CHAPTER 8

Water risks and win-wins for climate mitigation

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Wind turbines in the Gaomei Wetlands, which spans over 300 hectares close to Taichung City, Taiwan. Source: Shutterstock.

Highlights

- Water-wise climate mitigation plans across national and local levels must identify, assess, and incorporate water risks as well as win-win opportunities for water-related mitigation measures.
- **Identifying water risks includes analysis of how water might limit the success of many climate mitigation measures, as well as assessments of where mitigation measures could pose risks to freshwater systems and the water cycle**. Specifically, such analysis requires review of water-related risks in development of different renewable energy options as well as the potential implications of biodiversity loss and ecosystem degradation – which not only reduce carbon sequestration potential of terrestrial and aquatic ecosystem-based mitigation measures but can also lead to emission of greenhouse gases.
- **Utilizing win-win opportunities will be critical to effectively and sustainably reduce emissions through water-wise climate mitigation action**. Highlighted measures include those that can be taken in drinking water and sanitation services as well as actions to protect, restore, and manage terrestrial and aquatic ecosystems (e.g., wetlands, river systems, forests, agriculture).
- Four leverage points are identified, which combined sets an agenda for action to ensure that climate mitigation is resilient, robust, and water-wise: 1) Promote sustainable low-emission water management; 2) Invest in Nature-based Solutions and healthy ecosystems; 3) Navigate water-wise energy pathways; 4) Accelerate transition to circular solutions and sustainable lifestyles.

8.1 Introduction

The sectoral chapters of Part II (Chapters 4–7) in this report give many examples of how freshwater is a key component of solutions to mitigate global warming in ways that are sustainable, resilient, and beneficial. They review key areas for climate mitigation across water, energy, and ecosystems to reveal where they directly depend on, or impact water systems, showing that:

- **Effective climate mitigation measures acknowledge and manage water interdependencies.** Most mitigation measures needed to reach climate neutrality depend on functional freshwater systems and healthy ecosystems. A great majority of mitigation measures worldwide have a link to water management and/or the water cycle in many and diverse ways that must be understood, planned, and accounted for.
- **Uninformed climate mitigation planning generates unintended impacts on water systems and the water cycle.** Most mitigation measures needed to reach climate neutrality also have an impact on freshwater resources. If not planned carefully, negative impacts on ecosystems and freshwater resources might threaten water security adding additional burden on adaptation measures or, in some cases, even leading to increased emissions hindering climate change mitigation. A strong interdependence exists therefore among climate mitigation, water resources management, and water security.
- **Effective management of water resources and water-wise management of land systems and freshwater ecosystems can actively contribute to emission reductions.** Sustainable land, water, and wastewater management, and healthy freshwater ecosystems hold large, untapped greenhouse gas (GHG) mitigation potential and thus, water is a crucial mitigation lever in its own right.

This chapter builds on these findings to identify risks and win-wins for carbon-smart and water-wise climate planning, investment, and implementation. Unmanaged risks could lead to detrimental outcomes, including failure to realize the expected mitigation potential of a measure; negative impacts on freshwater systems and human livelihoods; or even increased emissions caused by disrupted freshwater ecosystems. Section 8.1 identifies mitigation measures where water risks could limit the success of the climate mitigation measures, while section 8.2 reviews mitigation measures that could pose risks to the water cycle. In both these cases of water risks, thorough evaluation is needed to assess, avoid, and minimize potential trade-offs and ensure that the benefits provided by mitigation measures can be sustained and outweigh potential costs and possible negative impacts on water security.

Section 8.3 identifies win-wins where sustainable water management and governance can contribute to reduced GHG emissions. Four priority areas for water-wise climate action are presented. These highlight specific ways freshwater management can contribute directly to climate mitigation and therefore must be included in climate (mitigation) plans and policies. They also showcase areas where mitigation measures can provide co-benefits or do not endanger water security compared to alternative climate mitigation options.

Overall, this chapter closes the knowledge gap concerning the interrelations between the water cycle, freshwater availability, freshwater limitations, and mitigation of GHG emissions. It points to essential opportunities to reduce potential trade-offs, mitigate risks and enable synergies that mitigate climate change, and relieve pressure on freshwater systems.

8.2 Water risks can limit the success of climate mitigation

Mitigation does not work without water. Most mitigation measures needed to reach climate neutrality depend on functional freshwater systems. This report underscores the central role of freshwater as an enabler for climate change mitigation across sectors, showing evidence that as most mitigation activities rely on freshwater access, mitigation targets cannot be met without sufficient freshwater resources and sustainable water management. This section reviews mitigation measures that have been identified throughout this report as being particularly sensitive to constraint by water risks, such as water shortages, floods, or climate-induced changes to the water cycle, unless effective plans are in place for the event of such risks.

8.2.1 Water risks for mitigation measures in freshwater ecosystems

Freshwater ecosystems can function as carbon sinks; however, this is reliant on a healthy water cycle and sustainable water governance. Water scarcity and ecosystem degradation in freshwater systems, caused by climate change and unsustainable land use practices, can instead cause these carbon sinks to release GHGs (Anisha et al. 2020; Paranaíba et al. 2022). As the climate change mitigation potential is essentially connected to water availability, ecosystem conservation and restoration measures to ensure a healthy water cycle are critical for freshwater ecosystem-based mitigation. For instance, between 1970 and 2015, the area of the world's natural inland and coastal wetlands declined by ~35% (Gardner and Finlayson n.d.). About 15 per cent of the world's peatlands have been drained for agriculture, forestry, and grazing, resulting in at least 5 per cent of the total global anthropogenic emissions (Joosten et al. 2012; Tanneberger et al. 2017). A recent study confirmed that increasing water limitation occurs in 73 per cent of global warm land areas, that is, where air temperature >10°C for most of the year (Denissen et al. 2022).

Climate change is already altering ecosystems' water cycling and habitats, which has an impact on their mitigation potential (IPCC 2022), even more so under future climate and environmental changes. Key risks highlighted in this section explain how ecosystems that are subjected to water scarcity, degradation, and pollution, are expected to increase emissions of GHGs.

8.2.2 Water risks for mitigation measures in land systems

Land systems can function as carbon sinks; however, this function is reliant on an intact water cycle and healthy soils. Without freshwater, soils are sensitive to undergoing a shift from storing GHG to becoming a source of emissions. The carbon sequestration potential of soils is impacted by a number of factors including inherent soil texture, temperature, water, and nutrients. Water scarcity is already constraining both soil carbon sequestration and food production potential, not least in regions with rapid population and economic development. For instance, according to FAO SOFA (Gustafson 2020), 40 per cent of rainfed high and low input agriculture and 20 per cent of irrigated agriculture are currently affected by water constraints, and hence productivity is lower than attainable (i.e., there is a water yield gap). Water is a natural limiting factor in food and biomass production in both rainfed and irrigated crop-livestock systems. Climate change, rainfall variability, and freshwater availability and access can be expected to further limit the process of carbon sequestration in soils, as well as in biomass, in highly managed crop, agroforestry, and grassland systems. However, the actual rate of change at regional to local levels has yet to be explored, and different systems will be impacted in divergent ways. Increased rainfall can lead to higher soil erosion rates with loss of soil organic matter, as well as flushing of soil and carbon from wetlands to streams and rivers and result in higher GHG emissions. Planning ecosystem protection, restoration, or management must also consider potential impacts of climate change by implementing measures that can adapt to changing conditions (IPCC 2022).

Similarly, the capacity of forests and grasslands to function as carbon sinks is dependent on freshwater. Drainage, clearcutting, or excessive grazing of ecosystems accelerate emissions of CO_2 and methane, which must be halted. The carbon sink strength in some tropical forests has recently peaked, while in other tropical, subtropical, and temperate forest zones it appears to be slowing down (Hubau et al. 2020). Deforestation, forest degradation, and unsustainable management of tropical forests are likely to cause regional reductions in rainfall, increased frequency and severity of droughts, and teleconnected hydrological and climatic impacts through influences on large-scale atmospheric and oceanic circulation dynamics (Wang-Erlandsson et al. 2017; Lawrence and Vandecar 2015). Deterioration of forest water cycles risks lowering agricultural productivity regionally and globally, causing irreversible damage to biodiversity, and turning the forest carbon sinks into carbon sources.

8.2.3 Water risks for transitioning towards low GHG emission energy sources

Changes in the water cycle have significant implications for hydro- and thermoelectric energy production, which account for some 95 per cent of global electricity generation (IPCC 2022). Hydropower currently provides 16 per cent of total electricity generation and 43 per cent of global electricity from renewables (IEA 2021). There are risks to energy generation by hydropower where there could be a decrease in the volume of water that flows through a plant. This could occur as a result of the effects of climate change and variability, which can cause less rain and more evapotranspiration, or from increased water withdrawals for other uses (such as the domestic, industrial, or agriculture sectors). Therefore, the potential impact of climate change on hydropower generation during the lifecycle operation of the infrastructure and the entire river basin system must be considered to ensure that energy generation of a hydropower plant can be sustained or adjusted under different plausible scenarios. For example, in some cases, dams can support flood protection downstream, but can also pose higher risks for flooding upstream in areas surrounding constructed reservoirs, as well as more devastating flood events occurring if there are dam breakages.

Impact assessment and risk mitigation strategies are needed for hydropower development and operations to reduce negative effects on water balances and freshwater ecosystem functions as well as potential increased emissions from water bodies that result from alterations caused by hydropower installations. For instance, reservoirs created by dams, with fluctuating water tables and a high occurrence of organic material, produce considerably more methane than natural lakes or other surface waters, and it is asserted that newly formed hydroelectric reservoirs emit between 3 and 10 times more GHG than natural lakes of the same size (Prairie et al. 2021; Fearnside 2006; Tremblay et al. 2005). The depth, age of the utrientrs, temperature, pH, and availability of utrientts in these waters and their catchments all influence GHG emissions. Accounting for downstream impacts is particularly important in transboundary basins together with processes for risk mitigation and benefit sharing.

Freshwater is also vital in the context of thermoelectric plants for nuclear, concentrated solar power, and geothermal energy. When planning and developing such plants requiring large volumes of water for cooling processes, the availability and impact upon water resources must be considered. Thermoelectric plants generate 80 per cent of the current electricity worldwide, primarily with coal and gas power. They are also used in nuclear, concentrated solar, and biomass plants, where those energy sources heat water to power a steam turbine and generate electricity. Water is also required for cooling in the vast majority of plants, and some geothermal power plants use water for cooling and re-injection rather than geothermal liquids (Jin et al. 2019). Many thermal power plants are currently located in areas under high water stress, with estimates ranging from 33 per cent (IEA 2021) to 50 per cent (Kressig et al. 2018). Water shortages and droughts can lead to either disruptions or reduction of energy generation, as seen in Europe, India, and the United States in the past decade, or heightened competition for water use in other sectors (Ahmad 2021). From 1981 to 2010, electricity production from thermoelectric plants decreased by 3.8 per cent in places experiencing droughts (IPCC 2022). Incomplete information on water use by thermal power plants (both existing and planned) in many regions can further increase risk for disruptions of electricity generation or unsustainable withdrawals of water (van Vliet et al. 2016). For example, once-through wet cooling processes withdraw high volumes of water, which could be reduced, where feasible, by use of recirculating water systems, and dry cooling systems.

Access to freshwater is also critical for Bioenergy with Carbon Capture and Storage (BECCS). Potential land constraints and requirements for water are key determinants to potential investment in BECCS in different locations around the world. BECCS has a certain theoretical potential to provide energy and increase carbon sequestration, leading to climate-positive results (where more carbon is removed than emitted for energy production). However, the IPCC showed in its 1.5°C compatible pathways that scenarios in which emissions reductions occurred required large expansion of BECCS to capture more released carbon (IPCC 2018). Projected freshwater use for mitigation appears to be particularly high for potentially irrigated biomass plantations dedicated to BECCS (see Chapter 7). Current and projected freshwater use in other sectors must be considered to evaluate feasible and sustainable expansion of BECCS. Figure 8.1 illustrates that the freshwater withdrawals required for BECCS may reach as much as, or more than, those in other sectors (agriculture, household, and industrial use). This could occur if BECCS is developed to reach a very high level of energy production and carbon sequestration and expanded beyond rainfed areas onto lands worthy of protection (Stenzel et al. 2019, 2021).

Achieving this maximum BECCS scenario would also place bioenergy as the largest water user in many regions (Figure 8.2). Such large-scale expansion could push total global human water consumption beyond the freshwater planetary boundary, suggested to be 4,000 $km^3\ yr^{-1}$ or even significantly lower (Gerten et al. 2013; Steffen et al. 2015). Accordingly, large-scale BECCS has been found to be incompatible with the freshwater boundary and also with other planetary boundaries such as those for land system change, biosphere integrity, and nitrogen cycling (Heck et al. 2018). Thus, such efforts to mitigate the transgression of a planetary boundary for climate change (broadly equivalent with the 1.5°C

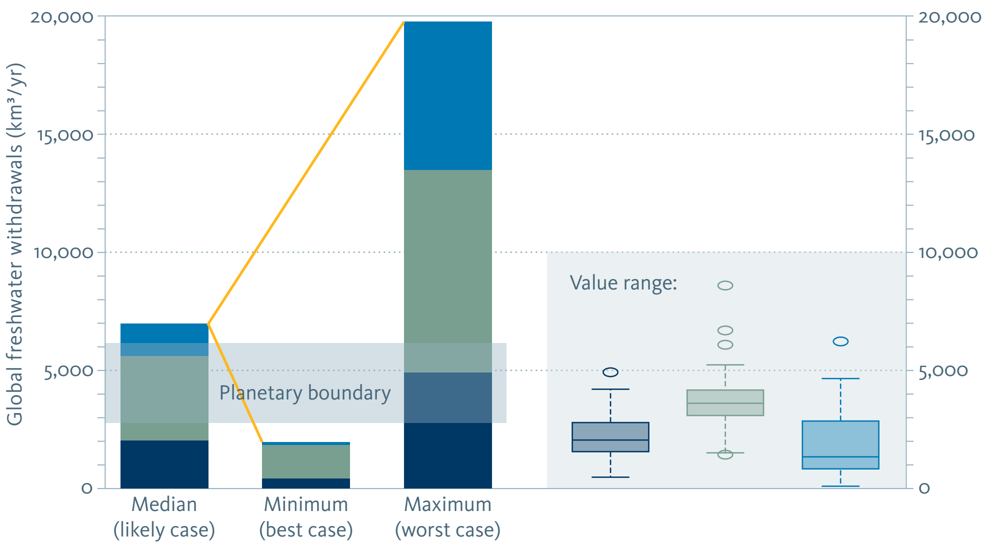

Figure 8.1. End-of-century projections of annual blue water withdrawals for bioenergy, agriculture, and industries plus households. Data from references in Stenzel et al. (Stenzel et al. 2021); water use for irrigation of biomass plantations normalized to negative emissions of 5 GtC. A) median value for each sector, b) uncertainty ranges for each sector according to study and scenario differences.

target) might severely compromise the status of other boundaries, which emphasizes that benefits and side-effects of mitigation need to be evaluated in a broader Earth system context (not solely focused on climate and water). These interactions and trade-offs require robust and integrated assessments, including identification of synergistic solutions. Such analyses also need to explicitly incorporate the multiple potential trade-offs regarding freshwater. This is particularly important as the uncertainty about sector-specific freshwater demands and possible intersectoral competition is very high. Scenarios of potential future water use that integrate the bioenergy sector with the agricultural, industrial, and domestic sectors are needed to highlight the potential scale of risks but are not yet available (Figure 8.2).

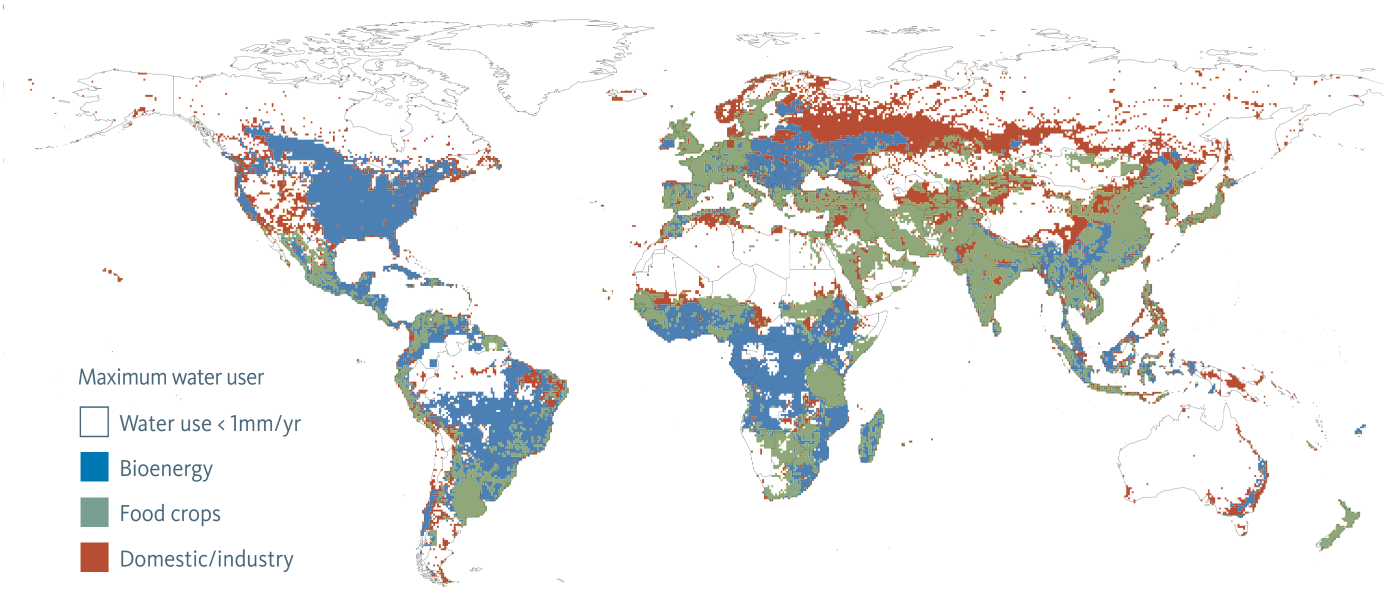

Figure 8.2. The global map indicates regions (blue colour) where bioenergy would use more freshwater than other crop production or domestic and industrial use. Dominant water use sector per 0.5° grid cell calculated from average annual water withdrawals for irrigation of agricultural crops, irrigation of BECCS biomass plantations, and households/industry purposes, respectively, for the period 2090–2099 under the HadGEM2-ES RCP2.6 climate and SSP2 socio-economic scenario of the ISIMIP2b model ensemble also analysed in Stenzel et al. 2021.

8.3 Mitigation measures can pose risks to the water cycle

Water must be protected from uninformed mitigation planning. Most mitigation measures needed to reach climate neutrality also have an impact on freshwater resources. If not planned carefully, negative impacts on freshwater resources might threaten water security adding additional burden to adaptation measures or, in some cases, even leading to increased emissions hindering climate change mitigation. This section reviews mitigation measures that have been identified throughout this report as running a particularly high risk of posing potential harm on freshwater ecosystems.

8.3.1 Risks to the water cycle posed by ecosystem-based mitigation measures

Misguided implementation of land systems climate mitigation measures can cause local water shortage, biodiversity loss, and harm to local communities. Chapter 6 outlined how mitigation measures and Nature-based Solutions (NbS) in land systems in general have a positive impact on the water cycle, but there are a few examples where action to mitigate climate change may risk disrupting water flows and reduce freshwater availability. Measures where trees are planted, such as in forest restoration, afforestation, reforestation, and agroforestry, risk incurring a high demand for freshwater and having negative impacts on river flows and groundwater, particularly in dry areas and during dry periods (Wang et al. 2020; McVicar et al. 2007; Mu et al. 2007). For instance, a study analysing reported change in annual water yield in forest restoration and other forms of forest cover expansion, showed that the yield decreased in 80 per cent of the cases, while in 6 per cent the effect was positive (Filoso et al. 2017). To minimize these negative effects, it is important to make water-wise plans for which tree species to plant and at what densities, for instance by promoting tree species that consume less water and/or are more effective at improving soil hydrological functioning (Scott and Prinsloo 2008; Ferraz et al. 2013) or by ensuring long rotation periods.

Species selection is also of high importance in agricultural lands for climate mitigation measures to sustainably manage soils, croplands, or grazing lands, especially in arid and semiarid regions. One option is to avoid planting species that are sensitive to water stress or have high demand for water, in favour of more resilient species. In situations where more water-demanding species are needed, there are sustainable management options that can reduce water risks in terms of agroforestry and other climate-smart integrated farming systems, such as use of shade crops, crop rotations, cover crops, and integrated crop-livestock systems (Kakamoukas et al. 2021; Niggli et al. 2009). Technical measures to improve water use efficiency can also be used, such as micro- or drip-irrigation (Parthasarathi et al., 2021).

8.3.2 Risks to the water cycle posed by energy systems mitigation measures

The transition away from high-emission fossil-based energy sources lies at the centre of all efforts to reach climate mitigation targets that can limit planetary warming to 1.5°C. Here, actions to mitigate risks posed to freshwater systems resulting from energy generation is critical. Chapter 7 outlined the many ways water is used for generation of low-emission energy from hydropower, bioenergy, nuclear, geothermal, solar, and wind power. In relevant cases, water risks should be evaluated and managed in line with the local conditions and in ways that are resilient under climate uncertainty. However, without proper planning, the transition towards renewable energy sources could pose significant risks to freshwater systems.

For example, thermal pollution (e.g., sudden discharge of warm or cold water into water bodies) harms water quality and ecosystem health. Fish and other wildlife can also be killed when water is abstracted from a river or lake. Some solar thermal systems may also use potentially hazardous fluids to transfer heat, which if leaked are harmful to ecosystems (US EIA 2020). In geothermal power development, measures are also needed to prevent contamination of groundwater with drilling fluids (during the drilling process), depletion, and warming of groundwater during the mass withdrawal operations, and contamination of groundwater and surface water ways in the disposal of waste liquids (from both surface disposal and reinjection processes) (Sayed et al. 2021). Accidents or failures at nuclear plants (such as the Fukushima Daiichi Nuclear Power Plant disaster of March 2011) can also pose harmful risks to ecosystems and human health that potentially last for decades (Lu et al. 2021).

8.4 Win-wins for high-potential mitigation opportunities

This section highlights four key ‘leverage points’ to ensure water and climate security. Leverage points are areas where actions can have great positive impacts on complex systems to achieve transformative changes (Fischer and Riechers 2019). They also cover critical areas for mitigation that have either positive co-benefits or reduce impact on water sources compared to alternative options. Actions in these areas include climate mitigation measures where the use, protection, or management of freshwater directly results in reduction of emissions. Such measures are recommended to be explicitly included in a climate mitigation planning process and implementation.

1. Promote sustainable low-emission water management

2. Invest in Nature-based Solutions and healthy ecosystems

3. Navigate water-wise energy pathways

4. Accelerate transition to circular solutions and sustainable lifestyles

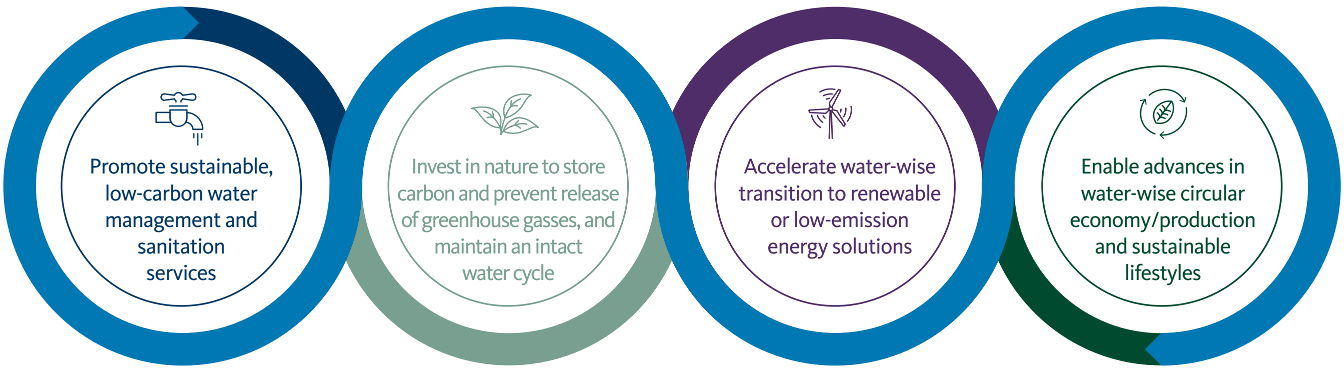

Figure 8.3. Key leverage points in climate mitigation to ensure water and climate security, ensuring a resilient, robust, flexible, and water-wise transition. Source: SIWI.

The first three leverage points are cross-cutting opportunities that are identified across the mitigation areas analysed in Part II, and which directly link to water. The final one covers issues beyond those covered in the report, but which have clear positive impacts on water, climate mitigation, and sustainable development. For each leverage point, recommended priority areas for action are provided.

8.4.1 Promote sustainable low-emission water management

This report has shown how the protection and sustainable management of freshwater in many cases can contribute to climate mitigation. Sustainable water management may help improve climate mitigation in water and sanitation services (Chapter 4); protect, manage, and restore freshwater and terrestrial ecosystems that store carbon (Chapters 5 and 6); and secure energy generation to limit potential harmful impacts (Chapter 7). For example, increased water productivity and sustainable practices can contribute to potential cultivation of BECCS that can be done without causing resource shortages.

1. Action: Reduce emissions and recover energy in drinking water and sanitation services

There is great potential to reduce or avoid GHG emissions while improving and extending wastewater collection and treatment, and safe sanitation for all people worldwide. Chapter 4 of this report detailed how improved water, wastewater, and sanitation management is a major opportunity for climate mitigation. A number of measures could be taken to reduce emissions from water supply and treatment networks, including optimized process selection and operations of wastewater and faecal sludge treatment and discharge as well as enhanced wastewater collection and treatment (including decentralized sanitation solutions). There is potential also for energy efficiency measures, increased use of renewable energy for water processes, as well as reducing demand for, and losses of, water. Reuse of greywater could also reduce energy demands and provide multiple benefits for climate resilience. There is also an enormous opportunity to transform wastewater and sludge into sources of low-emission energy and heat (IWA 2022). This energy generation potential could reduce the need for external energy inputs, perhaps even generating more energy than needed for water supply and sanitation services. Selling this low-emission electricity, heat, and biogas to others to replace fossil energy sources could help water and sanitation services both recover costs for treatment and achieve net-zero emissions (IEA 2018). Overall, to fully account for and report these activities as mitigation actions, it is critical to measure emissions from water and sanitation services as well as their reductions.

There is a need to identify areas where climate finance can provide incentive and capacity to reduce or prevent emissions in the provision of basic and advanced sanitation solutions. A large share of the wastewater and faecal sludge generated in low-income countries remain untreated or partially treated, which results in pollution of water bodies and uncontrolled release of nitrous oxide and methane gases through biodegradation of organic matter. Currently, 2 billion people lack access to basic, safe sanitation services and an additional 2 billion people will join the global population by mid-century (UN-DESA 2022). The extension of wastewater collection and treatment systems in all areas, including decentralized solutions, is essential for achieving the Sustainable Development Goals (SDGs). Some options can potentially lead to lower emissions, while certain treatment processes instead lead to increased emissions (SuSanna 2022). Water Sanitation and Hygiene (WASH) actors could also engage more actively in assessing climate risks and vulnerabilities that affect services provision, report GHG emissions from water and sanitation systems, and calculate reductions made of those emissions where possible. This could serve as a basis to promote WASH interventions that better integrate the mitigation potential in addition to serving as adaptation solutions. Project experience has created strong knowledge, guidance, technologies, and interventions for energy-efficient and low-climate-impact water and wastewater processes that can be scaled up through investment, capacity-building, and training using climate financing. Tools for measuring and reporting GHG emissions from water and sanitation systems to national GHG inventories have been developed and are available for use (Kerres et al. 2022). More and better efforts are needed, however, to secure adequate capacities of WASH stakeholders, at all levels. As a first step to strengthen WASH in the climate agenda, vulnerability and climate risks linked to the delivery of WASH services must be identified and assessed, particularly documenting GHG emissions from water and sanitation systems. Available knowledge and evidence need to inform climate policies, strategies, and the formulation of the response and related plans, that is, promoting WASH interventions that not only consider adaptation solutions but also better integrate the mitigation potential.

2. Action: Adopt watershed-scale emission reduction strategies

Emission reduction goals need to be given greater emphasis in broad water resources management strategies. Although wetlands and peatlands are often included in national climate policies (e.g., Nationally Determined Contributions, (NDCs), other freshwater systems, such as rivers, lakes, and reservoirs are still not commonly included. Freshwater systems in many places have been altered and risk becoming net sources of emissions. While there is evidence that rivers are emitting GHG, knowledge on the drivers of emission, the patterns and variability is incomplete due to a relatively small number of observations scattered around the world with varying measurement techniques used. Data on emission and sequestration patterns for rivers and streams are often absent, and these are sorely needed. It is important to facilitate development of measurement technologies that can be used to acquire standardized datasets worldwide, targeting long-term, continuous, large-scale data that can be measured simply and at low cost.

GHG production in aquatic systems is fuelled by inputs from the watershed (Li et al. 2021). Land use, pollution, human activities, hydrological regime, changing climate, etc., can influence the emissions of wetlands, freshwater lakes, streams, and rivers, and estuarine, coastal, and marine systems. Effective emission reduction strategies entail coordinated approaches for land management, restricting nutrient loading, maintaining and improving ecohydrological connections (see, e.g., landscape approaches detailed in Chapter 9). Watershed-scale soil erosion control and nutrient reductions may help reduce GHG emission from lakes and reservoirs. Additional measures that can contribute to GHG emission reduction include connecting rivers to floodplains, limiting channel alterations, and improved context-specific monitoring systems. There also need to be financing mechanisms and tools in place to monitor and reduce emissions from freshwater systems and blue carbon ecosystem management at the local, regional, and national levels. Capacity-building and other forms of support, including better data on aquatic environments, may be needed to materialize implementation.

8.4.2 Invest in Nature-based Solutions and healthy ecosystems

Human activities in agriculture, forestry, and other land use (AFOLU) account for 22 per cent of the net anthropogenic GHG emissions (Shukla et al. 2019). In addition, so-called negative emissions (net CO_2 removals) from ecosystems are part of all IPCC scenarios that limit global warming to +1.5°C (IPCC 2018). Over 90 per cent of AFOLU emissions result from agricultural practices, where IPCC has estimated a mitigation potential of 4.1 $GtCO_2$-eq yr^{-1} through measures taken across the sector over the next three decades (IPCC 2022). Beyond reducing emissions from agriculture, the capacity of ecosystems to absorb and store carbon is an essential component in those scenarios. Expanded and improved management of protected areas is critical moving forward. IPCC (2022) evaluated that 30–50 per cent of the planet's land, freshwater, and marine areas must be protected to sustain biodiversity and needed ecosystem services. This is significantly more than exists currently, where only 15 per cent of land, 21 per cent of freshwater, and 8 per cent of marine areas are in protected zones. IPCC (2022) assessed measures involving the protection, management, and restoration of forests, peatlands, coastal wetlands, savannas, grasslands, and other natural ecosystems to reduce emissions and/or sequester 7.3 $GtCO_2$-eq yr^{-1}, which represents the greatest climate mitigation potential in the AFOLU sector.

The ability of land-based ecosystems to adapt to a changing climate is defined by the availability and variability of freshwater (Boltz et al. 2019). The mitigation potential of ecosystems and NbS is limited in terms of adapting to increased global warming, in that mitigation potential will gradually be reduced with increased global warming. There is evidence that hydrological changes are already pushing some ecosystems and ecological processes towards irreversibility, such as retreating glaciers or tropical forests shifting into savannas. Also, it is important to note that ecosystem carbon sinks and storage only can be a complement to carbon reduction efforts in other sectors, such as in transport and industries.

Chapters 5 and 6 of this report showcased how healthy ecosystems – and thus a healthy water cycle – contribute to enhancing climate change mitigation potential by sequestering carbon below and above ground, while also safeguarding freshwater resources, protecting biodiversity, and ensuring sustainable and resilient livelihoods. Managing ecosystems to protect carbon stocks in biomass and soil can have immediate climate mitigation benefits but the stored carbon is vulnerable to drought and increased temperatures (Seidl et al. 2017; Bastin et al. 2019). In addition, ecosystem management interventions need to be put in a local context to be effective as the outcomes are dependent on, for example, elevation and topography, species composition, climatic zone, and level of degradation.

Further, this report examined the role of freshwater linked to measures in terrestrial and freshwater ecosystems, including wetlands, lakes, and rivers as well as freshwater-dependent coastal and marine systems (Chapter 5), forests and agricultural systems (Chapter 6). It shows how NbS for climate mitigation involve measures of protecting, restoring, and better managing the natural capacity of ecosystems to absorb and store atmospheric carbon, and how healthy water cycles are necessary to achieve full mitigation potential and ensure that the stored carbon is not released into the atmosphere.

1. Action: Invest to protect, restore, and maintain wetlands, peatland, and forests

Conserving wetlands, peatlands, and all blue carbon ecosystems is critical to avoid drainage and other anthropogenic pressures creating net sources of GHGs. With more than 75 per cent of Earth's land areas being substantially degraded (Kotiaho et al. 2018), it is essential to restore ecosystem functions and services for climate change mitigation. Freshwater and healthy water cycles are necessary for the ability of ecosystems to provide services, including carbon storage and sequestration in vegetation and soils. Healthy and well-managed ecosystems are key. For instance, wetlands store more than 30 per cent of the estimated global carbon emissions (Nahlik and Fennessy 2016) on about 7 per cent of the world's surface (Ramsar Convention on Wetlands 2018; Mitsch and Gosselink 2015), and peatlands, despite covering only 3 per cent of the global land surface, can store about 21 per cent of the global total soil organic carbon stock (IPCC 2022).

Investigating how polluted and altered water bodies lead to more GHG emissions is critical to understand how different rivers across the world contribute to GHG emissions, and how these can be mitigated. Rivers that drain watersheds in forested, urban, and agricultural landscapes result in different riverine dissolved GHG concentrations and fluxes, depending on the level of ecosystem degradation in the catchment area. Nutrient pollution makes most rivers in the world supersaturated with GHG. Still, very few studies have assessed concentrations of the three GHGs (CO_2, methane, and nitrous oxide) together in a river system and there is no consistent evidence showing the roles of specific river types in contributing GHG emissions. GHG emission assessments need to incorporate multi-year monitoring designs to account for temporal variability in environmental conditions that affect GHG fluxes. Fluctuating surface-groundwater tables in reservoirs, lakes, peatlands, and other lentic waters is another particular source of GHG emission that needs to be managed efficiently to reduce risks to climate change mitigation. For instance, reservoirs created by dams, with fluctuating water tables and a high occurrence of organic material, produce considerably more methane

The extensive peatlands of West Papua, Indonesia. Land clearance in peatland areas is now prohibited in Indonesia and there are ongoing projects to restore degraded peatlands across Papua. Source: Shutterstock.

than natural lakes or other surface waters. Worryingly, methane emissions and global warming reinforce each other in a vicious cycle. Higher water temperatures favour methane emissions (Zhu et al. 2020) and limitations in hydroxyl radicals in the atmosphere (caused by, e.g., wildfires) extend the lifetime of methane in the atmosphere (Cheng and Redfern 2022). Managing methane emissions from water bodies will be of utmost importance given that methane is at least 28 times more potent than CO_2, and given the feedback mechanisms that allow atmospheric methane concentration to rise synergistically with climate change. The depth, age of the reservoirs, temperature, pH, and availability of nutrients in these waters and their catchments influence GHG emissions. Integrated watershed-scale policies must be adopted for effective and sustainable emission reduction strategies, taking into account inputs from the ecosystems surrounding the watershed by entailing integrated approaches for land management, restricting nutrient loading, and maintaining and improving ecohydrological connections.

Halting deforestation and ecosystem degradation to reduce GHG emissions and help preserve water cycle dynamics is of key importance for regulation of the Earth's energy, water, carbon, and nutrient cycle dynamics. In addition, it is of high importance to invest in conservation and management of large carbon sinks in forests and agricultural soils. Restoration can also accelerate the recovery of degraded land areas, supporting or reinstating ecological processes, recovering forest structure and biodiversity (Elliott et al. 2013). However, the mitigation benefits from restoration are dependent on several factors, such as the initial level of degradation, the applied restoration methods, and the time required for recovery to take place (Mackey et al. 2020).

It is critical to address the drivers that pose limitations to conserving ecosystems in climate mitigation and development planning. Managers are often faced with challenging trade-offs to implement ecosystem protection and conservation, due to constraints in tackling the drivers of degradation, such as great demand for agricultural land, urbanization, aquaculture, and coastal development (Epple et al. 2016). Land degradation is a major contributing factor to climate change, and at the same time, climate change can exacerbate the impacts of land degradation, as some drivers of degradation, such as soil erosion, increased risk of forest fires, and increased expansion of invasive species, will be exacerbated by climate change (Kotiaho et al. 2018). These challenges can be overcome by bolstering monitoring, and reliable data evaluation and management. However, many countries still lack a holistic inventory of peatlands and wetlands, which means that degradation of these systems and the resulting GHG emissions may be missed, and that there is no incentive to prevent such degradation.

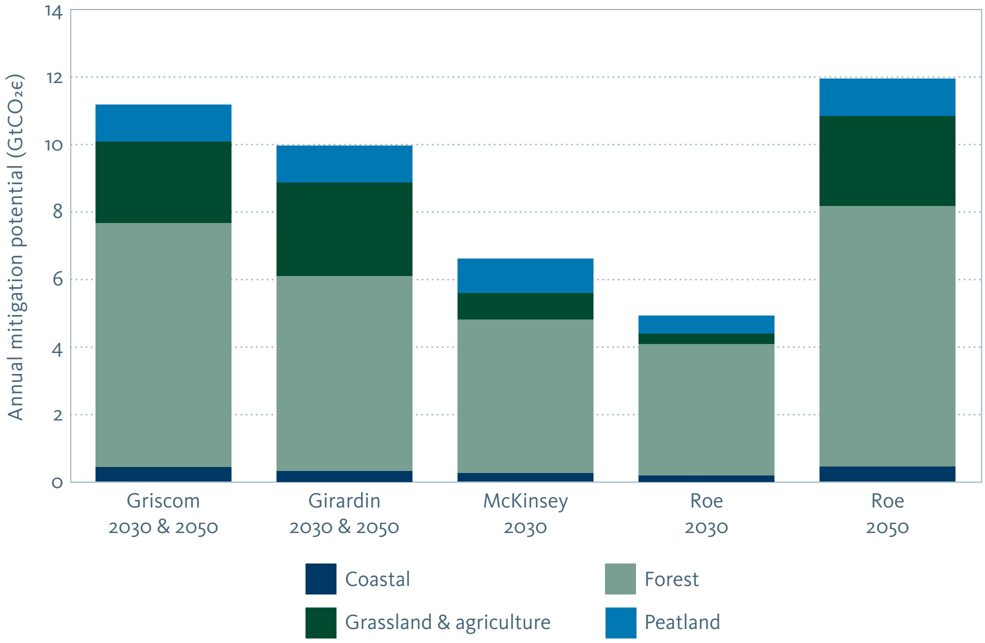

Figure 8.4. Global mitigation potential in different ecosystems. Mitigation measures in forests should be given top priority in limiting global warming, according to key studies mapping global mitigation potential in terrestrial ecosystems. (UNEP and IUCN 2021). Nature-based Solutions for climate change mitigation. Nature-based Solutions for climate change mitigation. Nairobi and Gland. https://reliefweb.int/sites/reliefweb.int/files/resources/NBSCCM.pdf

2. Action: Produce investment cases that go beyond carbon sequestration

Design NbS for mitigation, such as watershed-scale management, with the full set of ecosystem services in mind. Compared to alternative grey infrastructure development, NbS are generally found to be cost-effective while also providing co-benefits by supporting different ecosystem services (EC 2021). Still, they often require consideration of the full range of benefits provided for the return on investment to be fully appreciated (Cassin and Matthews 2021; Le Coent et al. 2021), including climate adaptation, ecosystem resilience, sustainable water management, conservation and enhancement of biodiversity, improvements in air quality, urban regeneration, and improvements in public health and well-being (Liu et al. 2021; Sturiale and Scuderi 2019).

Account for the multiple co-benefits provided by aquatic and water-dependent terrestrial ecosystems in addition to carbon sequestration, particularly in peatlands and coastal wetlands. This can include benefits for human well-being, ecosystem health, and climate resilience, such as flood and disaster risk reduction, biodiversity recovery, agricultural production, sustainable community livelihoods, water quality improvement, etc. (Raymond et al. 2017; UN Water 2018). For instance, watershed-scale aquatic system management can provide stronger cases for investment by contributions to emission reduction targets in the NDCs with multiple areas of additional value provided (Mayor et al. 2021). In addition, it is fundamental for a cost–benefit analysis to establish baseline data by ensuring the participation of stakeholders that know their environment (Le Coent et al. 2021). Although multiple co-benefits are generally provided by freshwater nature-based mitigation measures, there can be trade-offs to be considered (see Chapters 5 and 6).

8.4.3 Navigate water-wise energy pathways

Roughly 70 per cent of the water used by the energy sector goes to production of fossil fuels and thermal power generation plants (IEA 2018). Total water withdrawals and consumption for energy must be brought down from current levels to reach SDG targets with available resources. Demand and pressure on water sources could vary dramatically depending on the future energy mix and its water management. There are pathways to shift to low-emission energy that also require less water than fossil fuels and are more resilient to potential changes in the availability of water caused by climate change or increased demand from other sectors. It is important that such pathways are identified through investment and actions from governments.

1. Action: Accelerate solar and wind power where feasible

Wind and solar photovoltaic (PV) power are critically important components of the energy mix to lower pressure on freshwater ecosystems. They are fast-growing energy options that potentially have lower requirements for, and impacts on, water sources than alternatives (Lohrmann et al. 2019; Jin et al. 2019). In several scenarios designed to meet the Paris climate targets, expansion of solar and wind power and efficiency improvements will account for meeting as much as 50 per cent of energy demand by 2050 (IEA 2021; Rogelj et al. 2018; IRENA 2020). If these are not reached, there is likely to be greater demand and pressure placed on water resources from all other alternatives. Expansion of solar PV and wind power will also increase requirements for magnets, electricity storage, and batteries, as well as green hydrogen to replace and reduce requirements for fossil fuels. The corresponding increase in mining for minerals and rare earths could be both a limitation for their production, and have significant environmental impacts that need to be considered and mitigated (Elshkaki 2021).

Green hydrogen production through water electrolysis requires water to produce fuels in addition to the water required to generate the electricity to perform the electrolysis. Access and proximity to water is a fundamental requirement for green hydrogen, meaning that conversion of solar PV or wind power to hydrogen cells must be located near water sources. This could be a potential limitation on viable locations for green hydrogen production.

2. Action: Mainstream water risk assessment for energy development plans

Water must be integrated across all aspects of energy planning and development. This must be done while the transformation to clean and renewable energies is accelerated. An analysis of projected demands, availability, and impacts on water is needed to assess the feasibility of energy plans and best options at local, national, regional, and global levels. The analysis also must consider trade-offs with water demands from other sectors (e.g., agriculture) and ecosystem needs, as well as potential risks to water availability caused by climate change. Renewable energy generation that requires the operation of thermal power plants (geothermal, solar, nuclear) is highly dependent on water. This must be monitored, analysed, and managed to ensure sustainable access and limited impacts on water.

Wind and solar farm at Bac Phong, Ninh Thuan Province, Vietnam. Source: Shutterstock.

Consideration of potential impacts and constraints of water sources is especially critical in terms of the type and amount of bioenergy and hydropower that can be involved in mitigation strategies. Climate mitigation contributions from large-scale biomass production may partly fail due to water limitations, or their implementation may adversely affect water availability. It is imperative that the implications of their water and land use are considered first. This can seek to establish the maximum negative emission potential achievable with sustainable water management on both biomass plantations and agricultural areas that ensures the health of aquatic ecosystems. This can enable available water to be used more effectively, boost biomass production, and create synergies across multiple SDGs, such as food, water, and climate security (Jägermeyr et al. 2017). Stenzel (2021) highlights that substantial reductions in water withdrawals could be achieved if fewer plantations were irrigated and the carbon conversion efficiency was improved, thus enabling more production and sequestration with lower impacts on water. Effective planning, design, and management of hydropower is essential. Emissions from hydropower facilities with poor siting, design, and management can be significant (Ocko and Hamburg 2019). Evaluation should be made in advance of investment to ensure that the environmental and social costs do not outweigh potential benefits gained through the energy generated.

8.4.4 Accelerate transition to circular production and sustainable lifestyles

Efforts and investments to reduce demand for, and increase efficient use of, water, land, energy, and food resources can lead to decreased emissions, relieve pressure on ecosystems, and promote sustainable development (Rogelj et al. 2018). Two key areas to achieve this are continued innovations and improvements in circular production and solid waste management, and the promotion of sustainable lifestyles.

1. Action: Advance circular solutions in industry and waste management

Measures to reduce emissions in industrial processes and solid waste management generally provide water-related co-benefits.[1] Circular or more efficient industrial production can and should usually lower both water demand and pollution loads discharged into water bodies. Increased efficiency, safe reuse, and lower demand for water all contribute to less energy used to move and treat water, which in turn lowers emissions created by that energy use (Ramos et al. 2010). Circular water and sanitation systems that recover energy and heat from wastewater and excreta further decrease demands for external energy sources (Andersson et al. 2019). Improvements to solid waste management, with increased recycling and less landfilling and litter, provide local water benefits by lowering pollution as well as global benefits by lowering resource demands required across the lifecycle of production of the product. Reducing production of new plastic lowers emissions and pollution of water bodies and oceans. Decreased use and increased recycling of plastic reduces emissions and pollution that enter soil, freshwater, coastal, and ocean systems.

2. Action: Promote sustainable lifestyles and behaviour change

Sustainable lifestyles, including choices for housing, transportation, and food and material consumption, should be promoted to limit emissions, pollution, and resource waste. This must complement and cannot replace larger policy decisions and investments to transform our energy and agricultural systems and protect the capacity of ecosystems to mitigate emissions. Reduced demand from consumers and increased reuse of products lead to less emissions and pollution generated through industrial production, while also decreasing requirements for water for those same items being produced. There is large mitigation potential in dietary shifts to more carbon-smart and water-wise diets and in reduced food waste and loss (see Chapter 6). IPCC (2022) estimated potential reductions of 2–4 $GtCO_2E$ per year by 2030 through uptake of more sustainable diets and reduction of food losses and waste. Diets with lower portions of meat and reduced overeating particularly in the Global North and emerging economies, can result in lower emissions and water consumption required for agricultural production (Willett et al. 2019; Poore and Nemecek 2018). Behaviour changes to reduce waste are also critical as huge volumes of food are lost or wasted. Estimates from FAO (2011) noted that as much as one-third of

1. One potential exception is using carbon capture storage for industry to offset emissions, which may have implications that increase water resource demand (see Chapter 7 and section 7.3.2 on BECCS).

Bales of discarded clothing at an industrial textile recycling plant. Source: Shutterstock.

food grown that is fit for human consumption is never eaten and WWF (2021) claimed in a more recent calculation that it may be as much as 40 per cent. The US Environmental Protection Agency estimates that annual production of food that is lost and wasted in the US alone utilizes an equivalent of 560,000 km² of agricultural land, 22 trillion litres of water, more than 6 million kg of fertilizer, and results in 170 million tonnes of CO_2E (EPA 2021). These figures are further amplified when the waste goes to landfill or is incinerated. Beyond food, large energy, water, pollution, and carbon footprints result across the lifecycle production of crops, goods, clothes, and all products that are wasted. The fashion sector, for example, creates 20 per cent of global wastewater and 1.2 billion tonnes of CO_2E in emissions (Chen et al. 2021), while more than 90 million tonnes of textiles are disposed annually worldwide (Kerr and Landry 2017). At the same time, increased access to nutrition, energy, and materials are needed for billions of people globally. Net-zero transitions and sustainable development globally will require nations in the Global North to consume and waste less, and developing nations are able to avoid, to the extent possible, historical trends where economic growth is followed by more resource-intensive lifestyles. Individual, government, corporate, and civil society actions are all needed to promote health and well-being and reduced material consumption to ensure future water and climate security.

8.5 Conclusions

This chapter presented key opportunities to effectively mitigate emissions through measures taken in water and sanitation services, the protection, restoration, and management of terrestrial and aquatic ecosystems (forests, river systems, wetlands), and renewable energy transition. Essential areas were identified for investment and action to enable benefits for both water and climate mitigation critical for sustainable development in the coming decades. Key water risks were highlighted that must be evaluated in low-emission energy development, particularly in the planning of bioenergy, hydropower, and other sources such as thermoelectric plants used in nuclear and concentrated solar power. The chapter also provided insights to where ecosystem degradation can create risks to reduce sequestration potential of freshwater- and land-based mitigation measures or lead to emissions of GHG.

To ensure a resilient, robust, flexible, and water-wise transition, four key leverage points should be integrated as foundational pillars to climate mitigation planning:

1. **Sustainable, low-carbon water management and sanitation services should be considered as part of plans to achieve emission reductions.** This could

include development of watershed-scale emission reduction strategies and upscaling of substantial opportunities to reduce emissions and recover energy in water and sanitation services, building on existing technologies and project know-how. This is also a first step to address gaps to mainstream water into mitigation financing and policies.

2. **Investment in NbS and healthy ecosystems to store carbon and prevent disastrous release of GHG that follows ecosystem degradation.** This requires efforts to protect, restore, and sustainably manage aquatic and terrestrial ecosystems such as wetlands, peatland, and forests, and to ensure healthy water cycles necessary for these ecosystems' ability to provide these services. Political action is needed to address the core drivers of ecosystem degradation in agricultural, urban, and coastal development. Expanded science can facilitate these investments and actions. More systematic analysis is needed to comprehensively quantify how changes in the water cycles and in water availability affect the carbon sequestration capacity of ecosystems worldwide. Improved inventories of all freshwater systems – peatlands, wetlands, rivers, and streams – would enable countries to invest in their ability to sequester emissions. Much more attention to emissions and sequestration from rivers and streams is particularly important as relevant data are commonly missing and can result in a failure to connect pollution of water bodies with their implications on the climate. Investment cases for NbS must then be made that include benefits beyond sequestration.

3. **The transition to low-emission or renewable energy needs to be accelerated and be water-wise.** Different pathways for the energy transition can either have potential to reduce pressure on water sources or dramatically increase water demand. Chapter 7 recommended key considerations for sustainable and resilient water, energy, and climate planning. First, to accelerate relatively low-water-demand energy options, such as solar PV and wind power, where feasible. Mainstreaming and continually improving water risk assessment for renewable or low-emission energy development plans is also essential, particularly to ensure the sustainability of bioenergy, hydropower, and thermal power generation development. Failure to lower emissions rapidly will require exponential increases in carbon sequestration. An overreliance on BECCS, as projected in scenarios where there is failure to rapidly curtail emissions, can lead to untenable requirements for water (Stenzel et al. 2021).

4. The final lever for water, climate, and development will be **making advances in circular economy, production, and sustainable lifestyles.** This can present win-wins for people, economy, and nature. It reduces emissions and pressure on water by lowering demands for freshwater from the production of food and goods.

To mitigate the risks and utilize the opportunities identified in this chapter requires immediate action and systematic approaches. Systems-thinking facilitates design of solutions to complex environmental problems through a deeper understanding of the natural and social systems in which the problem and solutions are embedded. The next chapter will turn to how water-wise climate mitigation, where risks are mitigated and opportunities are leveraged, can be achieved through integrated approaches.

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