UN-Water Analytical Brief on Water for Climate Mitigation

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About UN-Water

UN-Water coordinates the United Nations' work on water and sanitation. There is no single United Nations Agency, Fund or Programme dedicated exclusively to water issues. In fact, over 30 United Nations organizations carry out water and sanitation programmes because these issues run through all of the United Nations' main focus areas. UN-Water is a 'coordination mechanism'. It is comprised of United Nations entities (Members) and international organizations (Partners) working on water and sanitation issues.

The UN-Water Expert Group on Water and Climate Change supports cooperation and coordination of UN-Water Members and Partners on water and climate change-related issues. The overarching focus is to support UN Member States to sustainably manage water in the climate change context by informing policy processes and addressing emerging issues, supporting monitoring and reporting, as well as building knowledge and inspiring people to take action.

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Contents

Summary

This report discusses the dependency of climate mitigation on the use of water and the effective management of water resources and of water and sanitation services. ‘Water’ in this report means terrestrial inland water (which may be surface water or groundwater) and for some uses could be desalinated seawater.

Water is an enabler of climate mitigation

Water is necessary for many key climate mitigation measures, including for the clean energy transition and the natural and artificial removal of carbon dioxide from the atmosphere.

Understanding water availability and constraints should assist in deciding on climate mitigation options and guide the design of climate mitigation projects.

Carbon dioxide (CO_2) is the most important anthropogenic greenhouse gas, followed by methane (CH_4) and nitrous oxide (N_2O). CO_2 is particularly difficult to mitigate due to the strong current dependence of energy systems on fossil fuels. Many clean energy transition measures require substantial volumes of water. Nature-based carbon direct removal (CDR) actions (such as tree-planting, peatland restoration and improving soils) also rely on water.

Water bodies and water, wastewater and sanitation services can also be sources of greenhouse gases. Their emissions can be reduced through improved management of water and sanitation services, providing multiple social, economic and environmental benefits which can add value to any climate finance contribution.

Climate mitigation success requires effective water management

Different clean energy and CDR measures have very different water requirements (see Annex 2) that may affect decisions on whether, how and where projects are implemented.

Implementation of many mitigation measures required to limit global warming to 1.5 or 2 degrees Celsius will affect demand for water and its availability for other purposes and in different places. For example, the phasing out of fossil fuels will reduce water demand by thermal coal power plants, enabling water in their locations to be redeployed to support other objectives. However, many alternative low emission energy sources will increase water demand and will need assured water supply in their locations for their successful implementation.

Water availability may influence which climate mitigation measures to implement, how and where, and inform decisions on how to secure and sustain the necessary water supply. Extensive consultation and coordination can be required on climate mitigation actions which add to water demand or affect water flows or availability for other uses, including in neighbouring countries. Water availability is therefore a necessary consideration in strategic planning for future climate mitigation actions, requiring information on water availability, use and trends.

Identifying and reducing water-related risks by applying integrated water resources management (IWRM) and sustainable wastewater management approaches should facilitate financing while contributing to successful climate mitigation and limiting further global warming.

Ideally, planning and implementation of nationally determined contributions (NDCs) will be closely aligned with planning and implementation of Sustainable Development Goal (SDG) 6 with its water and sanitation targets.

Climate mitigation actions involving trade-offs with other water uses will require substantial consultation and engagement, particularly in cross border systems. Regional and transboundary cooperation can help with optimizing the use of water resources for many kinds of climate action.

Balancing the multiple uses of water, especially with more extreme hydrological events as the result of climate change, is also vital for adaptation to climate change.

Ways forward

Aligning climate mitigation and water objectives requires that water availability and usage is considered in all climate strategic planning, particularly in the preparation of NDCs, and that climate change is considered in all water, sanitation and hygiene strategic planning, including for shared transboundary water resources.

Governments can be supported in this work through multilateral processes by authorizing the role of water in climate mitigation to be a subject of future climate discussions and agreements and supported by UN Framework Convention on Climate Change (UNFCCC) work programmes, as they have done with regard to adaptation through the Global Goal on Adaptation.

Members of the Intergovernmental Panel on Climate Change (IPCC) can also assess any new research on water and climate interdependencies in the current IPCC work programme.

Local authorities and sub-national governments can also be encouraged and assisted to ensure the water requirements of any mitigation actions they are planning are fully considered and incorporated into project plans.

Investing in water, wastewater and sanitation actions that deliver greenhouse gas emission reductions can deliver other highly valued social, economic and environmental benefits, including food security and health benefits. The climate mitigation benefits may justify higher climate financing prioritization. Private sector and other non-government entities can also help find solutions as the result of new climate disclosure requirements for reporting on water-related risks. There are also major cross-sectoral multistakeholder bodies with highly relevant programmes.

It would be useful for strategic planning if more information was available on the carbon and water relationships of different wetland types in different environmental settings. Estimates for the restoration of freshwater wetlands are difficult to undertake at the global scale. Further research is required globally and at a local level (IUCA, 2024).

Policymakers would also benefit from more information on the water needed for different clean energy technologies and how this may be provided in a way that does not compete with other freshwater users. If requested by countries or intergovernmental processes, global scale research providers may be willing to do further work in this area. The IPCC would be able to assess any new science on these matters in its next reports.

Support is available

Many global and regional organizations can support country-wide planning for the climate mitigation options and IWRM and sustainable wastewater management necessary for securing the water requirements of mitigation actions. This includes UN system-wide support to developing countries for the preparation of their next NDCs.

Now is the time

As countries review and update their NDCs, now is the time to understand how action on water and sanitation can contribute to climate solutions.

CHAPTER 1

Introduction

Many climate mitigation measures use water

The Intergovernmental Panel on Climate Change (IPCC) has assessed that to hold global warming to 1.5 or 2 degrees Celsius requires limiting the concentration of greenhouse gases in the atmosphere by reducing the emissions of carbon dioxide and other greenhouse gases such as methane and nitrous oxide and/or by increasing the sinks of these gases through for example carbon dioxide removal (CDR) from the atmosphere. Actions to achieve this are grouped by IPCC into 'climate mitigation measures'. A tabulation of all measures assessed by IPCC is in Annex 1 (IPCC, 2023).

Water is a necessary input to many of the clean energy measures for transitioning away from fossil fuel-based energy and for carbon dioxide removal from the atmosphere. These measures need sufficient water supply to achieve climate mitigation and other benefits required from them.

Effective water and wastewater management can also contribute directly towards emission reduction targets as poorly managed wastewater and sanitation systems, and some wetlands, reservoirs and irrigation systems, are sources of emissions of greenhouse gases, especially methane and nitrous oxide.

The International Universities Climate Alliance (IUCA) in partnership with the UN-Water Expert Group on Water and Climate Change has estimated the water requirements of a number of the climate mitigation measures assessed by the IPCC as tabulated in Annex 2 (IUCA, 2024). This work also estimated the relative 'water efficiency' of various mitigation actions. For example, for every billion litres of water used to enable clean energy to substitute for fossil-fuel based energy, green hydrogen production is estimated to save around 68.4 gigatonnes of carbon dioxide equivalent emissions, second-generation liquid biofuels around 2 gigatonnes, and electrification of light duty vehicles around 1.7 gigatonnes. IUCA estimates every billion litres of water directed at maintaining or restoring the water tables of peatlands would sequester around 18.5 gigatonnes of emissions.

The IUCA estimates are based on stated assumptions about production methods and other key factors affecting each calculation. The estimates do not account for water quality differences, such as hydrogen production requiring pure water for electrolysis whereas thermal systems are generally able to use any available water. References in this report to IUCA estimates are subject to these assumptions and other caveats in IUCA, 2024.

This report is structured to reference those IPCC listed measures (Annex 1) on which there are findings in IUCA, 2024, as follows:

- **Chapter 2: Water for the clean energy transition.** Measures in IPCC's 'energy supply' and transport-related 'settlements and infrastructure' categories.
- **Chapter 3: Water for carbon dioxide removal.** Measures in IPCC's 'land, water and food' category.
- **Chapter 4: Reducing greenhouse gas emissions from water and sanitation systems.** Measures in IPCC's 'land, water and food' and wastewater-related 'industry and waste' categories.

This report seeks to discuss the implications of the relevant IPCC assessments, IUCA estimates and information in other sources.

Water and sustainable development

The IPCC has advised that the sustainable development framework can be used to evaluate the long-term implications of climate mitigation actions on sustainable development and vice versa, and that the feasibility of implementing different sectoral mitigation options depends on how societies prioritize mitigation actions relative to other products and services (IPCC, 2022b).

The 17 Sustainable Development Goals (SDGs) to be achieved by 2030 include to "ensure the availability and sustainable management of water and sanitation for all" (SDG 6) and "urgent action to combat climate change and its impacts" (SDG 13). Most other SDGs are also water-dependent, including: to "end hunger, achieving food security and improving nutrition and promote sustainable agriculture" (SDG 2), to "ensure access to affordable, reliable, sustainable and modern energy for all" (SDG 7) and to "protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss" (SDG 15).

While progress in achieving the SDGs differs greatly between regions and countries, and within countries, current global data show none of the SDG 6 targets being achievable globally: 2.2 billion people lack safely managed drinking water; roughly half of the world's population experiences severe water scarcity for at least part of the year; and 3.5 billion people lack safely managed sanitation. Indeed, less progress is being made on SDG 6 than on any of the other SDGs (UNSDG, 2024).

Climate change, population growth and increasing water scarcity will also put pressure on food supply as most water used, about 70 per cent on average, is for agriculture, and it takes between 2,000 and 5,000 litres of water to produce a person's daily food[1]. Water stress also affects the multiple other uses of watercourses (such as energy, navigation and industry) and ecosystems.

Understanding the co-benefits and trade-offs associated with climate mitigation actions is key to understanding how societies prioritize the various sectoral policy options. The IPCC has assessed potential trade-offs, where achieving climate benefits may negatively affect other desired outcomes such as food security, biodiversity, energy affordability and access, and mineral-resource extraction, and co-benefits where achieving climate benefits may also benefit health, access to clean energy and water availability (IPCC, 2022b).

Changing water cycle

Climate change is making extreme weather events such as floods and droughts more likely and more severe worldwide by intensifying the global water cycle, including its variability, global monsoon precipitation, droughts and floods (IPCC, 2022c).

The IPCC has projected reduced extents and/or volumes of almost all frozen water as the result of climate change. Worldwide many glaciers are expected to disappear by 2100 regardless of the emission scenario, especially in regions with smaller glaciers (IPCC, 2022c). Globally, since 1990, the number and size of glacial lakes has grown rapidly along with downstream population. Glacial lake outburst floods (GLOFs) represent a major hazard and can result in significant loss of life (Taylor et al., 2023).

The volume of freshwater storage is in decline, and globally, the storage gap – the difference between the amount of freshwater storage needed and the amount of operational storage (natural and built) that exists for a given time and place – is growing (GWP and IWMI, 2021). Over the past 20 years, all terrestrial freshwater storage – including soil moisture, snow and ice – has dropped at a rate of 1 centimetre per year, with major ramifications for water security (WMO, 2021).

Water quality and hence its availability for other uses is also affected by climate change, as higher water temperatures and more frequent floods and droughts are projected to exacerbate many forms of water pollution – from sediments to pathogens and pesticides (IPCC, 2008).

These global-scale trends are likely to be adding to water supply risk in many places, making it increasingly necessary to plan, regulate and invest as required to secure sufficient water to meet future water use priorities, including for the clean energy transition and other climate mitigation strategies. The same national strategies that allow other imperative water needs to be met in periods of water stress will need to be adapted and applied to climate mitigation actions.

Uneven distribution of effects

The effects of global warming on the water cycle are highly variable between regions, with different vulnerability to flood, drought and storms (IPCC, 2022b at Figure 2.3).

The impacts of climate change will affect persons living in vulnerable situations owing to factors such as geography, poverty, gender, age, indigenous or minority status and disability. These existing inequalities tend to be exacerbated by extreme weather events, such as droughts and floods, the increasing scarcity of safe drinking water and the destruction of water and sanitation infrastructure[2].

1. FAO Knowledge Repository: https://openknowledge.fao.org/home
2. For more information on groups in situations of vulnerability, see https://www.ohchr.org/en/climate-change/impact-climate-change-rights-people-vulnerable-situations, and part 2 of a special thematic report of the UN Special Rapporteur on the human rights to safe drinking water and sanitation, "The impacts of climate change on the human rights to safe drinking water and sanitation of groups and populations in situations of vulnerability", available at https://www.ohchr.org/sites/default/files/2022-01/climate-change-2.docx

IPCC has assessed that between 2010 and 2020, human mortality from floods, droughts and storms was 15 times higher in highly vulnerable regions compared to regions with very low vulnerability, with the largest adverse impacts observed in Africa, Asia, Central and South America, Least Developed Countries, Small Islands and the Arctic, and globally for Indigenous Peoples, small-scale food producers and low-income households (IPCC, 2022c).

Data from the World Resources Institute's *Aqueduct Water Risk Atlas*[3] shows that one-quarter of the world population, living in 25 countries, face extremely high water stress each year, regularly using up almost their entire available water supply, and at least 50 per cent of the world's population live under highly water-stressed conditions for at least one month of the year. The most water-stressed region is the Middle East and North Africa.

Environmental and health impacts of flooding in sanitation systems is particularly high for low socio-economic groups due to poor infrastructure, high exposure and low capacity (Willets et al., 2023).

Regional and national differences in all these water-related impacts of anthropogenic climate change need to be considered in global policy agendas and in climate mitigation planning at all levels.

Water management and infrastructure constraints

Ensuring the availability of sufficient water in the right places at the right times for the climate mitigation measures required to stabilize the global climate will require more attention to water management capacity and water storage and distribution infrastructure at all levels, including with cross border systems.

There is much catching up to do. Current levels of water-related investment are also far from sufficient to achieve global water and sanitation targets, with estimates suggesting an increase in annual spending of 167 per cent is needed to achieve the targets on drinking water and sanitation (SDG 6.1 and 6.2). The aggregate global financing requirement for water-related infrastructure has been estimated at US$6.7 trillion by 2030 and US$22.6 trillion by 2050 (World Bank estimates in Khemka et al, 2023). Official development assistance, currently around US$8.5 billion per year (UN, 2024), can only make a small contribution to this investment demand. This financing shortfall suggests it will be necessary for many countries to implement integrated water resources management (IWRM) policies and practices and create the conditions for more water-related investment if they are to successfully implement water-dependent climate mitigation actions.

However, capacity for water management improvement is also very constrained. In the opinion of ministers and other 'national water leaders' surveyed globally in 2021, climate change was seen by most as their greatest risk to achieving good water management, followed by increasing demand and the effects of droughts and floods. However, in more than half of the surveyed countries, six of the eight SDG 6 water targets were considered to be either challenging or impossible. The reasons given for this were mainly about governance and financing (Water Policy Group, 2021).

These survey results should be no surprise as managing competing human demands for water and the imperatives of protecting water sources to enable them to service human needs into the future require a high degree of water management capability in all countries. In the case of water resources that cross national boundaries, cooperative arrangements with neighbouring countries are required. Yet the latest report of progress on the SDG 6 target of implementing IWRM at all levels is that this is only 57 per cent achieved[4]. Similarly, only 56 per cent of transboundary basin areas have an operational arrangement for water cooperation[5].

Mobilizing faster climate action

At the UN Framework Convention on Climate Change (UNFCCC) Conference of the Parties (COP) 28[6], a 'Global Stocktake' of progress was undertaken towards the objectives of the Paris Agreement. They agreed their next nationally determined contributions (NDCs) would have

3. World Resources Institute: Aqueduct: https://www.wri.org/aqueduct
4. UN-Water Integrated Monitoring Initiative for SDG 6: https://www.sdg6data.org/en/indicator/6.5.1
5. UN-Water Integrated Monitoring Initiative for SDG 6: https://www.sdg6data.org/en/indicator/6.5.2
6. COP 28 took place in Dubai, United Arab Emirates, in December 2023. This was also the 5th Conference of the Parties serving as the Meeting of the Parties to the Paris Agreement (CMA 5).

ambitious, economy-wide emission reduction targets, covering all greenhouse gases, sectors and categories[7]. COP 28 also agreed to continue to work towards achieving a 'just transition' through efforts on sustainable development and poverty eradication, and to enhancing adaptation and climate resilience at the national and international level[8].

Confirming this intent, the current and future COP Presidencies (United Arab Emirates, Azerbaijan and Brazil) have declared their intent to coherently address all pillars of climate action required to limit warming to 1.5 degrees, with strengthened targets and implementation frameworks[9].

COP 28 also adopted the Global Goal on Adaptation[10], including a target of "significantly reducing climate-induced water scarcity and enhancing climate resilience to water-related hazards towards a climate-resilient water supply, climate-resilient sanitation and towards access to safe and affordable potable water for all".

Water in nationally determined contributions

Under the Paris Agreement it is up to each country to work out how and how much it will contribute to the global effort to emission reductions through NDCs (Article 3) and how it will adapt to the changing climate through national adaptation plans (NAPS) (Article 7). Further information about NDCs is provided in Annex 3.

UNFCCC parties have agreed their next NDCs will have "ambitious, economy-wide emission reduction targets, covering all greenhouse gases, sectors and categories and aligned with limiting global warming to 1.5°C, as informed by the latest science, in the light of different national circumstances"[11].

UN-Water has recommended that NDCs incorporate risk-based approaches to water provision that align with climate mitigation and adaptation targets and facilitate institutional capacity-building for existing risk-based approaches at the decision-making and project levels (UN-Water, 2019).

However, recent analysis of current NDCs shows little mention of water in national climate mitigation strategies. Only 22 per cent of NDCs include hydropower and 32 per cent include wastewater, with very few raising water requirements for other types of mitigation actions (UNDP-SIWI, 2024).

Despite transboundary water resources constituting over 60 per cent of water resources globally, very few NDCs mention transboundary water management and cooperation (UNECE, 2024).

Preparing and updating NDCs is an opportunity to ensure strategies for securing water supply for planned climate mitigation measures that reduce greenhouse gas emissions, remove carbon dioxide from the atmosphere and sequester carbon are clearly identified.

The United Nations (UN) Secretary-General has announced the UN would commit its full capacity to support countries in the preparation of the next round of more ambitious NDCs and NAPs, agreed to be submitted in 2025[12]. This can be supported by the UN System-wide Strategy for Water and Sanitation, through which UN entities have committed to uniting their efforts and maximizing the collective strength of the UN system to support countries to accelerate progress on water and sanitation.

Access to climate mitigation technologies

The International Covenant on Economic, Social and Cultural Rights[13] states that everyone has the right to enjoy the benefits of science and its applications. In accordance with this Covenant, the Office of the United Nations High Commissioner for Human Rights (OHCHR) advises[14] that to ensure a just, comprehensive and effective international

7. COP 28 UAE, paragraphs 9a and 9d of decision CMA 5, at: https://cop28.com/UAEconsensus and UNFCCC, paragraph 33, at: https://unfccc.int/documents/636584
8. UNFCCC: https://unfccc.int/documents/636589
9. COP 28 UAE: https://www.cop28.com/en/Presidencies-Troika-Letter-To-Parties
10. https://unfccc.int/topics/adaptation-and-resilience/workstreams/gga
11. COP 28 UAE, CMA 5 paragraph 39: https://cop28.com/UAEconsensus
12. United Nations: https://www.un.org/sg/en/content/sg/statement/2024-04-23/secretary-generals-remarks-the-undp-climate-promise-2025-launch-delivered
13. International Covenant on Economic, Social and Cultural Rights Article 15: https://www.ohchr.org/en/instruments-mechanisms/instruments/international-covenant-economic-social-and-cultural-rights

response to climate change, all States should actively support the development and dissemination of new climate mitigation technologies including technologies for sustainable production and consumption. This includes these technologies being accessibly priced, the cost of their development equitably shared, their benefits being fairly distributed between and within countries, and technology transfers between States taking place as needed and appropriate.

OHCHR also advises States should take steps to ensure that global intellectual property regimes do not obstruct the dissemination of mitigation and adaptation technologies while at the same time ensuring that these regimes create appropriate incentives to help meet sustainable development objectives, and that the right of vulnerable and marginalized groups, including Indigenous Peoples, to participate in and to enjoy the benefits of scientific progress and innovations should also be protected.

Water and greenhouse gas quantities in perspective

Water units and quantities

This report generally counts water volume in units of cubic kilometres (km^3). This is one billion cubic metres or one thousand megalitres. For comparison:

- One megalitre of water fills a cube 10 metres wide, high and deep.
- An Olympic size swimming pool holds 2.5 megalitres of water.

Only 2.5 per cent of the Earth's water is non-saline, and of this, only a small fraction is in readily accessible lakes, rivers, shallow aquifers and reservoirs (together, less than 1 per cent) and in aquifers (up to 10 per cent) as renewable water resources[15].

This small proportion of accessible water is due to the fact, that the amount of precipitation falling on land (around 56 per cent or 110,000 km^3 per year) is consumed by evapotranspiration by forests and natural landscapes and 5 per cent by rainfed agriculture. Around 39 per cent (43,000 km^3) is 'accessible' as surface runoff into rivers and lakes) and groundwater from aquifers)[16].

Accessible water is also affected by increasing water demand (due in part to global warming), increasing over-abstraction and resulting aquifer declines. The volume of accessible water is also limited by the costs of accessing, storing, transporting and treating the water, and by high levels of seasonal and inter-annual variability in many water systems.

Total global water withdrawals are estimated at around 10 per cent of this 'accessible' water (4,200 km^3 per year). Around 69 per cent of this is used by agriculture, 19 per cent by industry and 12 per cent by domestic and other municipal uses, not counting water withdrawn through evaporation from reservoirs[17].

Greenhouse gas units and quantities

Greenhouse gases from anthropogenic activities are primarily carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Several other gases make much smaller contributions. IPCC expresses emissions of different gases as 'CO_2-equivalents'[18]. This report uses the usual practice of expressing greenhouse gas emissions as gigatonnes (billion tonnes) of CO_2-equivalent emissions abated per year ($GtCO_2$/year).

Global net anthropogenic greenhouse gas emissions have been estimated to be 59 plus or minus 6.6 $GtCO_2e$ in 2019 (IPCC, 2023) and to have reached 57.4 $GtCO_2e$ in 2022 (UNEP, 2023).

Approximately 60 per cent (~35 $GtCO_2$/year) of these emissions are from energy production and use other industrial activities, and around 40 per cent (25 $GtCO_2$/year) from land use, land-use change and forestry (LULUCF) and other sectors (interpreted from IPCC, 2023).

Land and ocean sinks take up around 56 per cent of CO_2 emissions from human activities (IPCC, 2023).

Climate change mitigation measures reduce and remove anthropogenic greenhouse gas emissions and maintain carbon sinks and stocks.

14. OHCHR: https://www.ohchr.org/sites/default/files/2022-05/KMTechnology-EN.pdf
15. Nature Geoscience: https://www.nature.com/articles/ngeo2590
16. FAO Aquastat: https://www.fao.org/aquastat/en/overview/methodology/water-use
17. FAO Aquastat: https://www.fao.org/aquastat/en/overview/methodology/water-use
18. The CO_2-equivalent is a metric measure used to compare the emissions from various greenhouse gases on the basis of their global warming potential (GWP), by converting amounts of other gases to the equivalent amount of carbon dioxide with the same global warming. The units for emissions are tonnes.

CHAPTER 2

Water for the clean energy transition

Clean energy systems of the future

The International Energy Agency (IEA) has projected that future energy systems are likely to be dependent on electricity and other fuels that are made, stored, distributed and used with no or very low carbon emissions. In the IEA's Net Zero Emissions by 2050 (NZE 2050) Scenario two-thirds of total energy supply is from wind, solar, bioenergy, geothermal and hydro energy, and electricity generation increases two-and-a-half-times. By 2050, almost 90 per cent of electricity generation should come from renewable sources, with wind turbines and solar photovoltaic (PV) technologies together accounting for nearly 70 per cent (IEA, 2021, and IEA, 2023c).

The IPCC has assessed that net zero CO_2 energy systems will entail "a substantial reduction in overall fossil fuel use, minimal use of unabated fossil fuels, and use of carbon capture and storage in the remaining fossil fuel systems; electricity systems that emit no net CO_2; widespread electrification; alternative energy carriers in applications less amenable to electrification; energy conservation and efficiency; and greater integration across the energy system" (IPCC, 2022c).

Water for future energy

The IPCC has assessed there will be increased water demand for some clean energy measures (IPCC, 2022a) and that thermoelectric and hydropower sources are vulnerable to water stress which can affect grid security and energy affordability (IPCC, 2022a).

The IEA advises that water is "essential for almost every aspect of energy supply, from electricity generation to fossil fuel production to biofuels cultivation". IEA estimates the global energy system gross water withdrawals to be around 370 km^3 of water (in 2021), or roughly 10 per cent of total global water withdrawals (IEA, 2023b).
IEA further estimates future water withdrawals to range between around 350 and 400 km^3 by 2030, depending on the pace of retirement of coal fired power generation and future energy efficiency assumptions (IEA, 2023b).
In addition, under its NZE 2050 scenario, IEA estimates water 'consumption' (no longer available for other uses) to increase marginally (~5 km^3) from 2021 to 2030, with diminishing water demand for fossil energy more than offset by higher water demand for bioenergy production (IEA, 2023b).

The UNESCO World Water Assessment Programme (UNESCO WWAP) has also reported on water and energy production, drawing on IEA data on trends to 2021 and estimates to 2030. Annex 2 has the tables from this report estimating water withdrawals and water consumption by four forms of power generation (renewables, fossil fuels, nuclear and biomass/bioenergy) and three fuel types (hydrogen, fossil fuels and biofuels). These show water withdrawals and consumption rising in aggregate to 2030 after falling from 2010 levels due to reduced fossil fuel-based water use (UNESCO WWAP, 2024).

A broader-based study by the IUCA has also estimated the water requirements of some clean energy measures assessed by the IPCC as being required to achieve Paris Agreement climate mitigation objectives. The energy measures assessed were geothermal, pumped storage hydropower associated with solar and wind energy, hydrogen, nuclear, biofuels and batteries for light electric vehicles, with estimates also shown in Annex 2 (IUCA, 2024).

IUCA, 2024, estimates that the global volume of water required for the clean energy measures it assessed is around 900 km^3 annually by 2030, about one third of global irrigation withdrawals. This volume includes the water requirements of some inputs not in the scope of IEA, 2023, particularly critical minerals for batteries used in light electric vehicles. IUCA, 2024, estimates the new water requirements it has assessed will be offset "to some extent" by less water being required from the 'old energy system' and by using sea water and brackish water (IUCA, 2024).

Estimates from these reports are based on different assumptions and baselines and this Brief does not explain or prefer any estimate. However, they all suggest significant water demand for the measures they have reviewed.

Decisions at the national and local level on clean energy choices will need to consider the water supply and demand balance, and how that is changing, at the relevant scale. The above estimates of future global water demand from clean energy measures indicate the materiality of this issue for regional and global processes and may be useful in guiding future global research and policy.

IUCA also estimates the 'water efficiency' of each of the clean energy transition measures it has assessed in terms of emissions 'saved' (assuming substitution for fossil fuel-based energy) for each unit of water consumed (as also shown in Annex 2). Similar estimates at the national and local levels may assist in mitigation technology choices.

There is also a reciprocal relationship between water and energy insofar as the delivery of 'fit for purpose' water to users, and the desalination of seawater, also requires energy (IEA, 2024b).

Dispatchability of future energy

As is the case with water, ensuring that energy is available in the right form, quantities, places, and times to service the complex needs of society at an affordable cost is a most difficult challenge for all governments, requiring complex technologies and management systems.

A critical issue with energy, as with water, is being able to always meet demand, when this greatly fluctuates according to the season and time of day. This makes the dispatchability of energy of critical importance. Dispatchability requires being able to store and deliver energy at the times it is needed.

Electricity from hydropower and thermal systems is produced at variable rates and transmitted to users in real time through transmission lines of sufficient capacity to meet variable demand. Any surplus electricity produced intermittently, such as from solar (daylight only) and wind powered systems can be stored in batteries, pumped storage (closed loop) hydropower systems and in heat retaining materials and delivered from the storage facility on demand. Other fuels can be stored in bulk depots and transported via pipeline and conventional transport modes.

As solar and wind can achieve the lowest marginal cost of the new energy systems yet are of an intermittent nature, they will depend more on energy storage for dispatchability. Where water supply is less reliable and/or where energy is not the highest priority water use, hydropower may be a less reliable source of dispatchable energy, and may need to be combined with batteries or other storage systems, or cross-border trade in stored energy (Mesfin et al., 2016).

Water for future electricity

Future electricity is predicted to be made increasingly from solar (photovoltaic cells), wind powered turbines, water powered turbines (hydroelectricity) and steam powered turbines heated by nuclear fission, geothermal sources, and biofuels (IEA, 2024a). To the extent that electricity from these sources substitutes for fossil fuel-based electricity, actions to achieve this will be climate mitigation measures.

Hydropower

In the case of hydroelectricity, water that passes through the turbines is not 'consumed' however may lose its utility for downstream users and cause environmental harm if the timing, rate and/or temperature of downstream flows is affected. Water is also 'consumed' through evaporation according to the characteristics of the reservoir (Mekonnen, 2012).

While hydropower is susceptible to droughts and climate variability, it also has flexibility to compensate for rapid variations in electricity loads and supplies and assure continuity of energy supply and storage.

Most major hydropower reservoirs provide water storage services for multiple other purposes, such as a more secure water supply for drinking and other household uses and for key industries, watering of public natural assets, irrigation of crops, reducing flood risk, and recreation.

However, hydropower can have social, economic and environmental consequences, such as from new reservoirs' flooding of productive or environmentally important land, and ongoing changed downstream river flows negatively affecting production, lifestyles and the environment. To the extent that retention of these values may be important for effective climate adaptation, there is a risk with hydropower of climate mitigation and adaptation objectives being in conflict. Also, competition for hydropower across country borders can lead to conflict, which could be exacerbated as climate alters rainfall and streamflow (IPCC6, 2022a).

Successful implementation of hydropower projects requires managing the trade-offs required between different users and uses of reservoirs and assessing and optimizing the resultant water and energy costs and benefits. Guidance is available on how these issues may be considered at the planning stage[19].

Power from wastewater

Wastewater is estimated to have the potential to provide electricity to around half a billion people each year and contains about five times more energy than is needed to treat it. This energy can be in the form of heat and from the chemical breakdown of organic matter (UNEP, 2023b).

Solar and wind power dispatchability

In the case of solar and wind power, water will be required for the manufacture of solar panels (mainly for silicon production), plants for concentrating solar-thermal power (CSP) as well as the storage and dispatch of this intermittent energy source, using batteries and pumped storage hydropower.

Lifecycle assessment estimates range up to 2.3 l/kWh for polysilicon panels (UNECE 2022). Based on the clean energy estimate of 6.08e10 GJ from IUCA 2024, this would equate to up to 39 km^3 of water annually.

Much more water is required for the mining and processing of critical earths and other necessary materials and for battery production. Copper and lithium are particularly vulnerable to water stress given their high water requirements, with over 50 per cent of lithium and copper production concentrated in areas with high water stress levels. IEA states: "As climate change causes more frequent droughts and alters water flows, the availability of high-quality water resources will become a crucial factor affecting stable mineral supplies". IEA also discusses the need to manage water quality risks from mining operations (IEA, 2023b).

Production of lithium-ion batteries for use in light vehicles is estimated to require 480 km^3 of water per year globally for a climate benefit of 0.8 $GtCO_2$/year, assuming energy from these batteries substitutes for energy from fossil fuels (IUCA, 2024). While this is the least water-efficient of all the clean energy measures assessed by IUCA (IUCA, 2024), advancements in the process of recycling the mineral content of batteries may reduce water requirements[20]. Further analysis could show how this compares with the water requirements of the production and use of internal combustion engines.

Water consumption for battery production will usually not be located in the country where the emission saving from the use of the electric vehicles will occur. As a result, this water dependency is unlikely to be considered in decisions about future low emission energy choices.

Pumped storage hydropower for the dispatchable supply of solar and wind energy has been estimated to require an additional 5 km^3 of water globally to be impounded each year for a climate benefit of 4.1 $GtCO_2$/year, assuming energy from these systems substitutes for energy from fossil fuels (IUCA, 2024). This does not estimate evaporation losses from the impounded water. Where the water for pumped hydropower is stored in a closed loop, any downstream effects will be limited to multi-use reservoirs where the need to reserve water in the system for pumped storage hydropower may limit other uses.

Geothermal, biomass and nuclear power

For clean energy systems requiring thermal cooling, mostly geothermal, biomass, and nuclear systems, water will be required as a cooling medium in locations where seawater is not available and will also be 'consumed' through any release of steam that is not recovered for re-use in the system.

Inland nuclear power plants may contribute to localized water stress and competition for water uses, with the choice of cooling systems significantly affecting withdrawal rates of water (IPCC, 2022a). Nuclear power plants located on the coast can use seawater for cooling (for example, Barakah in the United Arab Emirates) and inland plants may use treated wastewater (for example, Palo Verde in Arizona, USA)(WNO, 2020).

Concerns about geothermal energy, particularly for large-scale high-temperature geothermal power generation plants, include: water usage (such as from inadequate reinjection into, and overextraction of groundwater; water scarcity; and, seismic risks of drilling) (IPCC, 2022a). Drilling may cause concern for groundwater supply as it may affect the structural integrity of aquifers.

19. San Jose Declaration on Sustainable Hydropower: https://declaration.hydropower.org/
20. RMI: https://rmi.org/wp-content/uploads/dlm_uploads/2024/07/the_battery_mineral_loop_report_July.pdf

While geothermal energy is particularly limited in where it can be produced, it is the most water-efficient of all the mitigation measures assessed (IUCA, 2024). It has been estimated that geothermal and nuclear energy for electricity production would require around 0.5 and 16 km^3 of externally sourced water globally per year respectively for a climate benefit of 0.5 and 0.9 $GtCO_2$/year respectively (IUCA, 2024).

Carbon capture and storage (CCS)

Net zero CO_2 energy systems will need to include use of carbon capture and storage for any remaining fossil fuel systems (IPCC, 2022c). The IEA advises that while CCS deployment has grown substantially in recent years, it remains well below what is required in the Net Zero Emissions Scenario[21].

Plants fitted with CCS require substantial water for cooling and for the carbon capture process (UNESCO WWAP, 2024), making CCS vulnerable to water scarcity. The water footprint of CCS that does not use bioenergy has been estimated at between 0.74 and 2.22 m^3 per tonne of CO_2 depending on the technology used (Rosa et al., 2021). Water use can be managed by choice of technologies and by reusing wastewater (IPCC, 2022a).

For bioenergy with CCS (BECCS) that uses vegetation as feedstock for thermal power, water is required for growing the feedstock and for processing, cooling, treatment and preparation of carbon capture solvents. IPCC states that "large-scale BECCS may push planetary boundaries for freshwater use, exacerbate land-system change, significantly alter biosphere integrity and biogeochemical flows" (IPCC, 2022a).

BECCS projects sequestering 1.6 $GtCO_2$ per year could require around 640 km^3 of water per year globally by 2030 (IUCA, 2024).

Water for future fuels

Hydrogen

Water of the highest purity is required as the feedstock for hydrogen production. Water is also required for cooling. Different hydrogen production technologies have very different water requirements, with the 'green hydrogen' pathway being the most water-efficient (IRENA-Bluerisk, 2023).

The global water requirement for converting water into green hydrogen[22] and cooling is estimated to be around 6 km^3 per year globally, for a climate benefit of around 0.4 $GtCO_2$/year, assuming this substitutes for energy from fossil fuels. (IUCA, 2024)

Biofuels

Water is required to grow the organic materials that are the feedstock for producing biofuels, particularly 'first generation' biofuels from crops such as corn or soybeans[23].

Large-scale bioenergy production requiring more source material from marginal lands may raise conflicts with SDG 6 and other environmental and societal priorities[24]. While the environmental impact of bioenergy production at scale remains uncertain, this will vary by region and application (IPCC, 2022a).

The global water requirement of the biomass feedstock and production of biofuel is estimated to be around 400 km^3 per year globally by 2030, for a climate benefit of around 0.8 $GtCO_2$/year, making this one of the two least 'water-efficient' ways of reducing emissions of the measures assessed by IUCA (IUCA, 2024). This 'water efficiency' may improve over time due to the increasing use of organic waste and forest and wood residues with lower water requirements[25] (IEA, 2023).

21. IEA: https://www.iea.org/energy-system/carbon-capture-utilisation-and-storage
22. Green hydrogen is made by using clean electricity from renewable energy sources, such as solar or wind power, to electrolyze water.
23. 'Second generation' (biomass-based) and 'third generation' (algae-based) biofuels may also require water in their production cycle.
24. Environmental Integrity Project: https://environmentalintegrity.org/news/biofuels-manufacturing-releases-large-amounts-of-hazardous-air-pollutants/
25. Under the IEA's Stated Policies Scenario (STEPS), while bioenergy supply increases by around 85 per cent to 2030, related water consumption grows slower, by 70 per cent.

IPCC also identifies the potential for 'trade-offs' being required between bioenergy and food security objectives, possibly due to the competing demand for land and water (IPCC, 2023).

Biogas can also be produced from wastewater treatment processes which capture carbon dioxide and methane. Solid fuel briquettes produced from faecal sludge can provide an alternative to traditional cooking energy sources (UNEP, 2023b).

Water sensitive planning for clean energy

As governments consider the options for their clean energy transitions and the types of energy systems that will be most suited for their country's circumstances, water availability will need to be assured to enable successful financing, implementation and resiliency.

Different clean energy measures also have different vulnerabilities to water scarcity and other climate change impacts on freshwater availability that may affect decisions on whether, how and where clean energy projects are implemented. The IEA has expressed this risk as: "Different pathways towards a low-emissions future have different implications for water use. Some low-emissions technologies such as biofuels, concentrated solar power, carbon capture or nuclear have high water requirements. Without efforts to reduce water use in these technologies as well as in fossil energy supply, a pathway to lower emissions could exacerbate water stress or be limited by it" (IEA, 2023b).

There have already been many situations where low emissions energy generation (from hydropower and nuclear plants) have been constrained by the lack of water, such as in in France (nuclear, 2003), India (hydropower, 2013-16) and USA (hydropower, 2016) (UNESCO WWAP, 2020 Table 7.2). Environmental thresholds on downstream water temperatures may also limit water releases from these energy sources.

Particularly in conditions of water scarcity, governments may need to prioritize water access for purposes other than energy supply, such as for drinking water and for food production, hence the need to have a resilient energy sector. Understanding these constraints and priorities at the planning stage should assist in decisions on energy options and reduce project risks.

Reducing energy demand and de-commissioning water-intensive, high emissions energy sources such as fossil fuel-based thermal systems may free up enough water to meet the water demand of new clean energy measures.

In water scarce locations, selecting among clean energy options for their water efficiency as well as the climate benefit provided would maximize the climate benefit of every unit of water committed. It may also be cost-effective to use desalinized seawater and to re-use wastewater as a means of meeting energy sector water requirements without detriment to other water users.

Effective planning for water risks to clean energy transition actions requires continuous and good quality hydrological data for modelling and forecasting studies of water flows and storages. Socio-economic data can identify potentially competing uses for the same water so relevant communities and industries can be identified and engaged.

The water requirements and implications for other water users of clean energy transition actions, especially those that add to water demand in an area, or affect downstream water flows, should justify the involvement of the institutions responsible for water resources management in planning and decision making on clean energy measures. In the case of actions with cross border water impacts, engagement with neighbouring governments may also maximize shared benefits and reduce risks. Energy, water and other relevant experts will need to work together.

Uneven water and energy availability between countries is being and can continue to be addressed through trade in water-embodied energy products and services. It will be important that these balancing actions continue to be enabled and facilitated.

All of these processes can reduce project risk and increase the likelihood of project financing and the potential for multiple benefits.

Conclusions about water for clean energy

- Clean energy measures may require more water than has previously been estimated. The actual balance will be location- and technology-specific.
- Each type of clean energy measure has its own 'water intensity' per unit of climate mitigation benefit. Of the measures assessed in IUCA, 2024, geothermal energy and solar and wind energy using pumped storage hydropower are estimated to be the most water-efficient in terms of water consumed for each tonne of carbon dioxide equivalent emission saved; with batteries (for their critical minerals content) and bioenergy being the least water-efficient.
- Understanding water availability and constraints at the planning stage should assist in decisions on energy options, reduce project risks (and hence costs) and improve project resilience and sustainability. In the case of hydropower expansion, care should be taken to align with other sustainable water strategies, including for the protection of fisheries and other ecological conditions.
- Solutions and innovations to achieve the most efficient use of water for clean energy transition actions can contribute to the success of these actions. Such solutions can reduce the vulnerability of energy supply to water scarcity and other climate change impacts on water availability.
- Addressing the water availability risks for clean energy projects will potentially require intensive public consultation, cooperation between government agencies and engagement with neighbouring countries on how best to meet new demands by balancing the multiple uses of water resources.
- The efficient trading of water-consumptive energy between countries with uneven water availability will be increasingly important where climate change is worsening water security.
- A successful clean energy transition requires integration of water, energy and climate strategies.

CHAPTER 3

Water for carbon dioxide removal

How water enables carbon dioxide removal (CDR)

The mitigation actions discussed in this chapter convert greenhouse gases in the atmosphere to carbon stored in other forms. Carbon dioxide removal (CDR) incorporates a range of technological and natural approaches to carbon drawdown and sequestration. The process that occurs naturally through the photosynthesis by plants that need water to live and grow can potentially be done artificially through direct air carbon capture and storage (CCS) and other technologies (known as 'novel' CDR). The IPCC describes 'biological' CDR as including afforestation, reforestation, improved forest management, soil carbon sequestration, peatland restoration, coastal blue carbon management and production of biomass crops (IPCC, 2023).

Almost all current CDR (2 $GtCO_2$ per year) comes from biological CDR and scenarios that limit warming to 1.5 or 2 degrees require more of this CDR (specifically more forest sinks and less deforestation) as well as more novel CDR (Smith et al., 2023).

Water for direct air carbon capture and storage

The IEA has projected that under its net zero emissions by 2050 scenario, direct air carbon capture and storage (DACCS) removals would increase from current negligible levels to 0.6 $GtCO_2$ per year by 2050 (IEA, 2023a). While noting that DACCS technologies have not yet been deployed at scale and are in an early stage of development, IUCA, 2024, estimates DACCS global water requirement at 4.2 km^3 per year by 2030.

Other carbon capture and storage systems, associated with energy production, are discussed in chapter 2.

Water for CDR using natural processes (biological CDR)

The IPCC has assessed that many agriculture, forestry, and other land use (AFOLU) options provide mitigation benefits, with conservation, improved management, and restoration of forests and other ecosystems offering the largest share of 'economic'[26] mitigation potential of all climate mitigation measures. Conservation of high-carbon ecosystems (e.g., peatlands, wetlands, rangelands, mangroves and forests) delivers faster climate mitigation benefits than the restoration of degraded ecosystems (IPCC, 2022c).

Wetlands including peatlands

Many natural systems are classified as wetlands. For the purposes of this report with its freshwater focus, wetlands include all inland naturally-vegetated marshes, peatlands, swamps and floodplain areas, as well as human-made or human-modified systems such as rice paddies and flood recession agriculture as used for reporting on progress with SDG 6[27]. This is narrower than the definition in the Convention on Wetlands which includes mangroves and shallow marine waters[28], which are less dependent on freshwater supply.

Wetlands provide essential climate stabilizing services through CDR and carbon sequestration as well as many other socio-economic and cultural services. Climate change affects the availability, distribution, and quality of water which in turn affects all ecosystems and human well-being (Ingermarsson et al., 2022).

Wetlands have the capacity to store carbon (as summarized in Anisha et al., 2020) and to produce methane and nitrous oxide (as discussed in chapter 4). Changes to the hydrology of wetlands, whether driven by natural causes, climate change or the effect of infrastructure or other decisions, affects these balances between carbon sequestration and greenhouse gas production. For example, re-wetting of some wetlands has been estimated to absorb sufficient carbon to fully offset their methane and nitrous oxide emissions (Zou et al., 2022).

26. IPCC terminology for costs of up to US$100 per tonne of carbon equivalent abatement (as shown in the figure in Annex 1).
27. UNEP: https://unstats.un.org/sdgs/metadata/files/Metadata-06-06-01a.pdf
28. Convention on Wetlands: Convention on Wetlands Article 1.1: https://www.ramsar.org/sites/default/files/documents/library/handbook1_5ed_introductiontoconvention_final_e.pdf

Where the mitigation measure involves the protection and restoration of a wetland, the water supply for wetlands restoration may be in the form of enhanced environmental water flows (GIZ, 2020). Successful implementation may require a combination of special purpose infrastructure, adequate releases of water from dams, and regulatory protection of the water from being taken for other uses.

Globally, peatlands are estimated to store twice as much carbon as all above-ground forest biomass. Although covering only about 3 per cent of the Earth's land surface, peatlands contain about one-third of terrestrial soil organic carbon (UNEP, 2022 and Anisha et al., 2020). For drained peatlands, a climate mitigation action may be to modify drainage infrastructure to allow peat-forming vegetation to re-establish (FAO, 2020, and UNEP, 2022).

It has been estimated that emissions reduction of around 0.88 $GtCO_2$ per year could be achieved from 'economic' peatlands restoration actions (IPCC, 2023) and that restoration of water tables of peatlands with a total area of around 556,000 square km could require around 47.6 km^3 per year of water to be returned to these peatlands globally (IUCA, 2024). This re-watering could occur through natural rainfall retained by peat that is restored by the removal or blockage of drainage channels.

Afforestation

Afforestation of around 2.1 million square kilometres (as required to remove around 1.6 $GtCO_2$ per year) has been estimated to require over 1,000 km^3 of water per year, the highest water demand of any of the assessed measures (IUCA, 2024). Forests provide co-benefits of regulating the climate locally, reducing runoff and erosion and mitigating the effect of extreme events in the long run, in particular on sloping surfaces. However, to the extent that water is absorbed in the forest area and not discharged for downstream uses, there will also be consequences for downstream water users that will need to be managed.

Water sensitive planning for biological carbon dioxide removal

Despite the multiple potential benefits of actions to restore and protect natural systems that provide CDR and storage services, providing more water for these systems will be difficult where the same water is used for other compelling objectives, such as drinking water supply, economic development, food, and energy security. Indeed, the Water Policy Group's *Listening to National Water Leaders* global survey found that "protecting and restoring water-related ecosystems" was the most difficult of all the SDG 6 targets to achieve (WPG, 2021).

The IPCC also cautions that "ecosystem restoration, reforestation, and afforestation can lead to trade-offs due to competing demands on land" (IPCC, 2022c). Nevertheless, 56 per cent of countries have NDCs referring to ecosystem restoration, afforestation and/or reforestation (UNFCCC, 2023), indicating these can be cost-effective actions.

Evaluating and communicating the economic and social value of protecting and restoring water-related ecosystems, to support the achievement of multiple development objectives, climate adaptation and mitigation, will help governments to prioritize actions to achieve biological CDR (UNEP, 2024).

Recent global initiatives can guide and support nature-based CDR actions. The Kunming-Montreal Global Biodiversity Framework[29] targets that by 2030 at least 30 per cent of areas of degraded terrestrial, inland water, and coastal and marine ecosystems are under effective restoration. The UNFCCC *COP28 Joint Statement on Climate, Nature and People*[30] affirms that achieving these goals and those of the Paris Agreement and Agenda 2030 requires "addressing climate change, biodiversity loss and land degradation together in a coherent, synergetic and holistic manner, in accordance with the best available science".

In addition to these global commitments, The Freshwater Challenge[31], a country-led initiative under the auspices of the UN Decade of Ecosystem Restoration, aims to restore 300,000 km of degraded rivers and 350 million hectares of degraded wetlands by 2030 as well as conserve intact freshwater ecosystems with purposes of tackling the climate crisis. Also, the Enhancing Nature-based Solutions for an Accelerated Climate Transformation (ENACT)[32] initiative aims to increase global mitigation efforts through

29. CBD: https://www.cbd.int/doc/decisions/cop-15/cop-15-dec-04-en.pdf and https://www.cbd.int/gbf/targets
30. COP 28 UAE: https://www.cop28.com/en/joint-statement-on-climate-nature
31. Freshwater Challenge: https://www.waterchallenge.org/about-the-challenge
32. IUCN: https://iucn.org/our-work/topic/nature-based-solutions-climate/our-work/enact-enhancing-nature-based-solutions

protecting, conserving, and restoring carbon-rich terrestrial, water, and marine ecosystems, also with quantitative global goals.

As governments consider which biological CDR measures will be most suited to their country's circumstances, water availability will need to be assured to enable successful implementation and resiliency. Water quality may also be a risk. For example, water bodies receiving nitrogen and phosphorus from excess fertilizer or untreated human or farm animal waste may have algae growth and depleted oxygen that affects their capacity as sinks for greenhouse gases.

As with clean energy transition actions for water scarce locations, governments may prefer options that are relatively more water-efficient for the climate benefit provided. While global estimates of the water efficiency of two kinds of biological CDR (peatlands restoration and afforestation) are available (IUCA, 2024), actual water demand will depend greatly on local factors and species choices for afforestation. Decision makers will need to obtain local scale data to estimate the water requirements and climate mitigation benefit. This would ideally include relevant basic hydrological data, information on the environmental consequences of different options and economic data on potentially competing uses for the same water so potentially affected populations and industries can be identified and engaged.

Governments can also access tools for land-use planning and ecosystems decision-making, such as for mapping and measuring hydrological and water-related ecosystem changes at Water Ecosystems Explorer[33] and Global Wetlands Watch[34]. There are also global guidelines on peatlands restoration[35].

In conditions of water scarcity, governments may wish to prioritize water supply for other purposes, such as for drinking water and for food production. Understanding these constraints and priorities at the planning stage should assist in decisions on biological CDR and assist in finding solutions that can provide multiple benefits.

As is the case with planning and decision-making on the clean energy transition, the water requirements and implications for other water users of biological CDR actions, especially those that add to water demand in an area, or affect downstream water flows, should justify the involvement of the institutions responsible for water resources management in planning and decision-making on biological CDR measures. In the case of projects with cross border water impacts, engagement with neighbouring governments may also maximize shared benefits and reduce risks. Relevant environmental, agriculture and hydrological officials and experts will also need to work together.

Conclusions about water-dependent CDR

- CDR actions require water for the operation of DACCs and for growing vegetation and maintaining carbon absorption functions of natural ecosystems. Where this water is committed for other uses, these ecosystem services can be compromised.
- Each type of CDR measure has its own 'water intensity' per unit of climate mitigation benefit. Of the measures assessed in IUCA, 2024, the unproven DACCS technology is estimated to be by far the most water-efficient in terms of water consumed for each tonne of carbon dioxide equivalent emission saved, and afforestation the least water-efficient. Of CDR through the maintenance of natural ecosystems functions, maintaining the hydrology of peatlands is considered to be the most water-efficient.
- There is limited globally-coordinated information about the water and carbon relationship for many types of wetland ecosystems.
- As with clean energy planning, understanding water availability and constraints at the CDR project planning stage should assist in decisions on options, reduce project risks (and hence costs) and improve project resilience and sustainability.
- Addressing the water availability risks for CDR projects will potentially require intensive public consultation, cooperation between government agencies and engagement with neighbouring countries.

33. UNEP: https://www.sdg661.app/
34. Global Wetland Watch: https://www.globalwetlandwatch.org/
35. The Convention on Wetlands: https://www.ramsar.org/document/ramsar-technical-report-11-global-guidelines-peatland-rewetting-restoration

CHAPTER 4

Reducing greenhouse gas emissions from water and sanitation systems

Natural and artificial water bodies and water, wastewater and sanitation services and processes emit greenhouse gases (primarily methane and nitrous oxide) due to the presence of nutrients and organic matter (GIZ, 2020). Methane is also an energy source which, if captured and controlled, can be used beneficially with further economic and climate benefits (IEA, 2018).

A literature review conducted as part of a study of reservoir methane emissions (Johnson et al., 2021) summarizes methane quantities volumes as follows:

- methane contributes to ~20 per cent of present-day observed global warming;
- anthropogenic activities (e.g., fossil fuel use and production, waste disposal including wastewater and agriculture) emit around 0.35 gigatonnes per year and are assumed to be the primary contributors to increases in atmospheric methane concentrations;
- natural wetlands emit 0.1–0.2 gigatonnes per year; and
- inland aquatic systems (e.g., lakes, reservoirs, rivers) emit from 0.05 to >0.2 gigatonnes per year but are considered the most uncertain components of global methane.
- One megalitre of water fills a cube 10 metres wide, high and deep.

Dissolved gases in groundwater leaching from top- and sub-soils can also be a source of greenhouse gas emissions to the atmosphere. As groundwater discharges to surface water, the dissolved greenhouse gases are emitted to the atmosphere, thus transferring carbon and nitrogen from terrestrial ecosystems to the atmosphere via the aquatic pathway (Jahangir et al., 2012).

This report discusses only the direct emissions from water and sanitation systems, and not emissions from the energy used by the sector[36].

Wastewater and sanitation

Sources of emissions

Wastewater treatment processes contribute almost as much to global greenhouse gas emissions as the global aviation industry (UNEP, 2023b), ranking as the fifth largest contributor to global anthropogenic CH_4 emissions (Ocko et al., 2021) and the third largest source of global N_2O emissions (Tian et al., 2020).

When wastewater and faecal sludge from sewage effluent undergoes anaerobic digestion (typically in wet pits, septic tanks and anaerobic treatment plants) and biological treatment (in decentralized and/or centralized facilities/treatment plants), methane, nitrous oxide and carbon dioxide are produced.

While greenhouse gas emissions from wastewater and sanitation are highly variable and there is high associated uncertainty in reporting and accounting (IWA, 2023), the World Bank has reported Global Water Intelligence estimates of emissions from water supply, wastewater, sludge, and onsite sanitation at around 0.85 $GtCO_2e$/year. Of this, water supply is estimated to account for 38 per cent, wastewater and sludge account for 30 per cent, and onsite sanitation makes up the remaining 32 per cent, due almost entirely to emissions of methane. Emissions from wastewater and onsite sanitation have been estimated to account for around 10 per cent of anthropogenic methane emissions (Khemka et al., 2023). Global methane emissions from non-sewered sanitation systems such as pit latrines and septic tanks have been separately estimated to be 4.7 per cent of global anthropogenic methane emissions (Cheng et al., 2022).

36. The water and sanitation services sector is a major energy user and can reduce its sector emissions by the use of no- or low-emission energy (including using biogas and/or energy brickettes recovered from wastewater and/or faecal sludge) and by using less energy through reducing demand and energy efficiency improvements (IEA, 2018, and World Bank, 2019). Water-saving irrigation practices can also result in energy savings (Zou et al., 2012). For example, groundwater-based solar powered irrigation systems may reduce reliance on fossil fuels.

Mitigation measures

Climate-resilient sanitation can avoid an estimated 5 per cent of global methane emissions (Cheng et al., 2022). Actions may include improved management of onsite sanitation containment (better and more frequent emptying and transport), modifications to treatment, and improving the safe management of faecal matter. Where new or upgraded on-site sanitation investments are planned, smaller tanks or container-based systems may have a net positive impact on emissions (Johnson et al., 2022).

If waste from all those who lack access to safely managed sanitation in rural areas was processed through anaerobic digesters, the biogas potential could be roughly 20-50 billion cubic metres, enough to provide a clean cooking fuel to around 60-180 million households (IEA, 2018).

For wastewater treatment plants and other centralized sanitation systems, nitrous oxide and methane emissions can be avoided, reduced or destroyed. Methane emissions can be avoided by a range of mitigation methods including leak detection and repair. It is possible to reduce nitrous oxide emissions significantly through changes in operational parameters (such as optimization of processes, source reduction, balancing of incoming nitrogen and destruction of residual nitrous oxide) of centralized wastewater treatment facilities. (Liu et al., 2023, DEFRA, 2023, and Yindong et al., 2024).

In addition, upgraded or new sanitation systems, both full-scale treatment plants and low-technology on-site sanitation, have the potential to lower emissions or even become net zero. Firstly, if wastewater is treated to a sufficient quality, the effluent can be reused as a potable or non-potable source of water. The cost of treatment of wastewater to this level is cheaper per cubic metre when compared to desalination, so has the potential to provide a cheaper alternative water source that conserves water sources and limits greenhouse gas emissions from untreated wastewater (GACERE, 2024). Also, many treatment systems across the world have begun to harness the biogas produced from anaerobic digestion for energy, preventing its release and consequent emissions, and creating a clean energy source for the treatment system, or in some cases, excess energy that can be sold to the grid (World Bank, 2020). Therefore, the wastewater treatment process has the potential to generate revenue, providing a return on investment for the upgrade works and an additional stream of income.

Furthermore, the by-products of sludge production within the wastewater treatment process (nitrogen, phosphorous and potassium) can be used to produce fertilizer, decreasing the dependency on the mining of these elements, and their associated greenhouse gas emissions. The creation of facilities that produce and sell fertilizer can payback the investment costs required for upgrades the systems that facilitate the extraction of these by-products, eventually allowing for an additional revenue stream (Delgado et al., 2021).

Nutrients and other sources of greenhouse gas emissions from wastewater may also be removed through constructed wetlands replicating the physical, chemical and biological processes of natural wetlands (GIZ, 2020). However, as wetlands themselves are a recognized emissions source and life-cycle analysis should be undertaken to ensure projects have a net positive climate mitigation outcome over time.

Artificial water bodies and irrigation systems

Sources of emissions

Artificial water bodies, such as reservoirs created by dams, and constructed lakes and ponds, are sources of methane, carbon dioxide, and nitrous oxide emissions due to the presence of nutrient and the decomposition of organic matter. Reservoirs are estimated to emit around three per cent of global anthropogenic methane (Johnson et al., 2021) and rice production accounts for 615–900 million tonnes CO_2e/year, or around 1.3 per cent of total global greenhouse gas emissions. (Khemka et al., 2023 section 3.4).

Wastewater from industry and agriculture also emits greenhouse gases, for example and in particular nitrous oxide from fertilizer use in farms and gardens.

Mitigation measures

Emissions from reservoirs can be reduced by managing nutrient inflows – selecting sites for new reservoirs that are upstream of nutrient sources and removal of vegetation before flooding) and improving the design and management of existing reservoirs (GIZ, 2020). Reservoirs can also be sources of solar energy generation with many co-benefits including water savings from reduced evaporation (World Bank et al., 2019).

Improve catchment management and methods such as managed aquifer recharge (MAR) can enhance water storage in aquifers, reducing the need for large infrastructure projects like dams and their associated emissions.

Mitigation actions from water use in agriculture may involve reducing fertilizer use with co-benefits of reduced costs to the farmer.

Emissions from rice cultivation can be considerably reduced (methane by 53 per cent) by non-continuous flooding of crops where there is sufficient control over the watering regime to allow for alternate wetting and drying (FAO, 2023, section 7.1 and see also Lansing et al, 2023). Co-benefits of periodic dry cycles could include reduced water use, higher yields and increased fertilizer efficiency (GIZ, 2020).

Reducing the climate impact of rice cultivation requires the co-management of different emissions, water resources, and crop yields, requiring more integrated assessments of all these factors on a global scale (GIZ, 2020). This an example of food, water, energy and climate interactions that require a highly-integrated approach to management (UNESCO WWAP, 2020, chapter 9).

Emissions from wetlands

As well as providing carbon removal and storage services (discussed in chapter 3), wetlands are a natural source of methane emitted from decomposing vegetation, and of nitrous oxide which may enter from upstream water catchment as with artificial reservoirs (Ingermarsson et al., 2022).

While these emissions may be largely naturally occurring, they could be exacerbated by human activity such as changes to the hydrology of the natural system (for example holding a natural lake at an artificially constant level), which may increase emissions of methane, or nutrient pollution to cause nitrous oxide emissions.

IUCA, 2024, was not able to undertake global estimates for the climate benefit of freshwater wetlands because the IPCC AR6 report did not contain an estimate for the likely range of cost per tonne of carbon removed for this mitigation measure (IUCA, 2024). For this reason, this report does not provide any estimates of how, for example, the withdrawal of water from a wetland for other water uses may affect greenhouse gas emissions from the wetland, and whether that is adding to or reducing the emissions.

As reported in chapter 3, changes to the hydrology of wetlands, whether driven by natural causes, climate change or the effect of infrastructure or other decisions affects these balances. For example, re-wetting of some wetlands has been estimated to absorb sufficient carbon to fully offset their methane and nitrous oxide emissions (Zou et al., 2022).

Conclusions about reducing greenhouse gas emissions from water, wastewater and sanitation systems

- Reducing greenhouse gas emissions from water, wastewater and sanitation systems, including from reservoirs and irrigation systems, and possibly from wetlands, requires actions that prevent these gases forming or contain or convert them for beneficial uses (such as making clean cooking fuel from anaerobic digestion).
- There are considerable co-benefits from the improved and sustainable management of wastewater and faecal sludge for public health, the environment and economic development. This may include potable water and resource recovery from wastewater treatment processes with benefits for water, energy and nutrients for fertilizers.
- The water consequences of actions to reduce greenhouse gas emissions from water, wastewater and sanitation systems are very different to the consequences of the clean energy and CDR measures discussed in chapters 2 and 3 in that the water, wastewater and sanitation mitigation actions will generally not use additional water resources, and in the case of irrigation can also result in water savings that can be returned to the environment or deployed to other usage. There will also often be valuable co-benefits of improved water quality and public health.
- Water, wastewater and sanitation emission reduction projects will generally involve community and industry interests and may entail changes to historic practices, requiring substantial consultation and engagement.

CHAPTER 5

Ways forward

Aligning climate mitigation and water objectives

Considering water in climate strategic planning

Many of the climate mitigation measures required to limit global warming to 1.5 or 2 degrees will need more water and in different places than is now being used. Each country will need to consider water availability and usage in working out which climate mitigation measures to implement, how and where, and how to secure and sustain the necessary water.

Managing any changed demand for water as the result of climate mitigation actions will need effective planning and delivery of water and sanitation resources and infrastructure, and possibly changes to water allocations. While the volume, timing and form of the water requirements need to be worked out at the project level, the aggregated and downstream water effects of projects may have broader national, regional and cross border consequences requiring inter-government commitment and ongoing cooperation to manage.

In water scarce locations, where and when demand for water for all purposes exceeds sustainable supply, policies and processes are needed for the allocation of available water to public objectives. This may entail finding the best balance between different social objectives, and policies to reduce some sources of demand. In water-scarce countries, any rise in water demand can quickly escalate into a significant public concern, triggering public debates and potential disruptions.

Where water supply and demand are exacerbated by climate change, many countries will be considering ways of augmenting storage or alternative water supplies as a policy response, considering the cost-effectiveness of various options.

Supply and demand fluctuations over time are typically managed by water storages being filled when water is available and drawn down over time. In many places, nature provides these storage services at no cost in the form of snowpack, aquifers and wetlands. Ongoing alteration of these natural storage functions due to climate change needs to be taken into consideration at the strategic planning stage for climate mitigation, as it may constrain water-dependent climate change mitigation.

Artificial storages, mainly in the form of reservoirs enabled by dams, also serve this purpose and can also provide protection against flood events and enable hydroelectric power generation and irrigation. Dams also have many social, economic and environmental costs, both direct (construction, maintenance, operation and evaporative water losses) and indirect (through the flooding of the catchment and changes to downstream flow patterns). As a result, planning for new dams can require much consultation at the strategic planning stage, including with any downstream countries, and may require early commitment to be given to intended operational practices.

Supply and demand fluctuations and uncertainty can also be managed through the development of alternative water sources, typically desalination (in coastal areas) or usually less costly re-use of wastewater[37].

Exploring options to limit current and future water demand without compromising current water use benefits is crucial. Managing new demand by improving water-use efficiency allows different sector needs to be met using the same available water resources, addressing potential trade-offs. For example, modifying the configuration or technology of irrigation schemes could enhance water-use efficiency, reducing irrigation water consumption while maintaining crop yields[38]. With effective regulation, the 'saved' water could be allocated to support water demands for mitigation actions, without affecting food security or other national priorities. These efficiency gains may raise the resilience of the agricultural sector to droughts and benefit the agricultural sector as an effective adaptation measure against climate change as well as identify optimal sites for implementing climate mitigation initiatives.

37. IWA: https://iwa-network.org/from-seawater-to-tap-or-from-toilet-to-tap-joint-desalination-and-water-reuse-is-the-future-of-sustainable-water-management/
38. UNEP: https://www.unep.org/news-and-stories/story/five-threats-water-sustains-our-farms

Moreover, information and communications technologies can play a critical role in monitoring water usage, optimizing distribution, and predicting future demand patterns, helping to ensure these above outcomes.

Demand can also be influenced through water consumer information and pricing of water supply services and controlled by regulation. Reducing demand for water services will also reduce the energy demand of these services, contributing to emission reductions.

Wastewater is a valuable resource and an essential component of a circular economy. It has the potential to meet the growing demand for water, acts as a safe and sustainable solution to address not only the challenges of water security, but also the impacts of climate change, biodiversity loss, and pollution. There are considerable opportunities to sustainably manage wastewater for beneficial use.

Inter-government cooperation is necessary to allow the efficient trading of water and energy between countries with uneven endowments of both, and will be increasingly important as climate change worsens the water security and predictability in many countries. For example, a water scarce country may prefer to import biofuels and hydrogen than produce its own.

Ensuring water availability and managing water supply and demand is a necessary consideration at the strategic planning phase of future climate mitigation actions. Identifying and reducing water-related risks should also help attract project financing and contribute to successful implementation.

Preparing nationally determined contributions

If a country's NDC includes proposed climate mitigation actions that are dependent on water supply, any associated changes that will be required to water and wastewater infrastructure and/or management policy and practice to enable the action to be successfully implemented should be identified as early as possible.

This requires the expected water demand of the preferred mitigation measures, and the supply and reliability of the required water resources to be identified. Any significant water quality issues and impacts on other water users should also be identified. These factors can be preliminarily evaluated under a range of climate change scenarios (including drought, flood and other water-related disaster scenarios) using the best available hydrological and socio-economic information.

In the case of cross-border water resources, regional cooperation can be considered as an enabler of the most beneficial overall water use and to reduce the risk of conflict. Guidance for countries on preparing NDCs is available from the UN system coordinated by the UN Development Programme (UNDP), as well as through the NDC Partnership. It is now urgent that guidance on water dependency issues is also prepared and available.

In the case of climate mitigation measures involving the improved treatment of wastewater and utilizing the resources embedded within wastewater for water, energy and nutrients, the NDC should identify how these measures will decrease emissions while addressing social and environmental issues.

This is particularly necessary given that countries responsible for around 85 per cent of greenhouse gas emissions do not incorporate potential mitigation measures within wastewater treatment (Crippa et al., 2022). Improving access to wastewater treatment and utilizing the resources embedded within wastewater for water, energy and nutrients provide an opportunity to decrease emissions while addressing social and environmental issues with projects that often provide a sound return on investment. Therefore, it is vital that within the next set of NDCs, the potential of wastewater is truly realized.

Including water in mitigation project planning

IUCA, 2024, highlights the importance of further research to obtain more and better data, at all levels, to better inform mitigation project choices and proposes practical steps for planning of mitigation actions:

1. Ensure the availability of relevant data.
2. Adapt the assumptions in IUCA, 2024, especially about the climate mitigation technology being used and source and form of water required, to the circumstances of the proposed action.
3. Estimate the freshwater demand for each planned action, initially utilizing the water intensity calculation method in IUCA, 2024.

4. Estimate the overall 'water cost' and 'climate benefit' of each measure.

The scale and consequences of new demand will be situation-specific and affected by decisions on preferred technologies as much as by actions in water resource management and planning. Regardless of the final technological choices, contingency plans can show how water supply can be assured in periods of water scarcity, and project plans can be packaged with any associated water savings actions in that location.

Where affected water users are downstream of a project, consulting early to understand their needs and being as responsive as possible to these can reduce project risk and financing costs. Furthermore, cross-sectoral planning can help optimize the use of water resources through actions that deliver multiple benefits (UNECE, 2021). Similarly, where these users are in a water basin that is shared with another country, and historical water sharing may be affected, early inter-government consultations will reduce project risks and support water-use optimization (UNECE, 2018, and UNECE, 2020).

Considering climate change in water strategic planning

Changes to water demand as the result of climate mitigation actions coupled with climate change induced risks to water availability may justify a more comprehensive review of water policy and management at the national level. This could extend to the adequacy of and potential improvements to information sources (hydrological and socio-economic data), governance arrangements (decision-making processes, regulatory and other institutional arrangements, legal frameworks, and public engagement mechanisms), water allocation policies and infrastructure.

Building on IWRM and related cross-border and cross-sector frameworks will support the required activities on coordination, governance, management and financing. Countries working towards IWRM implementation (or similar frameworks), as tracked through SDG indicator 6.5.1 (UNEP, 2024), can expedite their efforts on coordinated climate and water management. Where water resources (in rivers, lakes and aquifers) cross national boundaries, this becomes a joint endeavour, requiring effective cooperation among neighbouring countries to ensure the necessary water is available and manage other water-related risks. Cooperation on exchange of hydrological data and modern water flow monitoring systems and technology can reduce many of the risks and allow for joint benefits for its users. Agreed principles such as those of the UN Water Convention, and guidance on the application of these, can help with optimizing the use of water resources for any kinds of climate action.

Updating global mandates

UN-Water considers that to increase mitigation project effectiveness and reduce risks, the role of water for mitigation should be well represented in climate discussions and agreements (UN-Water, 2019).

In-country work on assuring water availability for climate mitigation actions would be assisted and supported if there was agreement to relevant principles and guidance through processes of the UN Framework Convention on Climate Change. For example, this may be general principles for managing the allocation of water for climate mitigation actions without limiting the delivery of other water-dependent services, or technical guidance on the most efficient use of water in climate mitigation actions. Countries can advocate for such content in relevant UNFCCC work programmes.

An upcoming assessment of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) addressing the interlinkages between biodiversity, water, food, health in the context of climate change[39] may also provide helpful guidance.

Members of the IPCC can agree to assess any new research on water and climate interdependencies in its current cycle.

National efforts to ensure water issues are addressed in climate mitigation planning can also be supported through the work programmes of global bodies and regional bodies in which countries participate. These can share experience and set high level goals and principles to which country work can be directed. Examples are:

39. IPBES: https://www.ipbes.net/nexus

- UNFCCC Subsidiary Body work programmes on mitigation, just transitions, and impacts of response measures.
- Processes of the UN Water Convention (Helsinki), including the United Nations Economic Commission for Europe (UNECE) Health Protocol on reducing project risks and supporting water-use optimization (UNECE, 2018, and UNECE, 2020)[40].
- Processes of Agenda 2030, particularly the High-level Political Forum.
- Energy sector processes, such as of the IEA, International Renewable Energy Agency (IRENA) and International Hydropower Association (IHA).
- Environment sector processes, such as of the Convention on Biological Diversity (CBD), UN Convention to Combat Desertification (UNCCD), Convention on Wetlands, International Union for Conservation of Nature (IUCN).
- IPCC 7th cycle assessments of any new relevant science.
- Global climate financing entities (e.g. World Bank, Green Climate Fund and Global Environment Facility).
- Sub-global inter-governmental processes such as the Group of Twenty (G20), Brazil, Russia, India, China, and South Africa (BRICS), Group of Seven (G7), and Asia-Pacific Economic Cooperation (APEC).
- Governing bodies of relevant UN organizations.
- Joint institutions established by international treaties to manage international watercourses or basins.

Member countries of these forums can call for new processes on water and climate aimed at providing them with the best possible support. For example, in the case of peatlands, given their huge carbon storage, concentrated in relatively small areas, these systems may warrant global protection to avoid loss of this storage capacity.

Working with local authorities and sub-national governments

It is particularly necessary that emission reduction strategies relying on or affecting water supply are sensitive to local and regional contexts, considering their climatic, socio-economic, and environmental conditions.

Local authorities and sub-national governments can be encouraged and assisted to ensure the water requirements of any mitigation actions they are planning are fully considered and incorporated into project plans. Also, where national-level climate mitigation actions are dependent on water supply under the control of local authorities and sub-national governments, it will be particularly necessary for these authorities and governments to be fully involved in the planning of these actions.

Many city, town and regional authorities, and sub-national governments, are developing and implementing their own climate mitigation actions that are or will be embodied in national contributions. Their role has been acknowledged by the establishment of the Coalition for High Ambition Multilevel Partnership (CHAMP) for Climate Action[41].

At COP 28, Local Governments for Sustainability (ICLEI) declared the intent of their members to apply systems-based integrated approaches to climate adaptation and mitigation that fully consider the linkages with nature, food, water, pollution and health[42].

Financing opportunities

As discussed in this brief, investing in water, wastewater and sanitation actions that deliver greenhouse gas emission reductions can deliver other highly valued social, economic and environmental benefits, including food security and health benefits.

For example, there is potential to develop innovative projects for onsite sanitation, floating solar, and hydroelectric retrofits of storage dams, which offer strong mitigation potential and for which climate finance instruments are already available from the Global Environment Facility, the Climate Investment Funds, and the Green Climate Fund. Such projects should also be eligible for carbon credits which can be monetized separately if the emissions savings can be estimated with sufficient confidence (Khemka et al., 2023).

40. UNECE: The Water Convention and the Protocol on Water and Health: https://unece.org/environment-policy/water
41. COP 28 UAE: https://www.cop28.com/en/cop28-uae-coalition-for-high-ambition-multilevel-partnerships-for-climate-action
42. ICLEI: https://iclei.org/news/iclei-leaders-cop28-outcome-statement/

Analysis of financing opportunities for peatlands restoration shows scope for carbon credits as well as for private financing if investment risks can be reduced by limiting potential losses due to events not in the investors' control. This may be in the form of revenue guarantees, first loss tranche protection and/or risk-sharing agreements. Public sector funding can also develop projects to a stage of attractive for private investment (Hogan et al., 2024). These same principles are likely to be applicable to any private investment in 'nature-based' carbon-removal projects where innovative financial instruments may be needed (Friess et. al., 2022).

While climate financing for water, wastewater and sanitation actions have been primarily aimed at adaptation outcomes, the climate mitigation benefits may justify higher climate financing prioritization. More in-depth analysis of the multiple benefits of water-related climate mitigation actions should inform future approaches to climate financing.

Mobilizing private sector and other non-government action

Private sector and other non-government entities with interests in water and climate mitigation issues may have very little understanding of the water dependencies. Yet they now have strong incentives to assist in finding solutions as the result of new climate disclosure rules[43] requiring reporting on water-related risks with specific guidance available on these requirements[44].

Relevant forums of the energy, agriculture and environment sectors provide opportunities to raise awareness of the water dependencies of climate mitigation actions in each sector.

There are also major cross sectoral multi-stakeholder bodies with highly relevant programmes such as the World Economic Forum's agenda for a "paradigm shift" in how water management can address critical climate scenarios[45], the Marrakesh Partnership's Water-climate Action Pathway[46] and the CDP's Financial Sector Water Finance Hub[47]. In the water sector, bodies such as the Alliance for Water Stewardship (AWS)[48] and the CEO Water Mandate[49] may be willing to promote this issue, and their corporate members, who may have committed to observe the ISEAL-rated Water Stewardship Standard[50], and publicly endorsed the CEO Water Mandate may also be motivated to contribute technology and management solutions to how water can most efficiently be used in climate mitigation actions. In the energy sector, the Hydropower Sustainability Alliance is implementing the ISEAL-rated Hydropower Sustainability Standard[51] to promote how hydropower projects can improve socio-economic development and ecosystem protection.

Filling information gaps

The IPCC last assessed climate change and water issues comprehensively 15 years ago, identifying several knowledge gaps then which may still exist, including:

- adequate tools to facilitate the appraisal of adaptation and mitigation options across multiple water-dependent sectors, including the adoption of water-efficient technologies and practices.
- reliable projections of future changes in hydrological processes and water resources variables.
- identification of water resources needs for maintaining environmental values and services, especially related to deltaic ecosystems, wetlands and adequate instream flows.
- for carbon capture and storage: leakage processes, because of potential degradation of groundwater quality. This requires an enhanced ability to monitor and verify the behaviour of geologically-stored CO_2.

43. CDSB: https://www.cdsb.net/what-we-do/nature-related-financial-disclosures/water-related-disclosures
44. CDSB: https://www.cdsb.net/water
45. World Economic Forum: https://www.weforum.org/agenda/2024/01/how-can-we-ensure-water-resilience-in-a-climate-altered-world/
46. UNFCCC: https://unfccc.int/climate-action/marrakech-partnership/reporting-tracking/pathways/water-climate-action-pathway
47. CDP: https://www.cdp.net/en/water/cdp-financial-sector-water-knowledge-hub
48. Alliance for Water Stewardship: https://a4ws.org/
49. CEO Water Mandate: https://ceowatermandate.org/
50. Alliance for Water Stewardship: https://a4ws.org/the-aws-standard-2-0/
51. Hydropower Sustainability Alliance: https://www.hs-alliance.org/hs-standard

- for hydropower and dam construction: methane emissions and the net effect on the carbon budget in the affected regions.
- for bioenergy: water demand, and its consequences, of large-scale plantations of commercial bio-energy crops.
- with irrigation: net effects of higher carbon storage in soils through enhanced yields and residue returns and its offset by CO_2 emissions from energy systems to deliver the water, or by N_2O emissions from higher moisture and fertilizer inputs.
- with forestry, the effects of massive afforestation on the processes forming the hydrological cycle, such as rainfall, evapotranspiration, runoff, infiltration and groundwater recharge (Bates et al., 2008).
- with wastewater and water reuse: emissions from decentralized treatment processes and uncontrolled wastewater discharges, and the impact of properly reusing water on mitigation and adaptation strategies.

It would be useful for strategic planning if more information was available on the carbon and water relationships of different wetland types in different environmental settings. IUCA was not able to undertake global estimates for the climate benefit of freshwater wetlands because the IPCC AR6 report did not contain an estimate for the likely range of cost per tonne of carbon removed for this mitigation measure. Estimates for the restoration of freshwater wetlands are difficult to undertake at the global scale. Further research is required globally and at a local level (IUCA, 2024).

Policymakers would also benefit from a breakdown on how much of the water needed for different clean energy technologies could be provided through reuse, circularity, and desalination measures and not thereby compete with other freshwater users.

An update on the overall state of knowledge and research gaps on the role of water in climate mitigation would be useful to policymakers for prioritizing further research needs. International organizations can also coordinate research efforts at the regional or global level[53].

Improved knowledge will assist in reducing the uncertainties and reliance on assumptions in future assessments of water requirements of climate mitigation actions where there are high levels of uncertainty due to technology choices and other external factors. For example, the water needs of geothermal and nuclear plants are highly dependent on cooling system choices, and the water needs of biofuels are highly dependent on crop choices (IUCA, 2024, Notes and Assumptions).

Further research could be supported by information and communications technologies across sectors that would enable more accurate data collection, improved water management, and better alignment of conservation efforts with climate mitigation goals.

If requested by countries or inter-governmental processes, global scale research providers may be willing to do further work in this area. The IPCC would be able to assess any new science on these matters in its next reports.

Using available support

Many global and regional organizations can support country-wide planning and the IWRM necessary to understand and secure the water requirements of mitigation actions. UN organizations can provide guidance and technical and capacity-building support. For example, the World Meteorological Organization (WMO) can assist with technical guidance for standardised national assessments of water requirements, and the SDG IWRM Support Programme, led by the United Nations Environment Programme (UNEP), can support countries to develop and implement climate-resilient water investment plans[54]).

For incorporating water dependent actions into each country's NDC, UN-wide support is available to developing countries through Resident Coordinators, as described in Annex 3.

52. For example, the IAHS-International Association of Hydrological Sciences (https://iahs.info/) and Water4All (https://www.water4all-partnership.eu).
53. Global Water Partnership: https://www.gwp.org/en/sdg6support/iwrm-support/iwrm-support/
54. CDKN: https://ndc-guide.cdkn.org/book/planning-for-ndc-implementation-a-quick-start-guide/mitigation/
55. AGWA: https://www.alliance4water.org/water-resilience-tracker-for-national-climate-planning

There are also practical guides available such as the Climate Development and Knowledge Network (CDKN)'s 'Quick-start Guide' on *Planning for NDC Implementation*[55] and the Initiative for Climate Action Transparency (ICAT)'s guidance on assessing the impacts of climate policies and actions, which covers impacts on water resources and water quality (ICAT, 2022). The 'water resilience tracker for national climate planning'[56] can also be applied to support governments with water, climate mitigation cross-sectoral planning. Guidance on wetland restoration for climate change resilience is also available as a Ramsar Information Sheet (Fennessy et al., 2018).

Many global and regional organizations can support the integrated water resource planning and management necessary for the success of water-dependent clean energy actions. UN Water member and partner organizations can also provide guidance and technical capacity-building to support key aspects, for example:

- The Food and Agriculture Organization of the United Nations (FAO) on relevant agriculture sector technologies and management practices.
- The International Water Management Institute (IWMI) with integrated water resource management best practice.
- The Convention on Wetlands on national wetland inventory approaches and methods.
- The UN Water Convention Secretariat hosted by UNECE, and other UNECE Divisions on transboundary water cooperation, climate adaptation, water allocation, and planning with water-food-energy-ecosystems nexus approach.
- UNESCO with science inputs.
- UNEP on hydropower systems, water ecosystem management and environmental flows for nature-based CDR measures.
- OHCHR on technical assistance and capacity development in supporting the implementation of international human rights norms and standards.
- The United Nations Children's Fund (UNICEF) and World Health Organization (WHO) on wastewater and sanitation management, including guidelines on wastewater to inform policy making and regulations and guidelines on sanitation and health.
- WMO with climate and hydrological data and future predictions and methodologies for greenhouse gas emission quantification using atmospheric observations.

Now is the time

As countries review and update their NDCs, and consider potential climate mitigation actions, it is time to understand the potential water demand of possible actions, the reliability of future water supply, the needs of other water users, and the overall water costs and benefits of clean energy and other climate mitigation measures.

Now is the time for water resource managers to be planning for potential changes in water demand as the result of accelerated climate mitigation actions and considering any infrastructure and water management changes needed to support these.

Now is the time to consider how improvements in the management of water and sanitation services, reservoirs, irrigation and wetlands can reduce greenhouse gas emissions and be part of NDCs.

Now is the time to share experiences between countries and invite guidance and support from international processes.

It is intended that by identifying some of the key issues about the role of water resources and water and sanitation services in climate mitigation, this Analytical Brief can provide guidance and assistance to governments and international organizations as they work towards a climate-safer future for the world.

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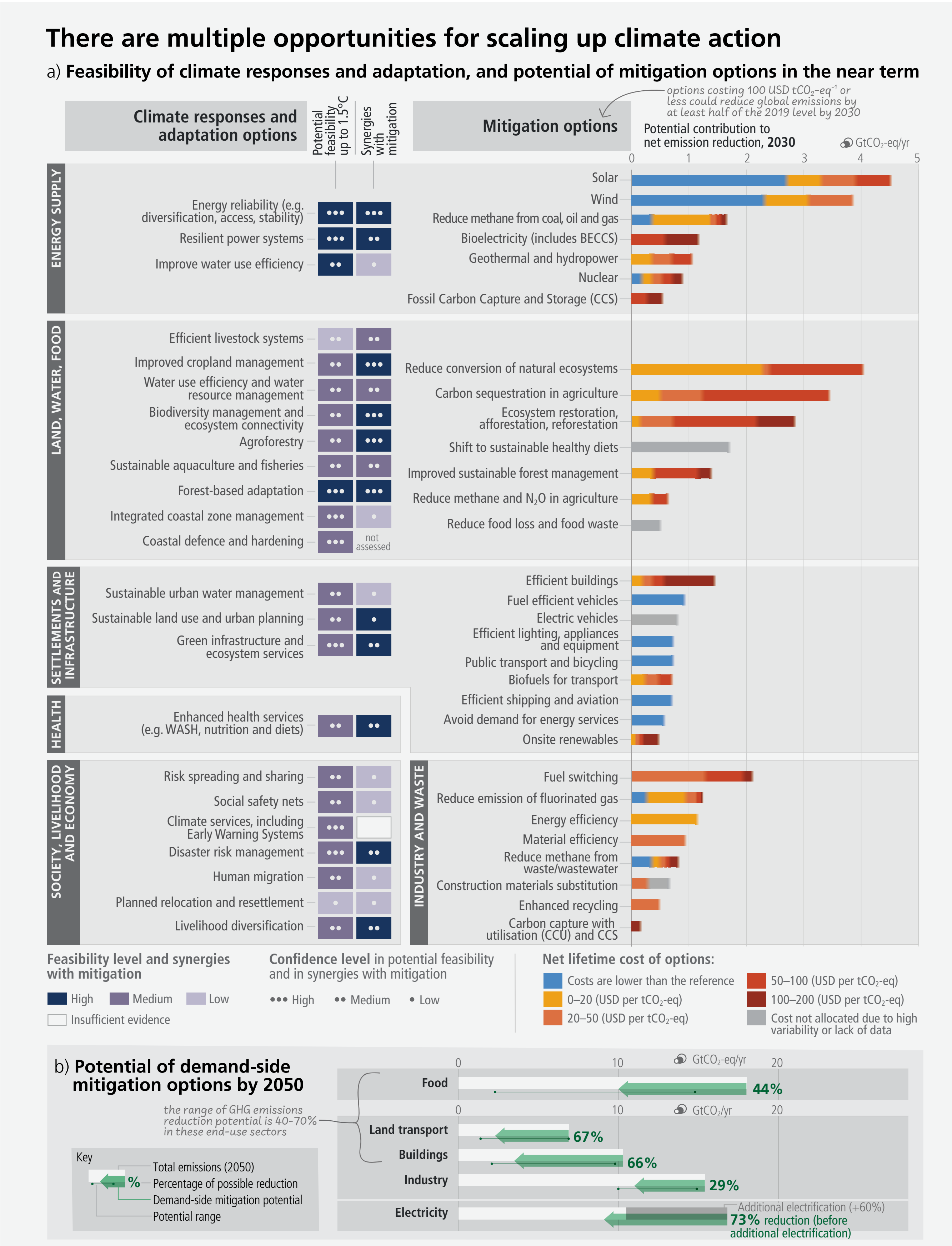
Annexes

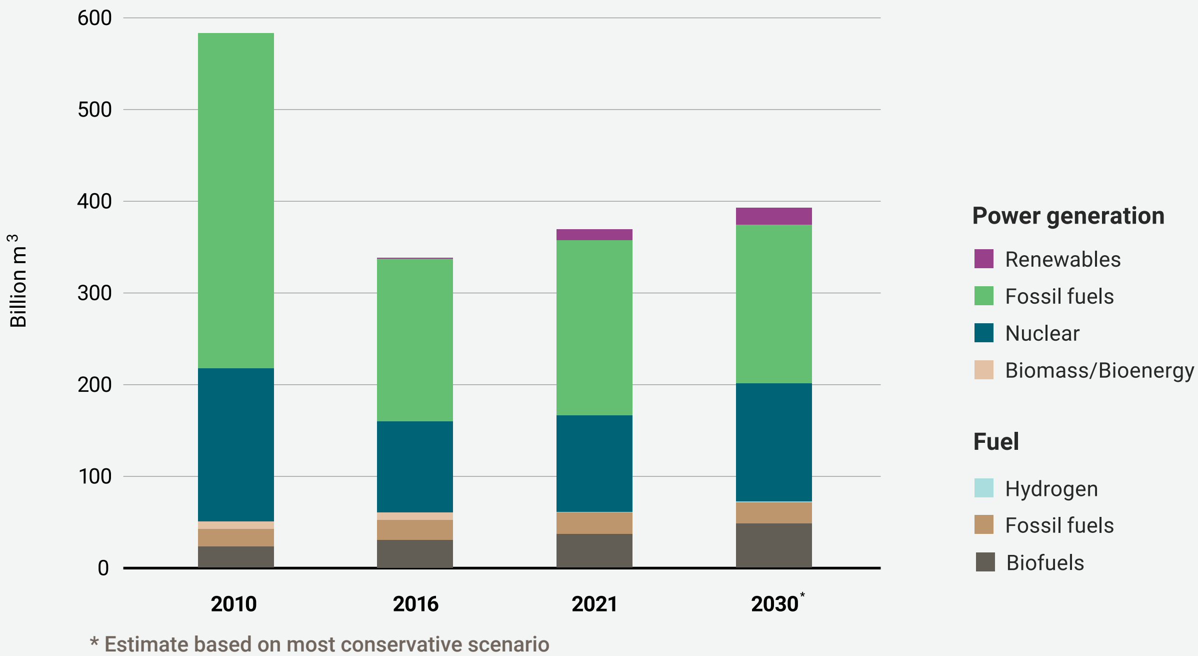
Annex 1. IPCC list of climate mitigation measures (IPCC, 2023)



Annex 2: Water demand of climate mitigation measures

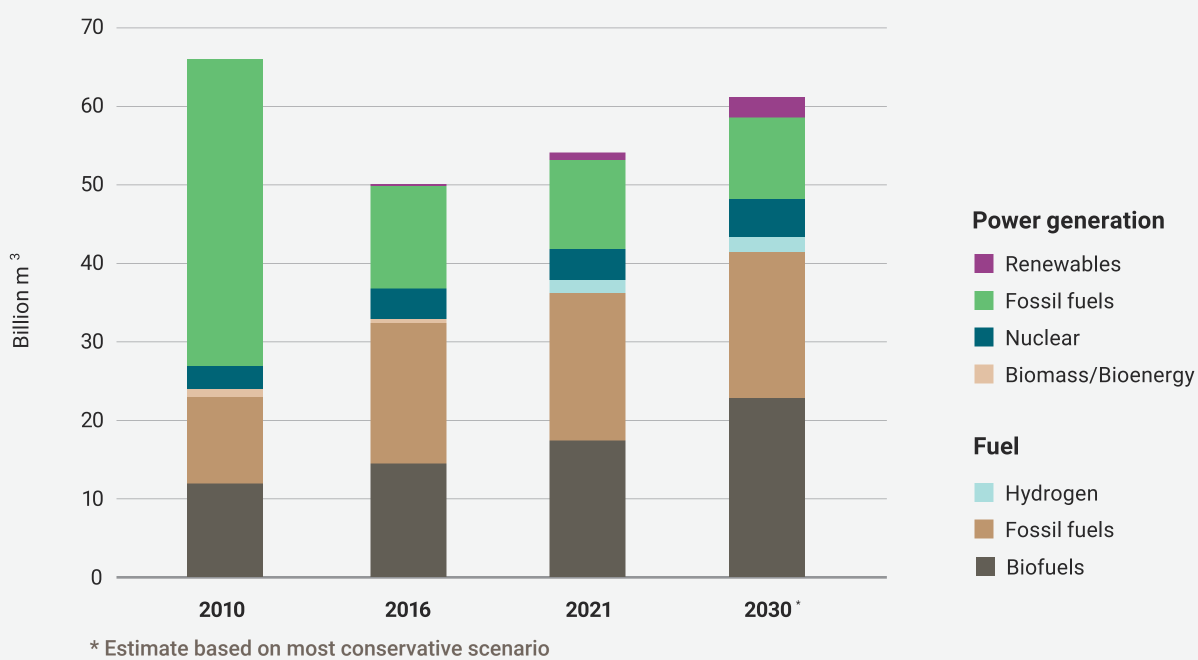
· UNESCO WWAP, 2024, tables 5.2 and 5.3

Figure 1: Global energy sector: Water withdrawal by fuel and power generation type



Source: Authors, based on data from IEA (2012) for 2010, IEA (2020a) for 2016, and IEA (2023) for 2021 and 2030. Licence CC BY 4.0.

Figure 2: Global energy sector: Water consumption by fuel and power generation type



Source: Authors, based on data from IEA (2012) for 2010, IEA (2020a) for 2016, and IEA (2023) for 2021 and 2030. Licence CC BY 4.0.

· IUCA, 2024, part B table 1

Table 1: Water dependencies of clean energy measures to 2030

1 **Measure**	2 **Water required for...**	3 **Clean energy produced** GJ/y **(a)**	4 **Climate benefit** GtCe/y **(b)**	5 **Water required** GL/y **(c)**	6 **Water efficiency of GHG reduction** m^3/tCe **(d) = (c)/(b)**	7 **Tonnes of carbon removed per million liters** tCe/ML
Use of geothermal energy to generate clean electricity	Water required per year for operation of geothermal plant	$1.1x10^3$	0.5	532	1.0	939.8
Use of solar and wind energy to generate clean electric power	Pumped hydropower for dispatchable energy supply	$6.08x10^{10}$	4.1	5,207	1.3	787.4
Hydrogen in decarbonisation of industry via fuel switching	Electrolyser demand + cooling water demand	$1.8x10^{10}$	0.4	5850	14.6	68.4
Use of nuclear energy to generate clean thermo-electric power	Cooling systems per year for operation of nuclear plant	$1.42x10^{10}$	0.9	16,366	18.2	55
Use of bioenergy to produce liquid biofuel	Growth of biomass, fermentation, and refining	$1.1x10^{10}$	0.8	400,000	500	2.0
Use of batteries in electric light duty vehicles	Mining and processing lithium, copper, cobalt and rare earth elements	$1.05x10^8$	0.8	480,000	605	1.7

· **IUCA, 2024, part B table 2**

Table 2: Water dependencies of sequestration measures

1 **Measure**	2 **Water required for...**	3 **Area** km² **(a)**	4 **Climate benefit** GtCe/y **(b)**	5 **Water required** GL/y **(c)**	6 **Water efficiency of GHG reduction** m³/tCe **(d) = (c)/(b)**	7 **Tonnes of carbon removed per million liters** tCe/ML
Direct Air Carbon Capture and Storage	Solvent regeneration	NA	0.6	4,200	7	142.9
Maintenace of the hydrology of peatlands	Maintaining natural functions	4,733,645	0.88	47,623	3.08	18.5
Carbon sequestration via carbon capture and storage (BECCS)	Maximising sequestration potential	NA	1.6	640,000	400	2.5
Tree planting (afforestation)	Maintaining natural functions	2,130,000	1.6	1,066,667	667	1.5

The information in these tables is based on the assumptions and other explanations given in Part B of IUCA, 2024, and are explained in that report as follows:

> *"Table 1 summarizes water dependencies of clean energy measures up to 2030, and Table 2 presents water dependencies of sequestration measures up to 2030. The numbers in the tables give an order of magnitude of the water dependency of key mitigation measures in absolute terms. Any comparison should be done with caution because in some cases the measures considered can also deliver energy services other than provision of electrical power, for example heating via geothermal and mobility via batteries. Commentary on conventional hydropower is available in section 11".*

> *"The values presented were not rounded to the nearest integer, however the number of significant figures should not be interpreted as carrying any degree of precision".*

Annex 3. About nationally determined contributions

The essential role of NDCs

UNFCCC explains how national effort is the 'engine room' of climate action under the Paris Agreement to stabilize the climate[56]. It was agreed that this required greenhouse gas emissions being reduced enough to constrain global warming to 1.5 and 2 degrees above pre-industrial levels, and that this would be achieved by each country determining its own contributions to this global effort.

> *"Nationally determined contributions (NDCs) are at the heart of the Paris Agreement and the achievement of its long-term goals. NDCs embody efforts by each country to reduce national emissions and adapt to the impacts of climate change. The Paris Agreement (Article 4, paragraph 2) requires each Party to prepare, communicate and maintain successive nationally determined contributions (NDCs) that it intends to achieve. Parties shall pursue domestic mitigation measures, with the aim of achieving the objectives of such contributions.*
>
> *"Together, these climate actions determine whether the world achieves the long-term goals of the Paris Agreement and to reach global peaking of greenhouse gas emissions as soon as possible and to undertake rapid reductions thereafter in accordance with best available science, so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of GHGs in the second half of this century. It is understood that the peaking of emissions will take longer for developing country Parties, and that emission reductions are undertaken on the basis of equity, and in the context of sustainable development and efforts to eradicate poverty, which are critical development priorities for many developing countries."*

The Global Stocktake – a 'wake-up call' for NDCs

The first five-yearly '[Global Stocktake](#)' (GST) of progress found the world was not on track to meet these goals and NDCs would need to be more ambitious, as described by UNFCCC[57]:

> *"The first global stocktake recognized that the Paris Agreement has driven near-universal progress on climate action, however despite overall progress, the world is not on track meet the long-term temperature goal of the Agreement, reach necessary levels of resilience and mobilize and align necessary financial flows. The NDCs to be submitted in 2025, also known as NDCs 3.0, are to be informed by the outcome of the first global stocktake. NDCs 3.0 need to be progressive and more ambitious than current NDCs and may be the last opportunity to put the world on track with a global emission trajectory in line with the Paris Agreement's 1.5C goal."*

NDC 3.0 requirements

UNFCCC explains the agreed approach to NDC 3.0 as follows:

> *"… the GST "encourages Parties to come forward in their next nationally determined contributions with ambitious, economy-wide emission reduction targets, covering all greenhouse gases, sectors and categories and aligned with limiting global warming to 1.5°C, as informed by the latest science, in the light of different national circumstances" and "Encourages Parties to communicate in 2025 their nationally determined contributions with an end date of 2035". However, the GST additionally "Reaffirms the nationally determined nature of nationally determined contributions and Article 4, paragraph 4, of the Paris Agreement". The NDCs 3.0 should therefore represent a progression from the last NDC and reflect highest possible ambition (as stipulated by the Paris Agreement and reiterated in the GST) but in a nationally appropriate way.*

56. UNFCCC: https://unfccc.int/process-and-meetings/the-paris-agreement/nationally-determined-contributions-ndcs
57. UNFCCC: https://unfccc.int/process-and-meetings/the-paris-agreement/nationally-determined-contributions-ndcs

"The GST also "encourages Parties to align their next nationally determined contributions with long-term low greenhouse gas emission development strategies" and "calls on Parties to contribute to the following global efforts, in a nationally determined manner, taking into account the Paris Agreement and their different national circumstances, pathways and approaches:

- *Tripling renewable energy capacity globally and doubling the global average annual rate of energy efficiency improvements by 2030;*
- *...Accelerating efforts globally towards net zero emission energy systems, utilizing zero- and low-carbon fuels, well before or by around mid-century;*
- *... accelerating action in this critical decade, so as to achieve net zero by 2050 in keeping with the science;*
- *Accelerating zero- and low-emission technologies, including, inter alia, renewables, nuclear, abatement and removal technologies such as carbon capture and utilization and storage, particularly in hard-to-abate sectors, and low-carbon hydrogen production;*
- *Accelerating and substantially reducing non-carbon-dioxide emissions globally, including in particular methane emissions by 2030;*
- *Accelerating the reduction of emissions from road transport on a range of pathways, including through development of infrastructure and rapid deployment of zero and low-emission vehicles;...*

"In addition to these energy-related recommendations, the first GST also highlights the following non-energy-related outcomes for mitigation:

- *"Further emphasizes the importance of conserving, protecting and restoring nature and ecosystems towards achieving the Paris Agreement temperature goal, including through enhanced efforts towards halting and reversing deforestation and forest degradation by 2030, and other terrestrial and marine ecosystems acting as sinks and reservoirs of greenhouse gases and by conserving biodiversity, while ensuring social and environmental safeguards, in line with the Kunming-Montreal Global Biodiversity Framework."*

UN support

To assist developing countries to prepare their NDCs, the UN has prepared a set of support processes[58], described as:

> *"...an interactive tool that supports the development of NDCs to be submitted in 2025. It helps countries raise ambition and accelerate implementation of the next round of NDCs (NDCs 3.0).*
>
> *"The NDC 3.0 Navigator seeks to support and inspire country NDC teams, their experts, and partners, bringing together knowledge and support in a series of Routes to Ambitious and Implementable NDCs[59], which:*
>
> - *Provide examples of opportunities to consider when developing NDCs 3.0*
> - *Highlight some of the Strategies that could enable each Opportunity*
> - *Identify the connecting Routes and Opportunities*
> - *Showcase country Case Studies*
> - *Provide links* to further Resources"

The NDC Partnership advises[60] that it:

> *"...supports its developing country members, upon request, with coordinated resources and expertise to develop and align Nationally Determined Contributions (NDCs) and Long-term Low Emissions Development Strategies (LT-LEDS) in line with the Paris Agreement.*
>
> *"If countries would like more information on how the NDC Partnership can support their NDC 3.0 development, they are invited to reach out using this form."*

The Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Water Convention), its Task Force on Water and Climate and the Global Network of Basins Working on Climate Change Adaptation in Transboundary Basins are key platforms that can support the development of joint adaptation strategies across borders.

58. NDC 3.0 Navigator: https://ndcnavigator.org/
59. NDC 3.0 Navigator: https://ndcnavigator.org/routes/
60. NDC Partnership: https://ndcpartnership.org/

Annex 4: Glossary of terms

An **'aquifer'** means a large body of permeable or porous material situated below the water table that contains or transmits groundwater (IEA, 2016).

'Clean energy' means those energy types identified by IPCC 6 – the IPCC's sixth assessment cycle – as contributing to greenhouse gas reductions and hence qualifying as climate mitigation measures.

'Consumed' means the water is lost to other uses by being converted into other substances or being committed to an exclusive ongoing use or is lost in the short term by evaporation or transpiration (IUCA, 2024), or the volume withdrawn that is not returned to the source (i.e. it is evaporated or transported to another location) and is no longer available for other uses (IEA, 2016).

'Dependency' means the measure cannot be implemented without the consumption or availability of water (IUCA, 2024).

'Desalination' means reducing the contents of total dissolved solids or salt and minerals in sea or brackish water (IEA, 2016).

'Water' means any water that is not seawater or saline groundwater that has no other use without desalination (IUCA, 2024) or water with less than 1,000-2,000 parts per million (ppm) of dissolved salts (IEA, 2016).

'Greenhouse gases' means carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).

'Groundwater' means water that is below the land surface in pores or crevices of soil, sand and rock, contained in an aquifer (IEA, 2016).

'Watercourse' means a system of surface waters and groundwaters constituting by virtue of their physical relationship a unitary whole and normally flowing into a common terminus, as defined in the Watercourses Convention (New York, 1997).

'Water sector' includes all processes whose main purpose is to treat/process or move water to or from the end-use: groundwater and surface water extraction, long-distance water transport, water treatment, desalination, water distribution, wastewater collection, wastewater treatment and water re-use (IEA, 2016).

'Water stress' is defined as when renewable annual water supplies fall below 1,700 m^3 per person; water scarcity is below 1,000 m^3 per person; and absolute scarcity below 500 m^3 per person (IEA, 2016).

'Withdrawal' is the volume of water removed from a source; withdrawals are always greater than or equal to consumption (IEA, 2016).

'Water treatment' is the process of removing contaminants from water or wastewater to bring it up to water quality standards and for storage in water reservoirs (IEA, 2016).

Notes

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