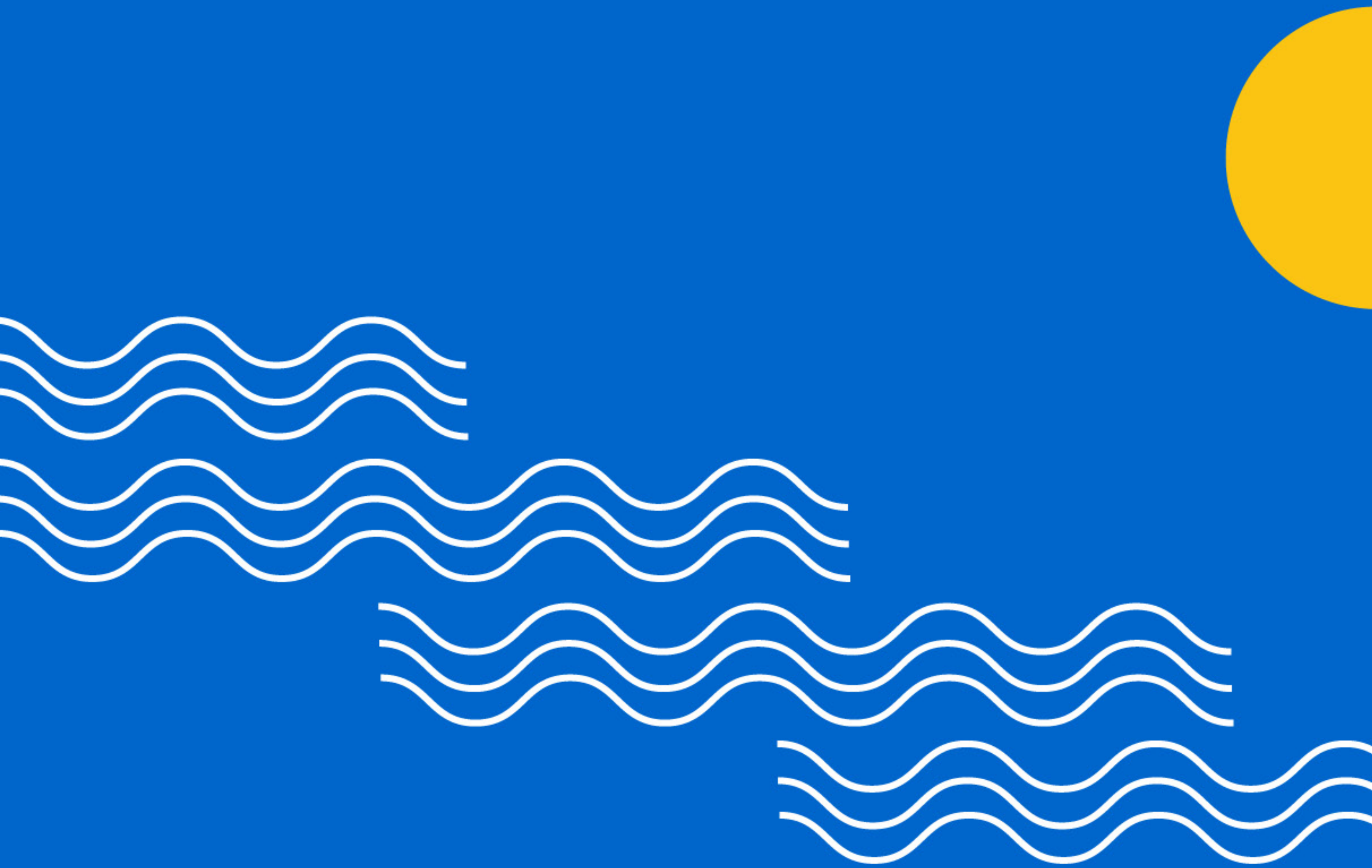
Report on Sustainable Water and Energy Solutions Addressing Climate Change



2021

SUSTAINABLE
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Preface

Preface

Water, energy and climate change are strongly interrelated. Understanding the interlinkages at global, regional, national, and local levels is crucial to anticipating future stress points, developing rational policies, selecting appropriate technologies, managing risks, realizing valuable synergies, preventing eventual conflicts and formulating effective and integrated sustainable water and energy solutions. Many sustainable water and energy solutions could be implemented to effectively address some of the most important climate change challenges. Multiple synergies could be realized where water and energy systems are developed and used in an integrated manner, supporting climate change mitigation and adaptation objectives.

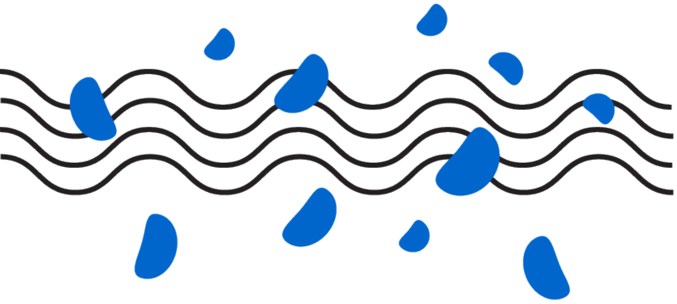
Recognizing the need to address the interlinkages between water and energy in a more systematic manner, the UN Department of Economic and Social Affairs (UN DESA) and Itaipu Binacional jointly launched a sustainable development initiative entitled “Sustainable Water and Energy Solutions Network” in December 2018. Itaipu is the bi-national organization established by the governments of Brazil and Paraguay to harness the hydropower of the Paraná River. The Network expanded to a total of 16 members from different worldwide stakeholders by the end of 2020.

This report is an output of this global multi-stakeholder Network which was created to enhance capacities and cooperation and to enable an integrated approach to the Sustainable Development Goals on water (SDG 6) and energy (SDG 7) and the interlinkages with other SDGs, particularly SDG 13 on climate change. The Network objectives include sharing best practices, experiences and lessons learned, capacity building, and global awareness.

The report seeks to inform the ongoing expert and public policy debate on sustainable water and energy solutions addressing climate change with a view to facilitate information exchange, enhance local, national and international cooperation, and stimulate collaborative development actions that “leave no one behind” in terms of water supply and sanitation, access to sustainable energy, and protection from potential negative impacts of climate change.

The importance of energy and water and their strong interdependence have become more evident during the COVID-19 world crisis. Without the critical services of water and energy, the full spectrum of health services could not be implemented. A devastating situation could occur anywhere if these services were to be disrupted even for a short period of time during a pandemic. In light of the grave consequences resulting from the COVID-19 pandemic, sustainable water and energy solutions are viewed as a necessary response for a more resilient and sustainable recovery.

Key messages for policy makers



Key messages for policy makers

- There are high and increasing needs for both water and energy, as the world population grows and economies expand. With persistent poverty, many people in developing countries still lack access to water, sanitation, and affordable sustainable energy, while becoming more exposed to the impacts of climate change.

- Water and energy sectors are highly interdependent, and both are significantly linked to climate change. Integrated development and management of water and energy could provide sustainable solutions that diminish negative climate change impacts. Potential risks and costs of climate change are becoming more evident. Actions on mitigation and adaptation are increasingly urgent, particularly in these two sectors.

- Sustainable water and energy solutions that support climate change objectives are identified in relation to technological systems or areas such as: (a) hydropower, (b) wind and solar photovoltaic systems, (c) cooling systems in thermoelectric power plants, (d) geothermal, (e) bioenergy, (f) ocean energy, (g) hydrogen, (h) water supply, distribution and irrigation systems, (i) wastewater treatment, (j) desalination, (k) decentralized water and energy supply systems, (l) water-energy end use efficiency, and (m) innovative sanitation systems.

- Policies, programmes, and actions that promote renewable energy and incentivize efficiency and conservation of water and energy use have significant positive benefits, support climate change objectives, and should be expanded in a coordinated manner.

- Hydropower generation from reservoirs, rivers, and for energy storage makes a significant contribution to renewable electricity supply systems. Modernization, capacity expansion, and powering of non-powered dams and water conveyances offer many options to increase power supply without consuming additional water or increasing emissions considerably.

- Dams and water reservoirs, constructed for hydropower generation, play an important role in the control and management of water flows reducing the risks of floods and mitigating the risks of draughts.

- Thermoelectric power systems generate emissions and consume large amounts of water for cooling. Integrated water and energy management and planning of these power systems is essential, particularly in water-scarce regions. Co-generation can greatly increase productivity.

- Sustainable bioenergy can contribute to climate change objectives by helping to reduce consumption of fossil fuels. It is important, however, that bioenergy development be based on sustainable water and land management practices that take into account other potential uses of these resources.

- Geothermal energy, ocean energy and hydrogen represent potential options for integrated water and energy solutions and can make significant contributions to the objectives of climate change and sustainable development in the future.

- Irrigation, wastewater collection and treatment, and water purification and desalination are energy-intensive and in general account for a large share of fossil fuel consumption and greenhouse gas (GHG) emissions in the water sector. Opportunities exist for efficiency and environmental benefits through greater use of renewable energy in the water sector. Biogas from wastewater facilities can reduce GHG emissions and generate electricity.

- Decentralized integrated water and renewable energy systems can play a pivotal role in advancing sustainable rural development and poverty alleviation. These innovative systems support the global objective of “leaving no one behind.”

- Improved efficiency at the point of end use provides a great potential to induce a more sustainable integrated use of water and energy and a reduction in GHG emissions.

- Innovative sanitation systems based on integrated water and energy solutions are being developed but need further worldwide support, particularly for application in rural areas of developing countries.

- Integrated resource development and investment planning for water and energy can offer multiple co-benefits, including lower costs and lower environmental emissions. Integrated planning should be fully participatory and address climate concerns.

- Coordinated decision making on the development and use of water and energy resources is necessary for: (a) developing countries with rapid economic growth, (b) less and least developed countries where large parts of the population lack access to modern energy and water services, (c) countries where water and/or energy resources are very scarce, and (d) countries that may be particularly affected by climate change.

- There remain major asymmetries between water and energy. Energy is recognized as valuable and it attracts investment and political attention while water is widely seen as a public good. Financing water and wastewater infrastructure therefore is particularly challenging. Availability of water data is another major challenge. Policy makers need to be aware of and address these sectoral asymmetries.

- Transboundary cooperation for integrated river basin water and energy development and regional power pools is essential for regional sustainable development.

- A review of national institutional and legal frameworks may create a more enabling environment for integrated and balanced decision making on water and energy.

- Additional support for research and innovation can accelerate further development, commercialization and diffusion of climate friendly integrated water and renewable energy systems representing sustainable solutions.

- Opportunities for development of water and energy resources differ among countries depending on the respective natural resource endowment and development priorities. Each country needs to determine its own approach to advancing towards achieving the Sustainable Development Goals on water, energy, and climate change.

- Greater international solidarity and technical and financial cooperation are necessary to enable less and least developed countries to develop and manage water and energy systems in a more integrated and sustainable manner.

I.

Introduction

Introduction

Water and energy are key preconditions for human life on earth, and fundamental for economic and social development. Most forms of energy production need water, whether for powering turbines, transferring heat, cooling machines, or growing biomass and fuel crops on irrigated land. At the same time, all modern systems that provide water for drinking, industrial production, or irrigation, and all systems that treat wastewater for reuse depend on energy for pumping, water transport and processing.

With continuing population growth, further expansion of industrialized and developing economies, and plans for accelerated provision of access to water, energy, and sanitation for the urban and rural poor, global needs for water and energy are projected to continue to grow rapidly. Much more water and much more energy will be needed to enable sustainable development. The needs for additional sustainable water and energy supplies are high in most developing countries, particularly in the least developed countries.

The interdependency between water and energy has significant implications for water and energy security and for climate change mitigation and adaptation. Understanding the interlinkages among water, energy and climate at global, regional, national, and local levels is crucial to anticipating future stress points, formulating and implementing rational policies, selecting appropriate technologies, managing risks, realizing valuable synergies and preventing conflicts.

In September 2015, the General Assembly adopted a new agenda to guide global development efforts for the period 2015 to 2030. The 2030 Agenda for Sustainable Development sets out 17 goals and 169 targets, which jointly constitute a comprehensive plan of action to eradicate poverty and ensure sustainable development. The Sustainable Development Goals (SDGs) cover a wide range of drivers across the three pillars of sustainable development, including a dedicated goal on water (SDG 6) calling to "ensure availability and sustainable management of water and sanitation for all", and a first-ever global goal on energy (SDG 7) that calls to "ensure access to affordable, reliable, sustainable and modern energy for all".

The 2030 Agenda for Sustainable Development recognizes the vital role that improved access to both water and energy plays in advancing progress in other areas. Powering progress on SDG 6 and SDG 7 will also have an effect on a range of other Sustainable Development Goals, such as those on health, food, poverty eradication, education, economic productivity, and climate change, as well as in interdependent processes including the Paris Agreement on Climate Change. A transformative, integrated approach to water and energy lies at the heart of the success of these interconnected agendas and processes.

The Paris Agreement also offers an opportunity to advance sustainable development through scaled-up action on integrated water and energy. Achieving SDG 7 will be an essential element for meeting the climate objectives agreed upon in Paris. Increasing the share of renewable energy in the global energy mix by 2030, underpinned by energy efficiency, will play a decisive role in setting the world on a pathway toward limiting global temperature rise to below 1.5°C. Water resources management is key for climate adaptation. Water is also critical for climate change mitigation, as many efforts to reduce greenhouse gas emissions depend on reliable access to water and on the integrated management of water resources.

A coordinated and integrated approach to water and energy should transcend national borders and could help to diminish potential conflicts arising from the sharing of these natural resources and from climate change. The integrated approach will also help to identify synergies and to avoid negative trade-offs that could result when water and energy are managed independently.

This coordinated approach is essential to the pursuit of climate change objectives given the fact that energy and water are key factors in mitigation and adaptation procedures. With energy-related CO2 emissions estimated at two-thirds of global CO2 emissions, transforming the energy sector is key for mitigating climate change. Water management also plays an important role in climate change mitigation through interventions such as wetland protection and conservation agriculture. Precipitation and temperature patterns are changing all over the world, implying a need to focus attention on water and potential needs for adaptation plans. As the impacts on climate change become more evident all over the world, policy makers need to realize the importance of following a coordinated and integrated approach to water and energy. Coordinated efforts on water and energy and integrated water-energy systems will be critical, especially for nations expected to experience rapid economic and population growths, nations with large segments of the population without modern energy and water services, nations with limited water and/or energy resources, and nations highly affected by climate change.

Water and energy are also critical during world health crises. The COVID-19 pandemic in record time has brought immense tragedy reflected by the large number of people who have died or have become seriously ill and the devastating impacts to the world economy. The crisis has made evident to everyone the importance of high-capacity, robust and reliable health systems, programmes and infrastructures as well as the availability of relevant medications. Behind reliable health programmes, there are a number of critical services, sometimes taken for granted, without which the full spectrum of health services could not be executed. These critical services include water and energy. The effective management of the interdependence between water and energy is very important for the world population particularly during a world health crisis. The world reliance on water and energy has never been more evident than during the COVID-19 world crisis. Therefore, sustainable water and energy solutions represent a necessary response to the COVID-19 crisis for a sustainable and more resilient world recovery that includes climate change considerations.

This Global Report on Sustainable Water and Energy Solutions Addressing Climate Change presents an overview of important and relevant issues related to water and energy and their interlinkages. Furthermore, the overview explains the interconnection among water, energy and climate change. Additional relevant issues are summarized related to interconnected water and energy systems, institutional and decision-making frameworks, data and statistics challenges, related innovative technological systems and COVID-19 relevant issues.

II.

Water

Water

Demand, availability, and energy requirements

Although major progress has been achieved in the last decades in relation to water and sanitation access, major challenges still remain. While the proportion of people using at least a basic drinking water service grew from 81 per cent in 2000 to 91 per cent in 2015, it is estimated that today about 2.2 billion people or close to three out of ten people lack access to safely management water supply. Of this, about 844 million still lack even a basic water service. In relation to sanitation services, the proportion of people using at least a basic sanitation service improved from 59 per cent in 2000 to 68 per cent in 2015. Nevertheless, over 4.2 billion people or about 54 per cent currently lack access to safely managed sanitation services (UNESCO et al, 2020) (UN, 2018).

Water resources are vast but only about 2.5 per cent of global water resources represent fresh water the rest is sea water. Close to 70 per cent of the global fresh water is confined in glaciers and ice and close to 30 per cent of the rest is deep underground water, some of which is contaminated and not proper for human consumption or use. Therefore, only less than 1 per cent of the global freshwater is available for human consumption. Furthermore, the amount of surface and groundwater resources (renewable water resources) available from the hydrological cycle varies extensively by regions and countries. There are also major seasonable variabilities that are not captured by the annual average data (IEA, 2016 Excerpt).

Many countries and regions are facing some levels of water stress that are intensifying due to climate change. Today over 2 billion people live in countries experiencing high water stress. Also, it is estimated that about 4 billion live in areas that potentially could face severe water scarcity for at least one month of the year. By 2050, the number of people in this situation is estimated to be in the range of 4.8 to 5.7 billion (UNESCO et al, 2018 and 2019).

Water use from surface water and groundwater sources has been increasing by about 1 per cent annually since 1980. Surface water represents about two thirds of the fresh water supply. About 60 per cent of the fresh water supply from surface water comes from over 270 transboundary water basins that exist in the world. The proper management of these major sources of water represents important governance challenges in many world regions. Groundwater sources, which provide a third of the freshwater supply, are being diminished at extraction rates greater than recharge rates. In particular, 21 of the 37 largest aquifers are considered to be severely over exploited. Given the interconnectedness of the hydrological cycle, how rivers and aquifers are managed or used in one area could dramatically affect the water supply in another area (IEA, 2016, Excerpt).

Water consumption varies across the different sectors of the economy. The demand of the agriculture sector is the highest, at about 69 per cent. This includes irrigation, livestock and aquaculture. Industry is second at 19 per cent, which includes power generation. The household sector demands the other 12 per cent of water resources. (IEA, 2018 Excerpt).

About 80 per cent of the wastewater from municipal, industrial and agricultural sources is discharged without any treatment, which constitutes a major pollution source affecting the availability of freshwater and degrading water and terrestrial ecosystems. Reducing pollution from wastewater discharges is a critical challenge in relation to contaminated freshwater, and the problem is increasing in many regions worldwide. Therefore, the management and treatment of wastewater represents an opportunity and an important option as a future potential water supply that could diminish negative environmental impacts. Wastewater is considered an undervalued source of water, energy, nutrients and other recoverable by-products. Many social, economic and environmental benefits can be derived from the recycling, reuse and recovery of what is considered wastewater. Water stress in many regions could be diminished by wastewater reuse and recycling (UN, 2018).

Energy is a major requirement for the provision, transport, treatment and distribution of fresh water from surface water and groundwater, for desalination and for the treatment of wastewater. It is estimated that about 120 million tons of oil equivalent (Mtoe) per year is used by the global water sector. More than 50 per cent of energy requirements is in the form of electricity at about 850 TWh or 4 per cent of the global electricity consumption. The global energy consumption in the water sector corresponds to 42 per cent for water supply, 26 per cent for desalination and water re-use, 14 per cent for wastewater treatment, 13 per cent for distribution and 5 per cent for transfer (IEA, 2018 Excerpt).

Water-use efficiency represents another key option to decrease water stress worldwide. The water losses in industrial processes (including cooling of thermal power plants) as well as in municipalities are considerable, and investments in reducing these losses could be more cost-effective than other alternatives to increase water supply in regions facing scarcity. Irrigation in agriculture represents another major area where efficiencies could be realized.

By 2050, global water demand is expected to increase by 20 to 30 per cent from the current level of demand, following a similar growth rate observed in the past decades of 1 per cent per year. (UNESCO et al, 2019)

In relation to future energy requirements by the global water sector, an estimate by the International Energy Agency (IEA), based on its Sustainable Development Scenario, indicates an increase in energy use by the water sector of 50 per cent by 2030. This Scenario is designed to achieve the SDGs on energy access (SDG 7), air pollution (SDG 3, Target 3.9) and climate change (SDG 13) in the most cost-effective manner. This Scenario does not consider in its assumptions achieving the SDG 6 on water. The increases in energy use, according to this Scenario, will be mainly in the following areas: desalination for water-scarce regions such as the Middle East and North Africa; large-scale water transfer projects such as the South-North Water Transfer Project in China; wastewater treatment; and water supply (IEA, 2018 Excerpt).

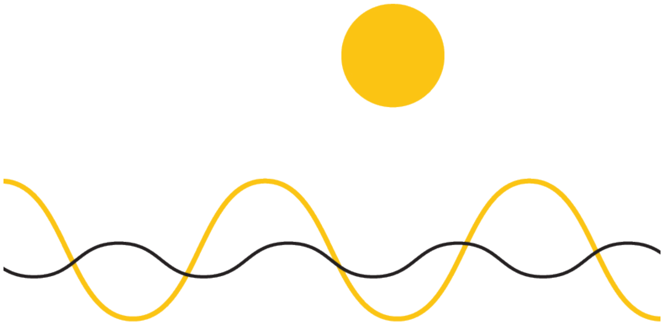
A variation of the IEA Sustainable Development Scenario, in which the SDG 6 on water and its targets are achieved, indicates that the energy consumption of the global water sector will not increase considerably. This means that 2.1 billion people could gain access to clean drinking water, and 4.5 billion could benefit from safely managed sanitation, while global energy demand would increase by only 1 per cent by 2030, assuming that water supply and wastewater treatment are provided in an energy efficient way (IEA, 2018 Excerpt).

III.

Energy

Energy

Demand, supply, and water requirements



Significant progress has been achieved in relation to the global sustainable development goal of ensuring access to affordable, reliable, sustainable and modern energy for all (SDG 7). The number of people without access to electricity has been reduced from 1.2 billion in 2010 to less than 800 million in 2018. About 367 million people gained electricity access during the 2016-2018 period. The use of renewable energy has increased considerably, reaching a share in global final energy consumption of 17.2 per cent in 2018, up from 16.3 per cent in 2010. Global energy efficiency has also been improving at an accelerated rate of 2.2 per cent per year during the 2010-2017 period (UN, 2019) (UN,2020).

Nevertheless, the global effort needs to be accelerated to achieve the necessary energy targets supporting sustainable development by 2030. With respect to the target of universal energy access, 2.8 billion people still depend on unsustainable solid biomass for cooking. This situation mainly affects children and women and results in about 3.8 million premature deaths annually. In relation to the use of renewable energy, the transformation of the global energy system that is needed to mitigate the negative effects of climate change implies a greater accelerated rate in the use of renewable energy everywhere. Also, the improvements in energy efficiency worldwide still have not reached the necessary annual rate of 2.6 per cent.

The world demand for energy and electricity continues growing at an accelerated pace. In 2018, the world total primary energy supply was 14,282 Mtoe corresponding to a world total final energy consumption of 9,938 Mtoe. Electricity generation was 26,619 TWh with shares of hydropower at 15.8 per cent and non-hydro renewables and waste (geothermal, solar, wind, tide/wave/ocean, biofuel, waste) at 9.8 per cent (IEA, 2020). In 2018, the global energy consumption grew by 2.3 per cent which is the fastest pace in this decade, driven by higher cooling and heating needs in some regions and a robust global economy. Over half of the growth was due to higher electricity demand which grew at its fastest pace since 2010. Renewables covered almost 45 per cent of the growth in electricity generation and now account for over 25 per cent of global power generation (IEA, 2019b).

Water is needed for most energy processes and systems. Water is necessary for the production of energy fuels such as coal, oil, uranium and gas. It is used as an input for energy crops or biofuels and biomass for fuel pellets. Water is a key factor in power generation for cooling purposes or as a driving force for hydroelectric and steam turbines. Water can also be used as a means of transportation allowing, for example, the transport of coal slurry through pipes from mines to power plants (UNESCO et al, 2014).

For 2016, it is estimated that the global energy sector withdrew around 340 billion cubic meters (bcm) of water, of which about 50 bcm were consumed. Water use by the energy sector represents about 10 per cent of the global water withdrawals and 3 per cent of the water consumption. In relation to water consumption, primary energy production (including production of fossil fuels and biofuels) is responsible for about 70 per cent of the water consumption in the overall energy sector.

Power generation is by far the largest subsector of the energy sector responsible for water withdrawals. About 88 per cent of the water withdrawals in the energy sector in 2014 corresponded to power generation. The water withdrawals in the power sector are 58 per cent for fossil fuel plants, 28 per cent for nuclear plants and 2 per cent for renewables. The other 12 per cent corresponded to primary energy production of fuels for the power sector including biofuels, coal, gas and oil. Many factors affect the withdrawal of water in the power sector, particularly the overall efficiency of thermal power plants and the type of cooling system. Other factors include the turbine design, fuel type and meteorological conditions. Nuclear power plants, when compared to coal or gas plants using the same cooling systems, withdraw more water per unit of energy produced. One of the main reasons is that nuclear plants have large cooling needs and cannot dismiss heat into the atmosphere. Conversely, combined-cycle gas turbines have some of the lowest rates of water withdrawals and consumption since they have higher thermal efficiency and require less cooling (IEA, 2016 Excerpt).

The estimates for water withdrawals or water consumption in the global energy sector do not include water used by hydropower plants. Although the majority of the water withdrawals by hydropower plants return to the source or river, the consumption varies depending on a range of factors (IEA, 2018 Excerpt). In general, data on water consumption by hydropower plants are inconsistent. Initiatives are being considered for the development of measuring methodologies for apportionment of water consumption in the various services of the reservoir (UNESCO et al, 2014).

Assessing water needs while considering the physical, economic and environmental viability of energy projects is becoming increasingly important, especially in relation to power plants. Water availability could represent a barrier for the expansion of the power sector in many countries.

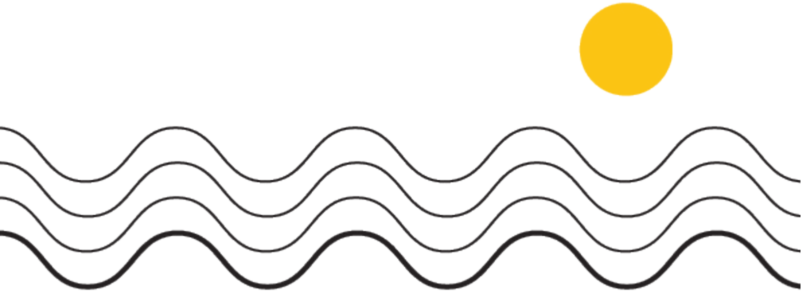
The projections of water consumption and withdrawals by the energy sector vary depending on the different scenarios that could be considered for energy demand and supply in the future. An estimate by the International Energy Agency (IEA), based on its Sustainable Development Scenario, indicates that water consumption will increase by 50 per cent to reach almost 75 bcm in 2030. This Scenario projects that global water withdrawals from the energy sector will decline to 275 bcm by 2030. The reduction in water withdrawals is the result of increases in efficiency, moving away from coal plants and the increased deployment of solar photovoltaic and wind power. The net increase in water consumption is a consequence of increases in nuclear power generation, bioenergy, concentrated solar power and carbon-capture use and storage (IEA, 2018 Excerpt).

Power generation from coal generates significant amounts of ash which can also cause river and ground water contamination. The related monitoring and regulation of ash disposal is important to reduce longer-term external costs, and environmental and health impacts.

IV.

Water, energy and climate change

Water, energy and climate change



Water, energy and climate change are strongly interrelated. Scientific evidence confirms that the observed global warming trend is linked to the anthropogenic emissions of greenhouse gases (GHGs) which are increasing at an accelerated rate since the pre-industrial era. The world is experiencing unprecedented levels of atmospheric concentration of GHGs, including carbon dioxide, methane and nitrous oxides. Water availability, quality and quantity are highly affected by the impacts of climate change. Energy, needed to power the economies of the world, is a major contributor to GHG emissions. Both water and energy can play very critical roles in climate change mitigation and adaptation.

Adaptation to climate change is critically related to water, given the impacts of high climate variability and extreme weather events on the water sector. Water resources are subject to greater variability in time and space due to intensifying climate change impacts. Adaptation is indispensable for the water sector to be able to offset the effects of floods and to diminish water stress in human settlements, agriculture and industry. The quality of water in many world regions is negatively affected by impacts from climate change such as higher water temperatures, reduced dissolved oxygen and by the diminishing capability of freshwater bodies for self-purification. Climate change can additionally degrade important ecosystems such as forests and wetlands and can also compromise water related infrastructures such as dams, water supply and distribution systems, and sewer pumps and networks.

Climate change mitigation can be supported by Integrated Water Resource Management (IWRM) through the protection of wetlands, conservation agriculture and other nature-based solutions. Wetlands hold the largest carbon stocks among terrestrial ecosystems, storing twice as much carbon as forests (UNESCO et al, 2020). The restoration and conservation of wetlands is vital for many reasons including their role in the mitigation of floods and droughts, in water purification and in biodiversity. Therefore, protection of water and terrestrial ecosystems is of great importance. These strategies could allow considerable carbon sequestration in biomass and soils. Additional ecological benefits can be realized by conservation agriculture, which allows soils to retain more water, carbon and nutrients. Forests, grasslands and wetlands, that are properly managed, provide biomass and soils that represent important opportunities for carbon sequestration with additional benefits in terms of biodiversity and nutrient cycling.

The water sector generates GHG emissions that contribute to climate change, but these emissions are mainly related to the energy used for water and sanitation systems or for biochemical processes needed to treat water or wastewater. Therefore, increasing the use of certain types of renewable energy (e.g., wind and solar PV) in water systems will reduce GHG emissions. Also, improving wastewater treatment processes as well as water use efficiency and reducing water losses will decrease energy use and consequently GHG emissions. In particular, innovative wastewater treatment could produce biogas which is a renewable energy source. Treatment of wastewater represents a great opportunity for mitigation given the fact that most of the wastewater around the world is released to the environment without any treatment.

Energy generated from fossil fuels is a major driver of climate change. Increasing concentrations of GHGs in the atmosphere and related negative impacts on ecosystems result from the use of fossil fuel for energy. An overall transformation of the global energy system is necessary to allow climate-friendly sustainable energy supplies to satisfy energy needs overcoming fossil fuel dependence (UN, 2019). This situation demands an accelerated move towards the use of renewable energy and effective measures to increase energy efficiency everywhere. The climate change objectives cannot be achieved without a timely and effective global energy transition supporting decarbonization and inducing climate change mitigation. Furthermore, a reduction in the use of fossil fuels and an increase in the use of renewable energy, such as wind and solar PV, translate into a considerable reduction in the withdrawal and consumption of water, which is another major global sustainable objective.

Some energy systems can be potentially impacted by water stressors resulting from climate change. For example, increasing water temperatures in rivers, lakes or oceans that are the sources of water used for cooling could affect the efficiencies of thermal power plants reducing power output or even forcing plants to shut down. Low water levels in water bodies feeding thermal and hydropower plants could also force operations to be stopped. Adaptation strategies and contingency plans are becoming essential to ensuring reliability and continuous operation of some energy systems in the long term. By the 2050s, climate change could force a reduction in thermoelectric power of 7 to 12 per cent in most regions and of 1.2 to 3.6 per cent in hydropower, especially in South America and Australia (UNESCO et al, 2020).

Changes in precipitation patterns and extreme weather events can very seriously affect the electric power sector. During the heat wave in July 2019, several nuclear reactors in France and Germany were temporarily affected, reducing operations due to insufficient cooling water from the nearby rivers. The impacts of cold waves and heat waves on the energy production sector have been assessed and the challenge of meeting peak energy demand during these particular periods has been pointed out (Añel, J.A., et al, 2017). Extremelly cold weather forced the shutdown of the power grid of the state of Texas in the USA in early 2021 for several days showing how vulnerable the existing power grid systems are, even in developed countries. Climate change will continue increasing the number of extreme events in different world regions. The systematic risks that are evident in existing water-energy production systems need to be assessed. Vulnerability assessments and resilience and contingency plans are recommended. Over time, greater diversification of the electric power sector and a higher share of renewable energy supplies, such as solar PV and wind, can also help to increase resilience. Other potentially necessary investments may include changes in cooling systems of thermoelectric plants which may be warranted if long-term projections suggest future shortages of cooling water.

Energy systems could also play an important role in adaptation to climate change. For example, hydropower dams could be used to store water during times of floods, potentially avoiding inundation and devastation of communities located on the lower side of the dam. Conversely, water could be released from hydropower dams during periods of droughts, allowing water access to affected communities.

al (2017) have surveyed the impact of cold waves and heat waves on the energy production sector (with particular reference to Spain) and have pointed out the challenge of meeting peak energy demand during these particular periods. Where they do not as yet exist, vulnerability assessments and resilience plans are recommended. Over time, greater diversification of the electric power sector and a higher share of renewable energy supplies can also help to increase resilience. Other potentially necessary investments may include changes in cooling systems of thermoelectric plans which may be warranted if long-terms projec

V.

Institutonial and decision making frameworks

Institutional and decision making frameworks

There are major asymmetries between energy and water in relation to economics, commercial viability of investments, and sectoral governance. Energy is a major economic domain. Energy is costly and considered very valuable. Hence, decision makers in both public and private organizations commit considerable resources to the development of energy systems. Although an indispensable factor for life, water primarily is regarded as a public health and welfare issue that attracts less attention. Access to clean water and sanitation is widely considered a human right and, in general, water resources are seen in many countries as a public good for which the public sector primarily is responsible.

In relation to the interconnections that exist between energy and climate change, and between water and climate change, there seems to be more emphasis on tackling the energy-climate interconnection. For example, water is not mentioned in the Paris Agreement per se and is hardly mentioned in the Sendai Framework for disaster risk reduction (UNESCO et al, 2020). The important role of water in mitigating and adapting to climate change should be further recognized across different policy frameworks.

Prices of water and energy are often subsidized and typically do not reflect the true scarcity, societal costs or economic value. In many countries, the price of water is particularly low, sometimes lower than the basic cost of supply. Therefore, private investors are less likely to engage in and finance water projects. Urgent investments in sanitation and wastewater treatment typically get little political attention. Only recently, more global awareness of the importance of water has developed. This reflects the eminent crisis happening in many countries due to lack of water resources and the already negative impacts on water resulting from climate change (UNESCO et al, 2014 and 2019). In many developing countries, major investments are needed for all types of infrastructure and services, but the development of water and sanitation infrastructure requires particular attention as well as international funding support. In general, there are major issues related to governance and government regulations, such as subsidies, that need strong consideration and assessment. In energy, one of the main issues is the large fossil fuel subsidies that are in place in many countries with important negative implications related to climate change.

In many countries, coherent policies encouraging integrated solutions to water and energy need to be formulated and implemented consistent with sustainable development and climate change objectives. The relevant Ministries will need to formulate coherent water and energy policies and programmes, taking into consideration national priority needs, the availability of resources, the interests and competencies of local actors, options for mobilization of financing, established legal and regulatory requirements, as well as environmental and climate concerns. Some developing countries have seen an advantage in combining the concerned ministerial portfolios of water and energy. Among others, the following countries have established Ministries of Water and Energy: Afghanistan, Angola, Barbados, Cameroon, Ethiopia, Lebanon, Malta, Morocco, Nepal, Tajikistan, Qatar, Rwanda, Somalia, and South Sudan. In other countries, ministerial portfolios on water, irrigation and energy are linked with other issues, including the development of other infrastructure, or other natural resources or industries, and environmental protection. Several countries have established departments specifically dedicated to enhancing the development and use of renewable sources of energy. Regardless of the particular national institutional arrangements, the main concern remains the inter-sectoral and inter-disciplinary coordination in the planning processes. Extensive consultations with concerned stakeholders also need to be institutionalized and implemented. Another important dimension is the actual allocation of resources for integrated water and energy development by the respective central planning authorities and finance ministries.

At local levels, initiation, planning and coordination of investments in water and sanitation typically fall within the mandate of municipalities and local authorities and the respective public enterprises. Investments in decentralized power generation systems may also be coordinated in consultation with local authorities. Planning capacities and location of local water, sanitation and energy infrastructure offer opportunities

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for synergies and efficiency gains (IEA, Excerpt 2016). Local integrated urban and rural development plans are best developed in direct consultation with the communities concerned. National authorities may provide the enabling framework and support local planning and decision making with expertise and capacity building. Many developing countries, notably least developed countries, would also greatly benefit from greater international technical and financial support for implementing decentralized water and energy solutions that address the most urgent needs of the urban and rural poor.

Coordination of the development of larger-scale water and energy projects is also of particular importance at the regional level. Larger-scale energy projects may be planned to also serve customers in neighbouring countries. Regional interconnections of power grids can help to balance structural differences or temporary fluctuations in national and local power generation and demand and supply and enable participants to use the available energy resources in the most sustainable and climate friendly manner. Electric power pools are operational in many developing regions and subregions of Africa, Asia, and Latin America.

Regional and cross-border cooperation is also particularly essential to enable a coordinated management and use of the waters of transboundary river basins. On all continents, concerned governments have formed regional inter-governmental bodies with a view to coordinate river basin-related development efforts. These inter-governmental bodies are well placed to conduct comprehensive development studies and establish forward-looking multi-sectoral models, including on the water-energy nexus, to facilitate collaborative planning and decision making processes and manage potentially competing uses of available water resources.

The Convention of the Law on the Non-Navigational Uses of International Watercourses, which was adopted in 1997 and entered into force in 2014, facilitates intergovernmental cooperation on water and energy at the global international level. To date, 39 UN Member states have ratified the Convention (UN, 1997; UNECE, 2019). In Europe and Central Asia, the UNECE has facilitated (sub)regional consultative processes, including comprehensive water-food-energy-ecosystem nexus studies for international river basins, comprising, among others, the Sava River Basin, the Syr Darya River Basin, and the Drina River Basin (UNECE, 2018). The International Institute for Applied Systems Analysis (IIASA) has undertaken water-energy nexus studies for the trans-boundary Zambezi River Basin in Africa, and for Indus River Basin in South Asia (IIASA, 2018).

VI.

Data and statistics challenges

Data and statistics challenges

Policy makers and experts from public and private sectors need to be aware of and to understand that there are major differences between energy and water in relation to data availability. As discussed previously, energy is considered a very important factor with great value, representing a significant cost to people in the household, industrial, manufacturing, services, and agricultural sectors of the economy. It is also a factor that normally can be quantified and measured through time and space, facilitating its control and accountability for commercial purposes. Water, however, seems to be perceived as a public good and therefore tends to receive less attention. Also, water resources are subject to great variabilities in time and space which are already intensifying due to climate change impacts. The worldwide variability in the water cycle makes it more difficult to measure and to assess water issues and to build comprehensive and disaggregated sets of data, statistics and indicators including time-series data.

Therefore, there are many issues related to data that need to be taken into consideration in the development of sustainable water and energy solutions. In general, the same level of data is not available for water and energy, representing a challenge for decision makers while assessing synergies and trade-offs that may result from the implementation of integrated water and energy projects. The lack of relevant water data is particularly important in relation to water withdrawals and consumption by energy systems and with respect to the energy intensity of water treatment and distribution systems. In relation to the SDG 6 on water, less than 50 per cent of the UN Member States have comparable data available on progress towards meeting each of the targets of this Sustainable Development Goal. (UN, 2018a)

Lack of shared, transparent data and information across sectors creates difficulty in analysis and planning as well as in infrastructure design for water and energy. In many countries there are few mechanisms and incentives across agencies for data sharing, which makes joint and integrated planning even more challenging.

Another challenge is that many organizations and businesses are obliged to treat their data as confidential; hence, some of the available data may not be accessible, even for research purposes.

A lot of the data needed to assess and develop sustainable energy and water solutions is related to social, economic and environmental projections into the future. Although there are many modelling and simulation techniques that try to develop integrated projections and alternative future scenarios, in many cases the basic information, data and indicators to run these models are not available, especially in developing countries.

Developed countries have a marked advantage over developing countries because, in general, they have robust institutions that collect, interpret and manage aggregated and disaggregated data that are indispensable for the effective use of modelling tools and for assessing future scenarios and potential integrated water and energy solutions.

Given the complexity in the management and optimal use of natural resources, a growing number of national economic planning authorities and several international organizations are engaged in global and regional water-energy nexus modelling efforts. Many comprehensive, integrated and long-term modelling extend to cover, in addition to water and energy, land, food security and climate change. These efforts are very valuable at the national and regional levels, but they depend on the availability of disaggregated data that sometimes are not readily available, particularly in developing countries.

An important gap is related to the lack of methodological tools that allow measuring the economic, social and environmental value resulting from services provided by combined water-energy systems. Multi-purpose hydropower plants represent an example in which benefits in the three dimensions of sustainable development need to be properly measured in addition to measuring the cost and benefits of generating electricity. Additionally, innovative modelling mechanisms are necessary to assess the opportunity and risks related to the use of water as energy storage while considering all other potential water uses.

In relation to climate change data, there are also major observational and relevant data gaps with respect to the impacts of climate change on water quality, aquatic ecosystems and groundwater conditions (UN-Water, 2019). Although there are relevant observations and projections in these areas in many countries, understanding how climate change is affecting the hydrological cycle and water-dependent services at the appropriate temporal and spatial scales needs further assessment, especially in relation to developing regions.

In relation to the global commitment of "leaving no one behind" many countries still do not have relevant disaggregated and historical time series data on disadvantaged communities to be able to assess and monitor access to drinking water and modern energy services. Disaggregated data on basic services by rural and urban area, wealth group and subnational region are available mainly for developed and middle-income countries. Governments need these critical data to better identify and target disadvantaged groups.

VII.

Sustainable water and energy solutions

Sustainable water and energy solutions

Sustainable water and energy solutions provide an opportunity to realize synergies that can help to address the need for the basic services of energy, water and sanitation in tandem while supporting climate change objectives. Understanding the benefits of integrated approaches to water and energy are particularly important for developing countries to ensure continuous availability of these critical inputs that are essential for sustainable development. International cooperation is necessary as well as strong support from the private sector which is indispensable to complement public efforts.

7.1. Technological systems using water for energy

Reliable and efficient energy services are critical during a time of a crisis like the one the world is experiencing due to the COVID-19. As the lives of people all over the world are upended in some way by the COVID-19 pandemic, many developed countries have relied on relatively robust energy systems. In these countries, energy companies are working to keep the lights on and natural-gas providers continue to supply their product to homes through pipeline systems. However, some developing countries do not count with reliable energy systems that could face a pandemic lasting months or years. Additionally, there are many communities in the world that lack access to energy services, particularly Least Developed Countries and Land-Locked Developing Countries.

The current situation presents an opportunity to increase the reliance on renewable energy technologies that use less water as compared to technologies based on fossil fuels. The goal is to build more resilient and reliable water and energy services for the world to have a sustainable recovery and to be better prepared for future pandemics and for the impacts of climate change.

7.1.1. Hydropower

Water is needed for most forms of modern electric power generation. Hydropower accounts for some 64 per cent of global power generation from renewable sources. Hydropower systems rely on waters stored in surface water reservoirs, and on water flows of rivers for powering turbines and driving generators. Hydropower can meet base or peak loads in a sustainable manner. Hydropower reservoirs can also be used for temporary energy storage and for balancing variable supply from other renewable power generating sources, including wind and solar. While hydropower facilities highly depend on natural water flows, the water used is normally returned to their natural streams. The actual water consumption, including through evaporation or leakage from hydropower reservoirs, is relatively low. Hydropower generation could be environmentally sustainable as it generates relatively low greenhouse gas emissions during operation. However, hydropower systems could be affected by climate change if patterns of precipitation change in significant ways.

Run-of-river (RoR) hydroelectric power plants generate electricity by using parts of natural river water flows and natural elevation differences. Water from the turbines is released on-site and returned unaffected back into the river. Fast flowing rivers with steady seasonal waters offer good options for genuinely sustainable run-of-river power generation.

While there are about 70 large-scale run-of-river hydropower stations around the world with capacities ranging from 100 to 1,500 MW, most commercial RoR power stations are smaller and have capacities between 15 and 75 MW. The electric generation rate of run-of- river projects is typically more stable than those of wind or solar power systems, but generation may vary depending on the seasonal volume of water. Run-of-river hydropower generation is an important renewable climate friendly source of energy. However, in some regions generation could be constrained in the future if and where regional weather and precipitation patterns change (IPCC, 2011).

Hydropower also serves as a major source of energy storage. In such a system, water is pumped from a lower reservoir into an upper reservoir during off-peak hours, while flows are reversed to generate electricity during the daily peak load period or at other times of need. Although some losses can occur during the pumping process, pumped-storage hydropower provides great economic and environmental benefits. Pumped storage is the largest capacity form of grid energy storage presently available worldwide. Integrated systems that use new renewable energy sources such as wind and solar could be used to supplement the process of pumping water from the lower reservoir to the upper reservoir.

The increasing use of renewable energy such as wind, solar and hydropower is making it more difficult to avoid seasonal mismatches between electricity demand and supply in some regions. Seasonal pumped hydropower storage represents in some places a long-term energy storage option at a relative low cost and with the co-benefit of freshwater storage capacity. These systems have the potential to play an important role in the future diminishing load problems from seasonal variations of electricity supply and demand and balancing the increasing use of intermittent sources of generation.

Over the years, the International Hydropower Association, has produced guidelines and analytical tools such as: Hydropower Sustainability Guidelines on Good International Industry Practice (IHA, 2018a), the Hydropower Sustainability Assessment Protocol (HSAP) (IHA, 2018 b) and the Hydropower Sustainability Environmental, Social and Governance Gap Analysis Tool (IHA, 2019 c). These tools are helping the industry, including project planners, operators, assessors, regulators, and investors, to comply in full with all sustainability principles, concepts and standards. These hydropower sustainability tools are governed by the Hydropower Sustainability Assessment Council which is a multi-stakeholder organization.

Hydropower from surface reservoirs and river flows is the main source of renewable power generation today. According to the International Hydropower Association (IHA), the total installed capacity of hydropower in 2018 amounted to 1,292 GW, generating an estimated total of 4,200 TWh of electricity during the same year without causing major greenhouse gas emissions (IHA, 2019). China, Brazil, the United States, Canada, Japan, India, the Russian Federation, and Norway are the countries with the largest hydropower generation capacities while China, the Russian Federation, USA, Brazil, India, Canada and Tajikistan are the countries with the largest hydropower potential. Several new large dams are currently being planned or under construction, but a major contribution to sustainable development could come from the rehabilitation, modernization and capacity expansion of existing hydropower facilities. Once constructed, dams and barrages have a very long lifetime, even up to or more than 100 years. However, turbines, generators, and other technical equipment need to be replaced periodically, thereby enabling the installation of more modern equipment with greater productivity and reliability. Upgraded and digitally controlled hydropower stations can produce more electricity from the same water flow.

Dams and water reservoirs, whether constructed for hydropower generation, drinking water or irrigation water storage, or for energy storage, play important roles in the control and management of seasonal water flows.

With interconnected power supply systems, hydropower energy storage plays an increasingly important role in balancing intermittent energy output of other renewable sources, notably wind and solar. With the back-up of high-capacity energy storage, renewable energy can be transferred to meet peak time power demand. In Europe, Norwegian hydropower operators have offered to provide their hydro energy storage capacities to support renewable energy producers on the continent.

Powering non-powered dams is another option to generate electricity without considerable increases in greenhouse gas emissions. Most dams serve solely as water reservoirs for urban water supply or irrigation systems. Existing water conveyances, such as gravity fed irrigation canals or drinking water flows, provide opportunities for non-traditional hydropower technology deployment while minimizing civil works and environmental impacts (USDOE, 2014). In this manner, some water supply systems can begin to generate electricity as a by-product, provided the operators are willing to capitalize on such non-conventional integrated water and energy solution.

Itaipu Binacional is an organization created in 1974 by the Governments of Paraguay and Brazil in order to utilize the Paraná River to generate hydropower. The Itaipu Hydropower Plant is the largest generator of renewable power in the world with a record annual generation of electricity of 103.1 million MWh in 2016 and a total installed capacity of 14,000 MW. In 2018, Itaipu generated 90 per cent of the electricity consumed in Paraguay and 15 per cent of the electricity consumed in Brazil. The reliance on clean and efficient electricity is greatly contributing to the relatively decarbonized economies of Paraguay and Brazil avoiding large volumes of GHG emissions throughout its 36 years of continuous operation.

The Itaipu reservoir contains 29 billion cubic meters of water with about 135,000 hectares of water surface. The reservoir is not only used for electricity generation but also for agriculture, fishing, aquaculture, touristic and leisure purposes and as a municipal water source and for maintaining wildlife and ecosystem services in the relevant area in both countries. Itaipu leads many activities designed to conserve and maintain the quality and conditions of all these water-related ecosystems at optimum levels. In relation to terrestrial ecosystems, about 101,000 hectares of forests surround the Itaipu reservoir. This area represents the protected belt for the reservoir along the Brazilian and Paraguayan margins. Itaipu manages within this area a total of 10 protected areas including biological sanctuaries and reserves that protect native flora and fauna and advance research and conservation initiatives. These areas and the reservoir provide valuable connections among important remnants of the Atlantic Forest located in Paraguay, Brazil and Argentina.

Itaipu is currently embarked in a comprehensive technological update and upgrade of its power plant and substations designed to enhance energy efficiency and reliability while reducing costs. This effort includes the digitalization of all the electricity generation and control systems. This modernization process will allow Itaipu to achieve higher levels of energy efficiency and consequently higher efficiency in the use of water.

Itaipu contributes to the global efforts on combating climate change and its impacts. The electricity generation from the Itaipu Hydropower Plant replaces the equivalent of 550,000 barrels of oil or 50 million cubic meters of natural gas each day. Itaipu is avoiding the emissions each day of about 87 million tons of CO2 equivalent if it is replacing coal and 39 million tons of CO2 equivalent if it is replacing natural gas. The GHGs fixation by the vegetation of the protection belt and wildlife refuges is estimated at 5.9 million tons per year.

The sustainable development strategy of Itaipu and its comprehensive program of activities related to climate change coupled with the optimum integrated management of water resources and protection of water and terrestrial ecosystems represent an excellent example of an integrated approach to sustainable development and climate change.

Tajikistan is building the Rogun Hydropower Plant which will be one of the biggest hydropower plants in Central Asia. The Rogun plant is planned to include six hydraulic units with a capacity of 600 MW each and the total capacity of 3,600 MW. Its average annual electricity generation is expected to exceed 17.0 billion kWh per year. The Rogun hydropower complex is designed as a multi-purpose dam for generating electricity, regulating water, and reducing the risk of floods and droughts. The Rogun HPP will produce sufficient environmentally friendly and clean electricity to fully satisfy Tajikistan's electricity demand. It will also generate enough electricity to export to neighboring countries which currently use mostly fossil fuels for electricity.

The Rogun Plant represents an integrated water and energy solution contributing to climate change global mitigation goals and regional adaptation objectives. It will provide a valuable contribution to the reduction of the CO2 emissions in the region. In addition, the Plant will help to create new jobs and businesses improving the social and economic situation in Tajikistan and neighboring countries and supporting the sustainable development goals.

Wind and PV solar systems could be used as major sources of energy in farming while at the same time having a positive impact on sustainable agriculture, food security and water management. Examples exist around the world that demonstrate this integrated approach to food, water and energy security in which synergies can be realized optimizing the use of land. This type of integrated system can contribute to global objectives related to climate change and sustainable development including: decreasing water use, increasing crop efficiency, increasing use of renewable energy, supporting sustainable agriculture by diversifying revenue streams for farmers and reducing GHG emissions.

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7.1.2. Wind and solar photovoltaic power generation systems

Increasing deployment and production of energy from renewable sources in affordable ways remains key to achieving the energy, climate change and sustainable development objectives of the world.

At present, renewable energy accounts for approximately one third of global power generation capacity, which represents a very significant increase over the past decade. However, in order achieve the goals envisaged by the Paris Agreement, the ongoing global energy transformation towards renewable forms of energy will need to be further accelerated (IRENA, 2018). Identifying and investing in integrated water and energy solutions can further advance the use of renewable energy and mitigate climate change.

Once produced and installed, wind and solar photovoltaic power generation systems practically do not consume any water. Hence, wind and solar systems can very well be used in arid or desert environments. However, technologies based on concentrated solar power (CSP) consume large amounts of water and may not be suitable for application in water-scarce areas.

The installation of photovoltaic panels floating on the surface of lakes, hydropower reservoirs, agriculture reservoirs, and industrial ponds is one of the easiest and fastest ways of increasing renewable energy generation today. At the end of 2014, total global installed capacity in this category was only 10 MW, but by 2018 it had grown by more than 100-fold to 1.1 GW. A World Bank report estimates the global potential of floating solar at some 400 GW to be reached in the next few years (World Bank 2018d). Floating solar panels do not require land acquisition. At some large hydropower plants, if only 3-4 per cent of the reservoir areas would to be covered with floating solar panels, the electricity generation capacity could be increased significantly. On agricultural reservoirs, floating solar panels can reduce evaporation, improve water quality, and serve as an energy source for pumping and irrigation. The technology is particularly promising for fast-growing Asian economies. Interest is growing rapidly in the region, and large plants have already been installed in China, India and countries of Southeast Asia.

7.1.3. Cooling systems in thermoelectric power plants

Water is also needed for cooling systems in thermoelectric power plants, regardless of the type of fuel used for power generation. There are three main types of water-based cooling technologies, including "once-through", "wet-tower" (recirculation system), and air-cooled condensers for "dry cooling." Once-through cooling systems operate by continually withdrawing large quantities of water from a nearby source, such as a river or a lake, and using this water to absorb the heat from the exhaust steam in steam-cycle plants. Recirculation cooling systems operate similarly, but rather than withdrawing and discharging the entirety of cooling water, the water circulates through cooling towers that lower the water temperature. Recirculation systems have lower rates of water withdrawal but higher rates of water consumption. Dry cooling systems condense the exhaust steam with air rather than water. Dry cooling systems operate though coiled cables with high surface area, and using convection, fans, and heat transfer to condense the steam. Dry-cooling systems have comparatively higher capital costs and involve an energy penalty, as the cooling system itself consumes some amount of the electricity generated. However, dry-cooling systems have very significantly reduced water withdrawal rates and are thus a more suitable option for power generation in water-scarce regions.

There are trade-offs associated with each cooling technology in terms of water withdrawals versus consumption, capital costs, and impacts on water supplies. In general, once-through technologies are the most efficient and have the lowest capital cost requirements but have the highest water withdrawal rate and can cause local thermal water pollution. Wet-tower technologies withdraw less water but consume more. On the other hand, dry cooling uses very little water but is more expensive and has the lowest efficiency (IEA, 2016a, 2016b). Availability of water for cooling is an important factor in the siting of power plants. Nuclear power plants are often located near the seaside where seawater is used for cooling.

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Global power generation depends for more than 70 per cent of its capacity on thermal power plants using coal, natural gas, or nuclear fuel (IEA, 2016a). The thermal power sector withdraws very significant amounts of water for cooling, mostly from surface water sources. Much of the cooling water is returned to the source after use but often at a higher temperature than at the withdrawal, thus potentially causing thermal pollution with negative impacts on aquatic life. As estimated by the IEA, worldwide power generation including primary energy production accounts for approximately 10 per cent of total global water withdrawals, and some 3 per cent of total water consumption (IEA, 2016a, IEA, 2018b).

After hydropower, thermoelectric power generation is one of the most important areas of focus in the water-energy nexus because of its dependence on water resource availability for cooling. Cooling needs vary with the fuel type and the power plant combustion technology and its efficiency. Coal-fired power plants typically have higher cooling needs than natural gas combined cycle (NGCC) plants. Nuclear power plants have much higher and special cooling technology needs. There are multiple options for reducing water withdrawal and water consumption of thermoelectric plants. One approach is to reduce the generation of waste heat through more efficient power cycles (e.g., recompression closed-loop Brayton Cycle). Another approach to improve the water efficiency of cooling systems is through modifications and advancements in technology, including more efficient air flow design, improved water recovery systems, changing over to hybrid or dry cooling, and treatment of water from blowdown.

Making existing and future power plants more energy-efficient and less water dependent will need to be a core concern for policy makers and managers of power systems.

Air-conditioning and heating consume large amounts of energy. As has been successfully demonstrated in several seaside cities in Hawaii (United States), Hong Kong (China), Singapore, Marseille (France), Cape Town (South Africa), and in various Japanese and Scandinavian cities, significant amounts of fossil fuel use and greenhouse gas emissions can be avoided by installing seawater cooling and/or heating systems in seaside commercial buildings or residential districts. Seawater-based cooling and heating systems may be costly in their installation. Most rely on electricity for water pumping. However, overall operational costs are comparatively low, and fossil fuel-based energy otherwise needed for cooling or heating can be saved by using heat exchangers, condensers, and chillers. Seawater cooling/heating systems vary in their designs. They use seawater either in open loop or refrigerants in closed loop systems. Seawater can serve as heat source and/or heat sink. Three quarters of the world's megacities are located at or near the seaside. Greater use of seawater for cooling and/or heating of buildings can greatly help reduce GHG emissions.

Enhanced energy efficiency through greater use of combined heat and power co-generation systems offers multiple opportunities for win-win options in which (fossil) fuels can be used more efficiently, productivity can be increased, and the heat generated as a by-product in power generation, can be used for economic purposes, including water purification or desalination. Experts of the International Atomic Energy Agency (IAEA) have also pointed out the potentials of CO2 emission-free desalination and freshwater production by co-generation at seaside nuclear power plants (IAEA, 2017).

7.1.4. Geothermal

Depending on local conditions, geothermal energy systems can provide uninterrupted, renewable, and sustainable heat supply for power generation or en-

energy-intensive industrial operations. However, geothermal energy systems depend on water to transfer heat from the underground source to the surface. Dry stream, flash stream and binary cycle geothermal plants reinject extracted water back to the heat source. Geothermal energy systems are climate friendly as they do no generate significant GHG emissions. Geothermal energy has been used for bathing and space heating since ancient times. Today, direct use of geothermal energy plays an important role for district heating and power generation in more than 50 countries, including China, Iceland, Indonesia, Japan, Kenya, Sweden, the Russian Federation, Turkey, and the United States (IEA, 2018a). There are considerable natural resource potentials for expanding geothermal energy use in commercially viable projects to enhance sustainable development without adding significant GHG emissions. Geothermal energy potentials are particularly promising in areas that are geographically close to volcanoes and located in regions that receive sufficient precipitation.

Geothermal energy systems, also known as hydrothermal energy systems, are widely considered an important renewable resource, as the constant flow of heat from the core of the earth ensures an uninterrupted, inexhaustible, and essentially limitless supply of energy. Some applications of geothermal energy use the earth's temperatures near the surface, while other systems require drilling deep wells.

More importantly, geothermal power plants can transform natural heat into electricity while mitigating carbon emissions. In 2017, the aggregate global geothermal power generation capacity stood at 14 GW, with a total annual production of an estimated 84.8 TWh. Global geothermal power capacity is expected to rise to over 17 GW by 2023, with the biggest capacity additions expected in Indonesia, Kenya, Philippines and Turkey (IEA, 2018a). Geothermal power generation at scale is only economical in or near volcanically or tectonically active regions (IRENA, 2017). Geothermal power plants consume less water per kilowatt-hour of lifetime energy output than other electric power generation technologies. However, lifecycle water consumption varies with the specific type of the geothermal power plant system. Geothermal power plants can provide a stable production output, unaffected by seasonal or climatic variations, resulting in high-capacity factors (ranging from 60 to 90 per cent) and making the technology suitable for baseload production (IEA, 2018a). However, each geothermal source is unique in its location, temperature and pool depth, and the choice of suitable designs and geothermal technologies will need to be adapted in each case.

Sustainable geothermal power generation needs water in the form of sufficient rainfall and natural replenishment of groundwater near the heat source and/or a systemic recycling and re-injection of used geothermal water after its heat has been extracted. The careful and complete reinjection of geothermal brines can also help prevent potential thermal and/or environmental pollution in the vicinity of geothermal plans. Geothermal brines can carry contaminants that must not be allowed to pollute surface water, soil or air in the vicinity.

Several international expert networks have been established to facilitate technology and information exchange among geothermal experts around the world. These include the Technical Cooperation Programme (TCP) on Geothermal of the International Energy Agency (IEA), the Global Geothermal Alliance, supported by the International Renewable Energy Agency (IRENA), as well as the International Geothermal Association (IGA).

Kenya is well endowed with high temperature geothermal resources most of which are located within the axial of the Kenya Rift valley. Kenya Electricity Generating Company PLC (KenGen) is one of the leading electric power generating companies in East Africa. KenGen operates several large and small geothermal power stations along the Rift Valley with a combined generation capacity of some 700 MW. At present, geothermal resources account for nearly 40 per cent of Kenya's power generating capacity.

KenGen's larger geothermal facilities are located close to national parks and natural lakes which ensure natural replenishment of ground water. KenGen's Environmental, Safety & Liaison Section carries out comprehensive pre-investment environmental impact assessments, environmental audits, and monitoring of environmental impacts arising from geothermal development. The Section is responsible for ensuring environmental protection and liaison with the local communities on all aspects of social concerns.

Kenya's development plan 'Vision 2030' lays out a policy roadmap to double Kenya's geothermal electricity generation every few years. Managing surface water consumption, maintaining sufficient groundwater reservoirs, and avoiding all potential forms of local pollution will be essential for the country to move forward and make progress towards the fulfilment of the SDGs.

In many rural parts of Kenya provision of safe drinking water remains a great challenge. In order to promote socio-economic development throughout the country KenGen established its own KenGen Foundation which among other social projects supports the drilling and upgrading of water wells. Provision of clean accessible water for communities neighbouring its power plants has been one of KenGen's key Corporate Social Investment programs since 2005. KenGen Foundation works with various partners in its social projects, including the Lake Victoria South Water Service Board and Tanathi Water Services Board.

7.1.5. Bioenergy

Bioenergy is renewable energy from organic material corresponding to the feedstock categories of agriculture, forestry and waste. Bioenergy can be used for transportation, heating and generation of electricity. Sustainable bioenergy can contribute to climate change objectives helping to reduce the consumption of fossil fuels. It can also contribute to agriculture and rural development and energy security. It is important, however, that bioenergy development is based on sustainable water management practices that take into account other uses of water as well as food security. Integrated approaches to bioenergy include innovative systems and strategies that maximize water use efficiency. Furthermore, a variety of examples exist of bioenergy systems in different world regions that contribute positively to the state of water (GBEP & IEA, 2016).

Sustainable production and use of bioenergy represent considerable opportunities that support the social, economic and environmental dimensions of sustainable development. The water-energy nexus has been identified as one of those opportunities. Nevertheless, there are significant barriers to scaling up and replicating bioenergy good practices. One of these limitations is the limited awareness and capacity of relevant stakeholders. The creation of an enabling environment for sustainable bioenergy production and the improvement of the management of water resources are necessary conditions for the development of bioenergy programmes in many countries that have great potential for biofuel use.

Bioenergy is a major type of renewable energy that could support the SDGs in the context of climate change and energy. Global assessments by REN 21, IEA and IRENA find that bioenergy accounts for three-quarters of all renewable energy use today and half of the most cost-effective options for doubling renewable energy use by 2030. Bioenergy is part of a larger bioeconomy, including agriculture, forestry and manufacturing (IRENA/IEA, FAO, 2016).

Bioenergy can play a role in most economic sectors. In the power sector, bioenergy can provide flexibility to balance intermittent and seasonal wind and solar resources. In industry, biomass can efficiently supply high-temperature process heat, in combination with a variety of valuable bio-based chemicals and materials. In the building sector, biomass provides the feedstock for highly efficient district heating systems, furnaces and cook stoves. In transport, liquid and gaseous biofuels can help reducing fossil fuel use. Biofuels also represent an alternative to fossil fuels for aviation, marine shipping and heavy freight transport (IRENA/IEA/FAO, 2016).

Both the feedstock production and the subsequent conversion to solid, liquid and gaseous biofuels can impact the state of water in many different ways. Therefore, increasing biomass demand could represent a challenge with respect to water and it is essential that good practices are implemented to ensure that negative impacts are avoided. The goal is to develop systems that are sustainable and that have significant beneficial outcomes when considered in an integrated manner. The optimal integrated use of water management techniques and land-use options allows bioenergy developments to provide opportunities for improving water productivity and increase access to water. A strategy for adaptation to water scarcity can be to use biomass production for energy as a tool for increasing the spatial and temporal accessibility of water resources and at the same time improving the quality of freshwater flows. Basin level planning could include biomass production as a land-use option with the potential for combining, for example, erosion control and flood prevention with income generation from carbon sink generation and biomass sales for energy. Intelligently designed bioenergy systems can significantly offset greenhouse gas emissions associated with fossil fuel-based energy systems, and at the same time lead to additional environmental benefits. The environmental and socio-economic benefits from a large-scale bioenergy programme could be substantial. (Univ. of Twente & IEA, 2013).

Some bioenergy systems could provide more general environmental benefits such as soil carbon accumulation which leads to improved soil fertility and enhanced climate benefit. Bioenergy systems can also be established to provide environmental benefits that are relevant in only specific conditions. For example, trees can act as wind breaks to reduce wind erosion, plantations of suitable species can be used to remove cadmium and other heavy metals from cropland soils, and plantations that are located in the agricultural landscape can become ecological corridors that provide a route through which plants and animals can move between different spatially separated natural ecosystems. This way they can reduce the barrier effect of agricultural lands. Examples of bioenergy systems that are established for the purpose of providing specific environmental benefits relevant for water include: soil-covering plants and vegetation strips located to limit water erosion, reduce evaporating surface runoff, trap sediment, and reduce the risks of shallow landslides; and tree plantations that are used for salinity management on land subject to productivity losses due to soil salinity induced by rising water tables (possibly leading to trade-offs due to reduced river stream flows). Specific bioenergy applications can also prove economically attractive compared to other approaches to address these problems. Plantations can also be located in the landscape and managed as buffer strips for capturing the nutrients in passing run-off water. Sewage sludge from treatment plants can also be used as fertilizer in vegetation filters (Univ. of Twente & IEA, 2013).

The Guatemala Sugar Agroindustry represents a good example of bioenergy use. This agroindustry has a long-time commitment to environmental and social practices supporting sustainable development. It has been improving its hydric resource management practices reducing by 70% the water used in the mills in the last 5 years. It has also invested more than any other industry in the country in Research and Development, leading to innovative practices and solutions, on field and in the mill, that are of the utmost importance to achieve the sustainability of the sector. R&D has allowed the Guatemala Sugar Agroindustry to evolve and innovate, which is why it not only produces sugar, but also renewable energy and ethanol. Another important contribution of the Guatemala Sugar Agroindustry to the country was the creation of the Private Institute for Climate Change Research (ICC) in 2010, now an autonomous organization, as it has become a leader on research and project development to mitigate and adapt to climate change in communities, productive processes and the region's infrastructure.

Guatemala's economy increasingly depends on export-oriented agriculture with sugarcane and sugar production playing a leading role. Sugar refineries have used bagasse for power generation since the 1990s. Sugarcane is also the main agricultural base for ethanol / biofuel production. With growing domestic and international demand and competition for land, water and energy, understanding their interlinkages and identifying opportunities for synergies and efficiency is of great importance in Guatemala (Guerra, 2019). Electricity from sugarcane biomass (bagasse) in Guatemala is a significant component of the energy matrix. Sugar companies generate electricity from bagasse to meet their own needs and to sell to the grid. Power generation from bagasse is typically seasonal from November to April. It complements electricity generation from hydropower, which is typically low during the same period. Electricity from the Sugar Agroindustry has covered up to 32% of the national electricity demand during the harvest season (Cordon, 2020). During the 2018-2019 harvest, sugarcane biomass allowed the generation of 81% of the total energy generated by the Sugar Agroindustry representing only 12% of the emissions from the energy generation process. (ICC, 2020)

The use of sugarcane biomass for the generation of electricity allows Guatemala to avoid 4 million tons of CO2eq annually that would have resulted if coal were used. By using sugarcane biomass for electricity generation, the combustion of about 316 million gallons of bunker or of 1.4 million tons of coal are avoided. The efficiency of the power plants has increased on average from 35 kwh/ton sugarcane (1997-1998) to 106 kwh/ton (2018-2019). The carbon footprint of electricity from sugarcane biomass is 0.26 CO2eq/kWh (2018-2019 harvest), whereas the overall national average carbon footprint for electricity is about 0.367 kg CO2eq/kWh. The reduction in the emissions from electricity is one of the important elements that has contributed to the low carbon footprint of sugar in comparison with other countries.

7.1.6. Ocean energy

Ocean energy technologies are commonly categorised based on the resource utilised to generate energy. Ocean energy includes tidal stream, tidal range, wave energy and Ocean Thermal Energy Conversion (OTEC). The theoretical resource potential of ocean energy is more than enough to meet present and projected global electricity demand well into the future. IRENA projects in its Energy Transition scenario, aligned with the objectives of the Paris Agreement (REmap case), that ocean energy could exceed 100 GW of installed capacity by 2050. At present, ocean energy technologies are still in developmental stages, with most technologies in the prototype phase and some just reaching commercialisation and cumulative installed capacity only amounting to 529 MW in 2018. Nevertheless, substantial growth in deployment and installed capacity is expected in the coming years. Whereas the technical potentials of ocean energy are indeed promising, high costs and other challenges, such as corrosion, remain considerable barriers preventing a wider and faster commercialization.

Tidal stream and wave energy converters are the technologies of greatest medium-term relevance. They are the most advanced ocean energy technologies available, albeit at a pre-commercial stage. Tidal projects can produce variable, but highly predictable, energy flows. Several pilot projects are also under way to generate electricity from ocean waves. Tidal range systems are in operation in France, the Republic of Korea, China, Canada, and the Russian Federation. Offshore tidal energy systems account for the smallest portion of renewable electricity globally, and the majority of projects remains at the demonstration phase. However, with large, well-distributed resources, offshore tidal has the potential to scale up over the long term (IEA, 2019c). A number of pioneering companies is also exploring hybrid renewable energy projects with combined wind and wave technology, as well as ocean-based floating wind or solar farms.

Other ocean energy technologies that harness energy from the differences in temperature and salinity of ocean water such as OTEC may become increasingly relevant over longer time horizon. OTEC's generation is based on the temperature difference between the surface and deeper layers of the ocean. The largest OTEC plant is in Hawaii as a testing facility with an installed power capacity of 100 kW. OTEC plants continue to be of interest, particularly in island applications, as they provide the possibility of using the cold deep water as well as the warm surface water flow for purposes other than energy generation, such as desalination, aquaculture and cooling.

Another renewable energy that could be considered an ocean technology is ocean offshore wind. Currently, offshore wind is becoming a mature technology with a global installed capacity of about 32 GW. Its growth in the next decade is expected to be very strong playing an important role in future energy systems.

The International Energy Agency supports a Technical Cooperation Programme (TCP) on Ocean Energy Systems (IEA, 2019c) with a view to accelerate the viability, uptake and acceptance of ocean energy systems in an environmentally acceptable way. There are currently 21 contracting parties, including developing country partners from China, Mexico, Nigeria, and South Africa.

IRENA, as a leading global intergovernmental organisation dedicated to energy transformation, is supporting countries in gaining access to the latest knowledge on marine energy, in the context of national strategies to achieve SDG 7 (energy) and SDG 14 (oceans), and support capacity building and international cooperation to foster a global blue economy. IRENA provides a common vision on marine energy potential and expected changes in the market. It helps to disseminate best marine energy experiences providing case studies, business cases and facts on the technology to policy makers.

7.1.7 Hydrogen

Hydrogen is the lightest and most abundant element in the universe. It has a high energy content, and it is storable, although it has a high flammability range. Hydrogen burns readily with oxygen, releasing considerable amounts of energy as heat and producing only water as exhaust. At the point of use, hydrogen can be burned in such a way as to produce no harmful emissions; thus, it has a great potential environmental advantage over fossil fuels.

Hydrogen can be produced using natural gas, oil, coal and electricity (as a secondary energy resource). Currently about 70% of the hydrogen is produced from natural gas. The most used method for hydrogen production is steam reforming from natural gas.

Hydrogen production through water electrolysis has been increasing in the last decade and it is seen as a major next step in the global energy transition. Hydrogen can be produced from water by utilizing electrolysers that split water into hydrogen and oxygen using electricity. Electrolysis currently accounts for only around 5 per cent of global hydrogen production. However, with declining costs for solar PV and wind, renewable electricity could become an important means to produce hydrogen.

Hydrogen, as an energy carrier, can in principle replace all forms of final energy in use and provide energy services to all sectors of the economy. Furthermore, if hydrogen is produced without emitting any GHGs, it could form the basis of a truly sustainable energy system. Hydrogen is emerging as an important component of the clean energy mix needed to ensure a sustainable future. Falling costs for hydrogen produced with renewable energy, combined with the urgency of reducing GHG emissions, is allowing clean hydrogen unprecedented political and business momentum (IRENA, 2019).

An increased number of projects, programs and policies for further development and commercialization of hydrogen produced with renewable energy are being implemented worldwide. Hydrogen produced with renewable energy is rapidly becoming more competitive. Important synergies can be realized by the combined used of renewable energy and hydrogen. Hydrogen can increase renewable electricity use and provide added demand-side flexibility. It can also be used for seasonal energy storage.

Despite the growing awareness and increasing involvement of governments and the private sector, a hydrogen-based energy transition will not happen overnight. Hydrogen supply costs are still considerably high, and its widespread use will require a dedicated new supply infrastructure. Further acceleration of efforts on research, development and demonstration as well as policies that will allow an enabling environment are critical and essential to ensuring a significant clean hydrogen supply in the future energy system.

7.2. Technological systems using energy for water

Today more than ever sustainable water and energy solutions are needed to support nations in their fights against health crises such as the 2020-2021 pandemic due to COVID-19. For the 3 billion people without basic handwashing facilities at home, practicing social distancing represents a real challenge (WHO, 2019). Innovative water-energy services resulting from integrated approaches in water and energy provide effective ways to expand water access while using clean sources of energy. For regions experiencing water stress and with population at risk due to COVID-19, integrated water and energy approaches can make a difference.

7.2.1. Water supply systems

The two primary sources of drinking water supply systems are groundwater and surface water. Groundwater typically has better quality. Processes to treat surface water include filtration, carbon absorption, and disinfection. For some water supply utilities, energy costs for water treatment and pumping can be very significant and amount to as much as 30-40 per cent of total operating costs. Water supply is typically priced low and most public utilities lack funding. However, important suggestions to enhance operational and energy efficiency in water utilities include: (a) maximum use of gravity for water transport, wherever possible, (b) periodical checks and remedies to detect and to close any physical or other leaks in water distribution and delivery networks, (c) replacement of obsolete water pumps and installation of variable speed drives, and (d) installation of supervisory controls and data acquisition (SCADA).

Water supply, treatment and distribution, as well as wastewater collection and treatment are typically in the domain of municipalities and public enterprises. In many developing countries, the development of water supply systems is often lagging, and in many less and least developed countries and regions and their rural areas, public water supply systems are entirely lacking.

In many locations, drinking water supply systems as well as irrigation rely on pumping to transport water to where it is needed. Installation of energy efficient water pumps can greatly reduce electric power consumption, operational cost, and associated greenhouse gas emissions. Avoiding water leakage is an important measure that makes water supply and irrigation systems more efficient. Installation of energy efficient water pumps that can be operated by remote control have greatly helped to save water, reduce energy use, and improve farmer incomes in many world regions. Using renewable energy such as solar or wind to power efficient water pumps will allow major decreases in GHGs in agricultural areas.

While improving irrigation efficiency it is important to avoid a rebounding effect that could translate into higher energy consumption. For example, saved water could potentially be used to expand irrigated agriculture or grow more water-intensive crops, which could lead to increasing both water and energy consumption.

7.2.2. Wastewater treatment systems

Wastewater is increasingly seen as a dependable and potentially valuable water resource, but it requires its own infrastructure and piping network for collection and adequate facilities for processing. In wastewater treatment heavy solids as well as oil, grease and lighter solids are removed first. Then, during secondary treatment the remaining liquid undergoes advanced bacterial processes that remove nitrogen and phosphorous. Sewage treatment plants have high energy needs, not only for pumping, but particularly for the secondary treatment processes. Older and traditional sewage plants do not capture and make any systematic use of biogas and sludge that occur as by-products of the treatment processes. Modern plants are equipped to extract and use the heat contained in wastewater. Biogas and dried sludge are used in onsite combined heat-and-power (CHP) generation. With these investments, modern wastewater treatment facilities can become net "Zero Energy" users, or even supply excess energy to neighbours, instead or requiring public subsidies to cover high energy costs. Modern wastewater treatment systems can also avoid significant releases of greenhouse gases. Lack of local public funding support, lack of national political interest, and lack of international assistance in addressing the challenges of wastewater treatment, particularly in less and least developing countries, remain the main barriers to accelerated progress towards more sustainable development in this area.

More effective and less energy consuming technologies are urgently needed for wastewater treatment, including for surface or subsurface water aeration and various technological options are available to reduce the energy footprint of the water service sector (EurEau, 2019). Aeration and oxygenation are also important processes for improving water quality in natural or man-made ponds and reservoirs, including aquaculture and fish farms.

Addressing the water-energy-climate interrelationship is particularly important in the expansion and technical upgrading of conventional wastewater treatment. Traditional wastewater treatment plants are used to procure large amounts of external energy to power wastewater pumping and aeration equipment installed to accelerate biological processes of wastewater treatment. During the same process, substantial amounts of GHGs such as carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O) were released uncontrolled to the atmosphere. CO2 comes from aerobic (oxidization) processes and CH4 from anaerobic processes during secondary treatment of wastewater. N2O results from denitrification.

Modern treatment facilities seek to reduce their carbon footprint significantly at the same time as they use the by-products of wastewater treatment to generate electricity. Some plants use gravity-fed wastewater flows for generating electric power , while others use heat exchangers to extract heat from wastewater. More importantly, a large number of wastewater facilities now capture the biogas generated for on-site or off-site use in combined heat and power (CHP) stations.

The UNFCCC Executive Board of the Clean Development Mechanism has approved a methodology for assessing emissions from wastewater treatment and related emission reductions (UNFCCC, undated). Some facilities transfer sludge and/or partially treated wastewater as fertilizer and for irrigation to nearby agricultural or horticultural enterprises. In other facilities, sludge is incinerated for power generation, a process which can also cause other environmental concerns. The Water and Wastewater Companies for Climate Mitigation (WaCCliM) is an international partnership established to address GHG emissions in water and wastewater utilities.

7.2.3. Desalination

Desalination is seen as an increasingly important option for meeting freshwater needs, particularly in Northern Africa and West Asia where most countries are under serious freshwater stress. Over the past decade, the improvements in reverse osmosis technology have made water desalination more efficient and less costly. It remains however a highly energy intensive process and energy needs are typically met by fossil fuels, mostly natural gas. Desalination is widely projected to grow rapidly during the coming years, with rapidly increasing contributions to GHG emissions. In several countries, including Cabo Verde, Djibouti, Saudi Arabia, and Spain, projects have been initiated to demonstrate the economic viability of seawater desalination using renewable sources of energy.

The most prevalent forms of desalination include thermal desalination and reverse osmosis (RO). Thermal desalination uses heat energy to separate distillate from high salinity water. In reverse osmosis, membrane barriers and pumping energy are used to separate salts from high salinity water. Desalination technologies can be used to treat brackish groundwater, surface water, seawater, or even wastewater.

Global desalination capacity has grown considerably in the last decades. Countries where desalination is most used include Saudi Arabia, the United States, the United Arab Emirates (UAE), Australia, the Islamic Republic of Iran, China, Kuwait, and Israel. As energy needs and energy costs are high, desalination facilities are often located near power plants. Whereas desalination may offer local solutions to address the growing freshwater shortages in fossil fuel rich countries of the Middle East, the scenario of rapidly growing global energy (fossil fuel) use for desalination is causing concerns over growing greenhouse gas emissions and accelerating climate change.

The importance of desalination to provide freshwater is expected to continue growing over the coming years. The use of wind and solar energy for powering commercial small-scale water desalination plants has already been demonstrated in countries around the world. Several private sector initiatives and non-governmental organizations are also assisting developing country partners with the deployment of this technology. Given the prospect of increasing water shortages in the future in many regions of the world, OECD countries have stepped up their programmes aimed at developing new desalination technologies that can address problems of the anticipated freshwater shortage in an economical way on a large scale (NSTC, 2019) (EC, 2019).

The Canary Islands of Spain represent a good example of a region benefitting from seawater desalination using renewable energy. The group of the Canary Islands include the islands of Lanzarote, Fuerteventura, El Hierro, Gran Canaria, Tenerife, La Gomera, and La Palma. Over the years, the islands have developed a combined desalination capacity of 731,000 m3/day, which is equivalent to 2 per cent of total global desalination capacity. A large portion of the desalinated water is provided to service the tourism industry. The Canary Islands Institute of Technology (ITC) has demonstrated that reverse osmosis desalination technologies can be powered by renewable energy. Water desalination can be performed in an economically feasible way with electrical energy provided by sun and wind. Additionally, intermittent energy supply can be backed up with hydropower storage.

ITC, a public enterprise established by the Government of the Canary Islands in 1992, has developed and tested various prototypes for off-grid small-scale and larger-scale renewable energy driven desalination systems since 1996. Most ITC's facilities are located in Pozo Izquierdo on Gran Canaria Island. Local conditions are excellent: the site has direct access to seawater, annual average wind speed of 8 m/s and average daily solar radiation of 6 kWh/m2. At its field project sites, ITC has tested different methods and products of various suppliers using water vapour compression, reverse osmosis (RO), electrodialysis, and membrane distillation. ITC holds its own patents in desalination technology powered by renewables.

The ITC projects suggest that desalination stations should be designed and tailored to meet the prevailing local conditions. In locations where water demand is limited, e.g. up to 100 m3 /day, the most feasible option may be the use of solar-PV-powered RO systems. For locations with medium or larger water demands (1,000–5,000 m3 /day), the more suitable systems may be combined off-grid wind farm and reverse osmosis plants. The installation of automated controls is important to reduce maintenance costs. Desalination technology based on renewable energy avoids the release of greenhouse gas emissions during operations. In some locations, the disposal of brine resulting for the desalination process can pose a challenge. Brines can be returned to the sea but need to be diluted to prevent local environmental impacts.

With respect to international cooperation, ITC offers training and advisory services to support and guide developers of desalination projects, particularly from developing countries, to design their own sustainable solutions. ITC has helped designing a desalination plant powered exclusively by photovoltaic solar energy that supplies drinking water to rural areas in Mauretania. The installation has been operational since 2006 and is based on the autonomous desalination technology developed by ITC.

7.3 Decentralized water and energy supply systems

"Leave No One Behind" is one of the major concerns reflected in the 2030 Agenda for Sustainable Development. Today, the poorest segments of the population are usually the ones who lack the three basic services of energy, water and sanitation. About two-thirds of people in rural areas who lack access to clean drinking water also lack access to electricity. The 2020-2021 COVID19 pandemic and health crisis call for effective actions and international cooperation to ensure access to these critical services. Decentralized integrated water and energy solutions represent innovative and efficient options to provide these critical services to the people who need them the most. Technological innovative systems exist and can be developed to specifically respond to the needs of poor communities.

Decentralised water purification systems powered with renewable energy are urgently needed, particularly for improved access to clean and affordable drinking water in water-scarce rural and (sub)urban areas of developing countries. Over the past several years, a growing number of universities, research institutes, and start-up companies have set-up and tested various prototype solar photovoltaic-powered reverse osmosis (PVRO) water purification stations. These systems typically use solar panels or wind turbines to charge batteries, which then power small electric pumps that push brackish well water and/or collected rainwater through filtration membranes. The batteries also supply the ultraviolet sterilization bulbs with electricity. Water purification stations can create important small-scale business opportunities for rural villages which supply their purified drinking water also to customers from neighbouring regions (MIT News, 2015).

Decentralized renewable energy systems are pivotal for poverty reduction and integrated rural development. Off-grid integrated water and energy solutions are playing an increasing role in isolated communities. Integrated water and electricity approaches could also be based on mini-grids or grid-connected systems where water could allow power generation and help with energy balancing and storage. Small-scale rural hydropower generation (using water for energy) offers proven systems for providing access to electricity at low costs enabling electricity supply to rural villages, schools and clinics. The small-scale rural hydropower potential is particularly good in mountainous or hilly regions of (sub)tropical developing countries which often have an abundance of water. Other rural poverty reduction projects have successfully introduced renewable energy use for pumping water and as a source of electricity for lighting, communication and information purposes. In many developing countries a variety of projects use wind or solar power to operate small-scale water pumps that improve local communal drinking water supply or power small-scale irrigation systems.

An innovative approach being promoted is the development of "energy-water in a box" solutions that are modular, portable, reliable and cost effective. Small modular energy-water systems have the potential to serve areas where energy and water are scarce, expensive or challenging to obtain. These systems are particularly useful as a response to catastrophic events such as the COVID-19 pandemic and other disasters resulting from climate change and affecting communities in isolated areas and islands. The reliability, portability and speed of deployment are key characteristics for the effectiveness of these systems during unexpected events (USDOE, 2019) (UNDP, 2020).

OffGridBox Inc and UNDP have installed twelve integrated, self-contained, modular systems in Tanzania to enable access to clean water and electricity in ten villages in three districts around Lake Victoria. They serve about 24,000 people who previously had no electricity and had to walk around five kilometres every day to get water. They are also being used by health centres and schools. In rural Tanzania 16 percent of people have no electricity and more than 70 percent of the country's 57 million people do not have clean and safe water.

The all-in-one utility system, which is called OffGridBox (OGB), integrates photovoltaic energy generation, rainwater harvesting, water pumping for family agriculture, and water purification through micro-filtration and UV sterilization for domestic use. A timer for irrigation can be added as well as additional water tanks. The capacity of the OGB is between 3kWp and 8 kWp, and this power can be stored safely in batteries or can be used to power productive use activities, or lighting and phone charging for households. The system includes remote monitoring through 3G or 4G and this signal is also used to provide WiFi to the community. The water-electricity-connectivity system and all its hardware are inside a 6ftx6ftx6ft steel container.

The decentralized systems are particularly valuable for isolated communities where there is no access to water and energy including refugee camps. The modular systems represent a promising solution for scaling access to clean water and renewable energy to the billion people in need across the globe. The systems are carbon neutral since they harvest solar energy and rainwater, emit no carbon dioxide into the atmosphere, and even replace polluting practices like diesel generators, kerosene lamps and disposable batteries. The project also helps to address the impact of climate change, which has had a pronounced impact in the Lake Victoria region. The negative effects of climate change disproportionately fall on marginalized and rural communities located in this region.

Women, who carry a disproportionate responsibility for household fuel and water collection as well as food preparation, are benefitting. Each of the twelve OGB systems installed in Tanzania is operated by two women from the community, who received training in technical maintenance and bookkeeping. It is expected that the project will also stimulate a wide range of economic activity. Tanzania's Ministry of Health has also indicated interest in deploying these systems to health centres throughout the country that lack access to reliable sources of clean, safe water and electricity.

These practical, relatively small and easy to install systems could also be very valuable for areas impacted by natural disasters or world crisis such as pandemics. Natural disasters can happen anytime and anywhere, impacting entire countries, cities and families. Electricity, water, and connectivity are critical services that usually become unavailable when a disaster strikes. These systems could provide power and water to clinics, schools or emergency centres when these services are disrupted. They could represent all-encompassing relief hubs providing communication (WiFi / cellular phones), electricity from renewable energy and clean purified water. The systems are designed, in general, to withstand a cyclone with emergency procedures to be implemented in less than one hour. Additionally, they can be easily transported by truck, boat or helicopter and could be installed in about three hours.

7.4. Water-Energy End Use Efficiency

Improved end use efficiency of water-energy systems is another example with great potential to induce a more sustainable integrated use of water and energy. Major savings in water and energy consumption can be achieved at the point of end use. In general, a reduction in water use will imply a reduction in energy use and of corresponding CO2 emissions. In many regions, the energy consumption for water systems at the point of end use represents around 80% of the overall energy use for water. Appliances such as dishwaters, water heaters, clothes washing machines are examples of water and energy interrelated systems that could be modified with high standards that reduce both the consumption of water and energy. Therefore, many regulations and policies related to demand-side management translate into synergies that effectively contribute to more sustainable water-energy systems. The positive impacts of such policies and regulations could be considerable in major economic sectors including the residential, commercial, manufacturing and industrial sectors.

Demand management programmes, projects and public awareness campaigns designed to enhance efficiency in water and energy use and calling for water and energy conservation are being implemented by countries, cities, utilities, and companies in order to address national or local shortages of water and energy. Even when launched independently and focusing on only one or the other resource, these approaches have demonstrated significant co-benefits. Programmes for water and energy demand management need to be expanded worldwide to enhance sustainable development and to achieve greater impacts and benefits. Coordinated programmes for water and energy demand management represent effective sustainable water and energy solutions.

Hot water heating uses considerable energy and it is one of the most energy-intensive water processes. Reductions in the volume of hot water used will result in reduction in both energy and water use. Examples of measures and innovative systems reducing hot water usage include low-flow shower heads, efficient clothes washers and dishwashers, and behavioural changes (Rao, et al, 2017).

Manufacturing systems also represent potential areas for water and energy savings. Steam system actions in the manufacturing sector, such as returning condensate, fixing broken steam traps and leaks, and eliminating continuous blowdown, will reduce both the energy required to produce steam, and water for generating steam. Additionally, unique energy and water-saving opportunities exist within manufacturing systems given the variety in processes and water use characteristics.

Not all water efficiency measures will realize energy saving at the point of end use. However, they will realize energy savings within the water supply and treatment network. The magnitude of these savings will vary by region and water source. As an example, water reuse within a facility may not always save energy at the end use, but it reduces energy consumption in the water and wastewater network. As another example, low-flow toilet fixtures will yield water and wastewater system energy savings.

Water-saving measures at the end use will likely yield additional water savings at the source, which, in turn, yields greater energy savings. Water losses attributable to leaks within water distribution networks are estimated to be 14% in the United States and as high as 50% in developing countries. In addition to losing treated water, energy for pumping and treating the water is lost, too. To minimize greenhouse gas emissions due in part to leaks, pipes should be replaced at least every 20 years. The current average replacement schedule for municipal pipes in the United States is once every 200 years. (Rao, et al, 2017).

Certain energy efficiency measures in water systems may not directly enable end-use water savings but can still reduce the amount of energy and CO2 emissions associated with generating the energy and reduce the amount of water required in the energy supply system. For electricity-saving energy efficiency measures, the reduction in electricity will yield water savings (both withdrawals and consumption) at the power plant if it is a thermoelectric plant.

In OECD countries, the development and commercialization of some residential on-site grey water recycling systems also offers options for important end use household water and energy savings in the future. In Europe, the average water usage is 120 litres water/person/day, of which about 55 litres is used for showers and baths. A new low-maintenance household greywater recycling system is being offered commercially in Europe which can recycle on-site up to two thirds of household greywater taken from bathtubs, showers and washing machines to be re-used for toilets, washing machines, or for watering gardens. The system can easily be installed in new houses and is available with varying sizes/capacities. Systems for retrofits are also available. In Europe, water rates and wastewater charges are comparatively high. Hence, the installation of such a system in a private household may well make economic sense, depending on the respective local rates for freshwater, energy, and wastewater treatment, and the total amount of grey water recycled. If such systems gain popularity, they may significantly reduce freshwater consumption and wastewater loads, while potentially also decreasing systems-wide energy consumption.

7.5. Innovative sanitation systems

Although progress in sanitation has been achieved in the last decades, about 4.2 billion people worldwide still lack access to safely managed sanitation. Of these, 2 billion are without basic sanitation services and 673 million practice open defecation (UN, 2020a).

More and better sanitation systems are urgently needed, particularly in rural areas of developing countries. Accelerating further research and development of affordable sanitation systems is of crucial importance for addressing the water-energy challenge, particularly in the developing countries. Some models of waterless "Eco-Toilets" are already available, but additional research and product development is needed.

A United Nations Observance related to sanitation is the World Toilet Day which is celebrated every year all over the world to raise awareness about the billions of people that still live without access to safely managed sanitation. The World Toilet Day is a call for action to tackle the global sanitation crisis that results in the death of hundreds of thousands of people every year (UN-Water, 2020).

A sustainable sanitation system could start with a toilet that effectively captures human waste in a safe, accessible and dignified setting. The waste can be stored in a tank or transport through pipes for treatment and safe disposal. Reusing human waste could help to reduce water consumption, serve as the basis for energy generation reducing greenhouse gas emissions, and provide nutrients for agriculture.

The are many efforts taking place worldwide for the design, development and demonstration of innovative toilets that would support sustainable development. These efforts are being undertaken by academic institutions, international organizations, foundations and NGOs in order to demonstrate practical, effective and sustainable solutions to sanitation. Some innovative examples include:

- The Loowatt is a waterless toilet system that transforms human waste into biofuel. The composting toilet features a biodegradable lining that stores excrement in a sealed, odor-free container. Once the toilet is full, the user takes the package to an outdoor biodigester, which in exchange, provides a free source of biofuel for cooking.

- The Sabine Schober toilet treats human waste by mixing it with charcoal to produce highly fertile soil for reforestation. The toilet is built using components made of sanitary ceramic on the outside and a plastic container on the inside. The treated excrement can be used as compost.

- The Loughborough University Toilet converts human waste into carbonized material to provide heat, min-

VIII.

Conclusions: Policy implications and priority actions

Conclusions:

Policy implications and priority actions

Water, energy and climate change are strongly interrelated. Understanding the interlinkages at global, regional, national, and local levels is crucial to anticipating future stress points, developing rational policies, selecting appropriate technologies, managing risks, realizing valuable synergies, preventing eventual conflicts and formulating effective and integrated sustainable water and energy solutions. Many sustainable water and energy solutions could be implemented to effectively address some of the most important climate change challenges. Multiple synergies could be realized where water and energy systems are developed and used in an integrated manner, supporting climate change mitigation and adaptation objectives.

The importance of energy and water and their strong interdependence have become more evident during the COVID-19 world crisis. Without the critical services of water and energy, the full spectrum of health services could not be implemented. A devastating situation could occur anywhere if these services were to be disrupted even for a short period of time during a pandemic. In light of the grave consequences resulting from the COVID-19 pandemic, sustainable water and energy solutions are viewed as a necessary response for a more resilient and sustainable recovery.

Policy implications

- Integrated resource development and investment planning for water and energy can offer multiple co-benefits, including lower costs and reduced environmental emissions.

- Major asymmetries exist between water and energy. Energy is recognized as valuable and it attracts investment and political attention. Water is widely seen as a public good to be provided by the public sector. Financing water and wastewater infrastructure therefore is particularly challenging. Availability of water data is another major challenge. Policy makers need to be aware of and address these sectoral asymmetries.

- Transboundary cooperation for integrated river basin water and energy development and regional power pools is essential for regional sustainable development.

- Additional support for research and innovation can accelerate further development, commercialization and diffusion of climate friendly integrated water and renewable energy systems representing sustainable solutions.

- Economic development is only socially sustainable if it genuinely “leaves no one behind”. Decentralized and integrated water and renewable energy systems as well as innovative sanitation systems can play a pivotal role in advancing sustainable rural development and poverty alleviation.

- Greater international solidarity and technical and financial cooperation are necessary to enable less and least developed countries to develop integrated water and energy infrastructure and services in an efficient and sustainable manner.

Priority actions

- Significantly expand and modernize existing water and energy supply systems in an integrated and sustainable manner to meet growing global water and energy needs with minimum environmental impacts.

- Increase energy and water demand management measures to improve efficiency and conservation, particularly in regions where water and/or energy resources are scarce.

- Increase the contribution of energy from renewable sources, particularly wind and solar photovoltaic, given their advantages in relation to water consumption and GHG emissions.

Actions on systems using water for energy

- Ensure that new hydropower dams and reservoirs are fully compliant with sustainable development criteria. Public participation in planning and decision making is essential.

- Assess options for increasing efficiency of existing hydropower generation plants.

- Assess options for new construction of run-of-river power plants considering social impacts, site-specific conditions, long-term projections of water flows and potential climate change impacts.

- Consider building additional small and micro hydropower generation facilities, wherever technically, environmentally and economically viable, to support interconnected and/or decentralized electric power supply systems, in particular for benefiting the poor in rural areas.

- Explore options for interconnecting national and regional electric power systems and for using existing hydropower reservoirs for energy storage.

- Study options for powering existing non-powered dams or gravity-fed water flows.

- Take measures to reduce water use for cooling of thermoelectric power plants.

- Ensure that bioenergy development is based on sustainable water and land management practices that take into account other uses of water as well as food security.

- Review projected future cooling water needs and cooling water availability in thermoelectric power plants, taking into account potential climate change impacts.

- Study options for greater use of co-generation systems at existing thermopower plants.

- Make greater use of geothermal energy resources wherever technically feasible, environmentally sustainable, and economically viable.

- Accelerate the viability, uptake and acceptance of ocean energy systems in an environmentally acceptable way.

- Increase support for further development and commercialization of hydrogen produced with renewable energy.

Actions on systems using energy for water

- Expand the use of renewable energy as a power source in water purification and water desalination.

- Build and expand sustainable wastewater collection and treatment systems.

- Monitor and reduce leakage in freshwater supply and distribution systems and reduce losses of water in wastewater pipes and wastewater treatment.

- Modernize irrigation systems to reduce water loss and ensure energy efficiency, inter alia by more gravity fed water transport systems, better and more efficient water pumps, and installation of variable speed drives and remote-control systems.

- Improve rain and storm water use and drainage and avoid run-off of storm water that pollutes freshwater supply or increases water load at wastewater treatment facilities.

- Promote the use of biogas from biological treatment of wastewater for on-site use of combined heat and power generation.

- Design and build new wastewater treatment systems to minimize GHG emissions. New wastewater treatment facilities should be designed to be energy self-sufficient, or net energy producers, where possible.

Actions on decentralized and integrated water and energy supply systems

- Mobilize international cooperation and technology transfer for decentralized water and energy systems and innovative sanitation systems for the urban and rural poor.

- Enhance local capacity building on decentralized integrated water and energy solutions.

- Support additional projects and local initiatives in rural drinking water supply and small-scale water purification/desalination systems using renewable energy.

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