Resulting losses of about 0.2 GtC over the period 2015-2050 can be regarded as CO_2 emission reduction potential, if no new drainage will be implemented and all drained peatlands are rewetted by 2025. The potential emission reduction would account for 678 Mt CO2 in total, or 19.4 Mt CO_2 per year. Calculations based on more differentiated estimations of initial drained area per country (in 2015) suggests an even higher emission reduction potential of 885.5 Mt CO_2 for the NEL region.

In order to prevent further peat loss in the region, NBI and GIZ are working together to deliver a sustainable peatland management for the region. The strategy features further research needed for a sustainable management, including mapping and monitoring efforts that are necessary to estimate the impact of land use and land-use change on peatlands' GHG emissions as well as the loss of ecosystem services.

Approaches to exploit the climate mitigation potential of peatlands

The ability of peatlands to absorb and store potential GHG emissions depends on the constant availability of water (among other factors, such as peat-forming plants). Consequently, the creation of oxygen-free conditions is an indispensable prerequisite for peat formation and conservation. In consequence, the mismanagement of water resources can disrupt the hydrology and ecological functioning of peatlands and, thus, weaken or nullify their climate change mitigation effects (Page et al., 2009). Water management institutions, such as river basin organisations, can be prime actors tasked with regulating the hydrology of peatlands. They have a great deal of influence when it comes to controlling threats in and around peatlands and cultivating and restoring them in a sustainable manner. Moreover, water-sector specialists, water managers, and freshwater conservationists can contribute critical expertise and know-how (such as in hydrological modelling) to inform a sustainable water management – also in face of expected global expansions of agricultural activity, transport infrastructures, and mining as major drivers for peatland deforestation and drainage (Roucoux et al., 2017, Dargie et al., 2019).

There are also **economic incentives** to protect wetlands. A study by Griscom et al. (2017) sought to quantify the mitigation potential of natural climate solutions, including wetlands. The authors suggest that EbM options can collectively meet 37% of cost-effective CO_2 mitigation needed by 2030 to keep global warming below 2°C. To this end, restoration and conservation of wetlands (including coastal wetlands) can offer a share of 14% of suitable EbM opportunities. Furthermore, in terms of low-cost EbM options (defined by Griscom et al. at or below USD 10 per tonne of CO_2-equivalents per year), measures aimed at wetlands can constitute a share of 19%. However, Griscom et al. also highlight that avoiding the loss of wetlands tends to be less expensive than wetland restoration. Furthermore, they stress that the prevention of loss is an urgent concern in developing countries. In addition, the **economic value of wetlands' ecosystem services** is usually higher than that gained from cultivating them in a not sustainable manner. Moreover, economic profits from intensive economic use of wetlands are often not shared with the society as a whole (Ramsar Convention on Wetlands, 2018). A recent study estimates that wetlands deliver 43.5% of the monetary value of all global inland and coastal biomes. Thereby, peatlands alone represent one-fourth of the total financial value provided by freshwater ecosystems (Davidson et al., 2019).

In this connection, discoveries such as the Cuvette Centrale peatlands further underpin the EbM potential of wetlands, while constituting promising opportunities of conserving them through sustainable water management and land use. Despite a growing acknowledgement of peatlands' importance for climate action, they still remain largely undervalued by governments. In addition, although peatland emissions are included in the IPCC guidelines for National Greenhouse Gas Inventories (Volume 4, Chapter 7 on wetlands; IPCC, 2006) and mitigation measures to reduce them are eligible for national accounting under the UN Framework Convention on Climate Change, they rarely make an appearance in national GHG emission inventories (Moomaw et al., 2018; Roucoux et al., 2018).

Co-benefits of wetland conservation and restoration

Peatlands and other wetlands come with various additional advantages beyond their climate-regulating functions. Compared to forests and grasslands, they do not only hold higher carbon stocks per area unit, but also provide more hydrologic ecosystem services. This efficiency in terms of ecosystem services per area unit is a great asset as many other EbM options demand more land to achieve comparable outputs. Thus, land use competition, e.g. with agricultural activities, is potentially lower (Leifeld and Menichetti, 2018). Furthermore, inland wetlands, such as peatlands, provide several ecosystem services, including water storage, treatment, or flood control. In consequence, EbM through wetlands usually comes along with various **co-benefits** beyond mitigation in the fields of climate adaptation, the protection and conservation of biodiversity as well as human well-being (*Figure 32 on page 90*) (Griscom et al., 2017). The conservation of tropical peatlands is not only accompanied by benefits for climate action, but by distinctly positive effects on biodiversity (Posa et al., 2011).

Unsustainable water resources management can pose considerable threats to peatlands. As displayed above, constant water availability forms the lifeline for natural peatlands. For example, planned dams and water transfers in both the Pastaza-Marañon and the Cuvette Central basin threaten floodwater-dependent downstream peatlands. Their hydrological connectivity with the landscape means that perturbations taking place upstream or closely around a peatland can negatively affect the whole system (Page et al., 2009). The principles of **Integrated Water Resources Management (IWRM)** on the policy, legislation and implementation levels can help to minimize damage from unsustainable developments. The IWRM framework considers natural conditions of freshwater and other ecosystems in decision-making. Thereby it pursues a basin-wide approach, which is one key to ensure that peatlands and other wetlands are managed along their hydrological boundaries. Another important approach

Good practice example

Indonesia: Peatland Management and Rehabilitation (PROPEAT)

Large-scale drainage areas and the conversion of peat and wetlands in Indonesia began in the late 1960s. These were established to promote the success of agriculture, where lands were converted to shrimp ponds. In the heart of North Kalimantan, the peatland and mangrove ecosystem are an integrated landscape in Delta Kayan-Sembakung. Over 20 years, the Delta has suffered from the conversion practices. The delta covers more than 580,000 ha area and provides the community with enormous natural resources and abundant environment services. Today 170,000 ha of Delta has been converted to shrimp ponds and leaving less than 30% of intact mangrove forest.

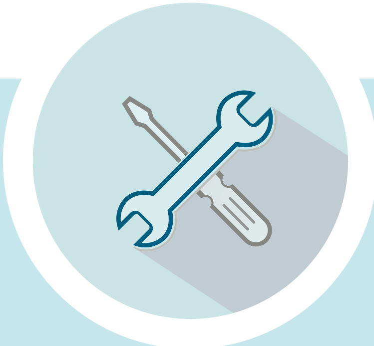
Since 2019, the **Peatland Management and Rehabilitation project (PROPEAT)**, financed by the German Federal Ministry for Economic Cooperation and Development (BMZ) and implemented by GIZ, has been working with the Ministry of Environment and Forestry of Indonesia and the Provincial Government of North Kalimantan to improve the management of peatland ecosystems in North Kalimantan. As of 2020, PROPEAT collaborated with local universities to conduct a baseline study on aquatic and terrestrial biodiversity as well as socio-economic issues. Results of this study will be used as basis for the government to formulate a policy on peatland management at the provincial level. Furthermore, the PROPEAT project conducted carbon assessments in three districts to assess the carbon stock of peatland and mangrove areas. These assessments will be further used for the provincial action plan on GHG, thus, also the mitigation contributions by peatlands will be considered.

In parallel to the above study, PROPEAT promotes the policy of peat and wetland rehabilitation and management through integrative planning processes. The project currently facilitates discussions with stakeholders to develop strategic planning in the Kayan Sembakung Delta, which is the core of the peatland and mangrove ecosystem in North Kalimantan. This strategic planning process will further be integrated in the long-term provincial management plan. In the long run, the project aims to improve current practices of peatland and mangrove management, thereby, it also aims to use findings from applied research and documentation of field experience for dissemination at the local, national and international level.

to protect wetlands and their carbon-pool function is to ensure that river flows sustaining wetland hydrology are not threatened through water resource developments (*see box below on Environmental Flows*).

If eligible, another possibility for safeguarding the integrity of wetlands can be to declare them as **Ramsar Sites** – wetlands of international importance. Pursuing such declaration requires signatories of the Ramsar Convention to conduct initial ecological inventories and develop management plans for wetlands. Both are vital elements to inform and guide a sustainable wetlands management and avoid disturbance of their hydrology. While not offering formal protection in itself, a declaration as a Ramsar Site can still constitute a first step to further promote the creation of legislation aimed at wetland protection (Roucoux et al., 2014; Darpie et al., 2019).

Tools



Environmental flows as a key tool for wetland protection and restoration

Environment flows are defined as "the quantity, timing, and quality of freshwater flows and levels necessary to sustain aquatic ecosystems which, in turn, support human cultures, economies, sustainable livelihoods, and well-being" (Arthington et al., 2018). When implemented, they can be part of reducing the degradation and loss of wetlands, protect, and restore their ecological integrity as well as halt the loss of biodiversity. While so far mainly applied for rivers, there are examples where the implementation of environmental flows has proven to maintain or improve biodiversity outcomes and ecosystem services of wetlands (Yang et al., 2016).

Successful implementation of environmental flows for wetlands can be attained through, among others, careful water-infrastructure planning and development; adequate releases of water from dams; or sustainable water allocation planning. All of these interventions need to be grounded in research that investigates the relationships between flow conditions, wetland ecology, and possible human interactions, so called environmental flow assessments. Within the context of climate change, **environmental flow assessments**, taking into account the effects of climate change, can also provide a better understanding on dynamics around water availability and allocation needs within river basin systems (Barchiesi et al., 2018).

Different tools have emerged to assess and implement environmental flows. The Environmental Flow Calculators, developed by the International Water Management Institute (IWMI), is a software solution to make rapid and desktop-based e-flow assessments.

Restoration: Rewetting of degraded peatlands

Strategies for the restoration of wetlands depend on the type of wetland, its hydrological characteristics, and the causes of degradation. For instance, if swamps connected to a river are degrading due to dam-based alteration of flows, water managers would need to restore environmental flows. If a wetland is drying up because of an overexploited groundwater source, it may be necessary to curtail water licences or tackle illegal pumping. In general, the prime method of restoring peatlands is their rewetting, for instance, through enhancing water inflow, soil saturation and stabilizing the groundwater level (*see Figure 36 on page 122*). Suitable measures in this regard could be the installation of ditch blockages or the sealing off cracks in the peat body, both measures aim to raise a peatlands' water table again until its peat layers are completely waterlogged again (Lunt et al., 2010). Once an oxygen-free environment and the native vegetation are restored, peatlands tend to stop releasing CO_2 emissions and start to sequester them again (Ramsar Convention Secretariat, 2018). While rewetting can raise CH_4 emissions initially, a neutral GHG emission balance is commonly achieved after a few years (IPCC, 2014; Joosten et al., 2016).

Wetland restoration can be a challenging task, especially for peatlands. The complex relationship between the hydrology and ecology of many wetland types demands that restoration measures are grounded in scientific knowledge and thorough assessments executed by sufficiently skilled water/natural resources managers. To develop restoration measures, comprehensive modelling exercises are often needed to simulate the water table for optimal ecological functioning. From a water perspective, the success of peatland restoration relies on maintaining a sufficiently stable water table over a long time period. Setting the water table correctly is not only a challenge for sustainable water management, but also key to re-establish the mitigation benefits of peatlands. This also includes the prevention of massive GHG emission through peat fires in drained peatlands (Page et al., 2009).

Sustainable cultivation of intact and degraded peatlands

Most forms of practiced peatland cultivation follow an initial drainage combined with a large-scale clearance of vegetation. This renders them unsustainable in most cases. However, economic or agricultural practices in wetlands have been developed that do not require their drainage. **Paludiculture** is one prominent example of sustainable wetland cultivation (Evers et al., 2017). Paludiculture commonly encompasses measures such as reed mowing or the manufacturing of economic goods. Generated incomes can provide local communities and governments with incentives to conserve or restore peatlands and other wetlands, as well as preventing their degradation (*see box about the Upper Amazon on the next page*).

Besides protecting wetlands' carbon pools, paludiculture constitutes further co-benefits for biodiversity, local energy supply, and climate adaptation (Wichtmann et al., 2016). However, paludiculture also faces challenges. For instance, it is hard to reach the same level of agricultural productivity through paludiculture if compared to environmentally adverse agro-industrial activities, such as extensive palm oil production. Still, only 1% of global agriculture is undertaken on peatlands (Leifeld and Menichetti, 2018). Therefore, multiple benefits provided by their ecosystem services make a strong case for a sustainably management and cultivation. The political framework can contribute to protecting ecosystems, for instance through economic incentives favouring sustainable peatland cultivation.

Good practice example

Upper Amazon – Peatland protection for climate change mitigation and adaptation by coupling climate finance, biodiversity conservation, and indigenous land use management

The project "Building the Resilience of Wetlands in the Province of Datem del Marañón, Peru" aims to improve the livelihoods of indigenous communities and making them more resilient against climate change impacts, for instance, by providing alternative income opportunities to curb deforestation and protect the carbon stocks of the peatlands. The project, which combines adaptation and mitigation elements, is financed by the Green Climate Fund with a budget of USD 9.1 million and executed by the Peruvian Trust Fund for National Parks and Protected Areas (PROFONANPE).

The project area is in the western middle portion of the Amazon Basin, in the Province of Datem del Marañón, Loreto Region, Peru. It is part of the Pastaza-Maranon Foreland Basin (PMFB), which is the largest peatland in the Amazon presenting 2.7% of the global tropical carbon stock. The Amazon peatlands in Peru remain almost entirely intact. Yet, they face an increasing number of threats from oil extraction, agriculture, illegal logging, and palm oil cultivation (Draper et al., 2014).

The project seeks to avoid deforestation of an estimated 4,861 ha of palm swamp and terra firma forests over a 10-year period and enhance the resilience and conservation of 343,000 ha of peatlands and forests. It does so by helping government departments to better facilitate land-use planning and management of the region's wetlands. The bulk of the funds will eventually be allocated to support indigenous communities to set up sustainable businesses. These resolve around sustainably harvesting peatland products, such as salted fish, the pulp of local palm trees, or natural substances for medicinal use.

The communities are supported through capacity building in business plan development, marketing and management, or equipment and supplies. The project provides a compelling case for an initiative that links climate action through community-based support of indigenous people, while combining these activities with biodiversity conservation and a better protection of tropical peatlands. Furthermore, it is the first project of its kind financed by the Green Climate Fund (Roucoux et al., 2017).

7.4 GHG emission from the cultivation of rice

Rice paddies are the largest artificial wetland type measured by their extent and constitute another source of GHG emissions. Consequently, they also come along with mitigation potential for the agricultural sector. Rice cultivation accounts for at least 2.5% of the global GHG emissions due to CH_4 and N_2O emissions that form under anaerobic conditions in flooded rice paddies. The value may be even higher given that most studies have rather underestimated N_2O emissions (Kritee et al., 2018). CH_4 emissions related to rice cultivation are expected to even double by 2100 due to global warming (van Groeningen et al., 2013). Interventions that seek to exploit this mitigation potential need to consider that rice is a food staple for almost half of the world's population.

Furthermore, an increased productivity is required to meet the growing demand for rice, especially in Sub-Sahara Africa. Rice consumes 3000-5000 litre of water per kilogram, more water than most other crops. If cultivated through irrigation, such high water demand can affect the overall water distribution and threaten supply to domestic users and ecosystems, possibly affecting water sector responsibilities. Already today, water scarcity threatens rice production in many countries. Successfully tackling inter-sectoral challenges through an independent user allocation requires an integrated water resources strategy that also accounts for conflicting user interests (Godfray et al., 2010). The water sector is a key player in terms of contributing knowledge about and solutions for producing the same amount of rice with less water, while reducing GHG emissions. This is illustrated in more detail below.

Different aspects of rice cultivation can result in GHG emissions, however, more than 90% of the emissions are associated with the flooding of paddy fields. The remainder stems from fertiliser application and water pumping. About 90% of rice is still produced and consumed in Asia, mainly in China, Indonesia, and India. However, other cultivation regions are on the rise, such as sub-Saharan Africa (Carlson et al., 2016). GHG emissions mainly correlate with chosen type of flooding regime used throughout the cultivation (*see box for different flooding strategies*). Continuous flooding, as often practiced in Vietnam, results in much larger CH_4 emissions than Mid-season Drainage (MSD), the dominant flooding practice in China. Consequently, China produces one-third of the global rice yet contributes only 23% of the rice-related CH_4. Vietnam, in turn, produces only 5% of the global rice production but 10% of the related global emissions (ibid.). Recent studies have shown that GHG emissions from rice cultivation can be reduced by up to 90% through the use of more suitable flooding techniques such as MSD. Compared to Alternate Wetting and Drying (AWD), MSD involves only one instead of several rounds of drainage, eventually reducing GHG formation. At the same time, sustainable techniques can help to achieve higher yields, increase nitrogen-use efficiencies and reduce water use (Wu et al., 2018; Kritee et al., 2018).

Different forms of intermittent flooding regimes have emerged to replace continuous flooding in some areas. AWD, for instance, is a response to water scarcity in many rice cultivating regions. This regime can save up to 30% of needed irrigation water, depending on local conditions.

Another main benefit of AWD is that it has proven to reduce CH_4 emissions by as much as 80% (Sander et al., 2016). However, there is growing evidence that N_2O emissions from intermittent flooding may be higher than those of permanent flooding regimes (Kritee et al., 2018). In order to fully account for GHG emissions from rice cultivation, actual N_2O emission need to remain a subject of further investigation in the future, mainly led by the agriculture sector.

Different flooding regimes used in rice cultivation:

Permanent flooding: The rice field is constantly flooded during the entire growing season.

Alternate Wetting and Drying (AWD): Water levels during intermittent flooding are typically allowed to fall to 15 cm below the soil surface before starting another round of irrigation. AWD is typically characterised by several drainage events.

Mid-season Drainage (MSD): The rice paddy is drained only one time for around seven days. Intermittent flooding causes one single aeration event for an extended period.

➔ *Water institutions can help to reduce GHG emissions and water demand.*

The agricultural sector has been a leading voice in terms of research and dissemination of water-efficiency technologies that can reduce water demand from rice cultivation. However, water institutions – such as ministries for irrigation and water management – are among the main partners of the agricultural sector in designing policies and instruments that would promote water-saving measures on the ground, and these institutions are also heavily involved in their

implementation. Water institutions might further develop and promote appropriate flooding regimes, policies and other instruments for enhancing water-efficiency, while reducing GHG emissions and improving climate resilience of rice cultivation (ibid.). At a local level, water user associations are important actors with a strong influence on cultivation practices of farmers. In this connection, new flooding regimes could be promoted through education, awareness-raising, capacity building or incentives (Sithirith, 2017).
In order to reduce the climate impact of rice cultivation, water institutions could support the co-management of different GHG emissions, water resources, and crop yields. The urgency to act upon this triple challenge facing rice cultivation requires more integrated assessments considering water use, N_2O and CH_4 emissions, and rice yields for different rice production systems on a global scale. Such holistic assessments are necessary to identify flooding regimes most promising to minimise both water use and GHG emissions in an integrated manner, while maintaining yields.

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