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BRACING FOR CLIMATE IMPACT:
Renewables as a climate change adaptation strategy

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ABBREVIATIONS

CCA	community choice aggregation
COP	Conference of the Parties
DRES	distributed renewable energy solutions
EU	European Union
GCF	Green Climate Fund
GEF	Global Environment Facility
GHG	greenhouse gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
IPCC	Intergovernmental Panel on Climate Change
LTS	long-term low emission development strategy
MDB	multilateral development bank
NAP	national adaptation plan
NAPA	national adaptation programme of action
NDC	nationally determined contribution
NGO	non-governmental organisation
PPP	public-private partnership
PV	Photovoltaic
RET	renewable energy technology
SDG	Sustainable Development Goal
SIDS	small island developing states
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
WHO	World Health Organization

EXECUTIVE SUMMARY

The impacts of climate change are being seen with increasing frequency and intensity around the world. Climate change mitigation (action to reduce greenhouse gas emissions) remains vital but is just one of the two main pillars of climate change response. The critical importance of the second pillar, adaptation (action to adjust to and protect against the impacts of climate change), has gained significant recognition in recent years, and an increasing flow of finance to adaptation activities is being seen at the international and national levels. Many climate adaptation strategies require considerable energy use, yet the role of reliable, affordable and modern renewable energy services in climate adaptation is not widely acknowledged in policy making or practice.

This report discusses the benefits of renewables-based adaptation and illustrates the importance of renewable energy within an integrated mitigation-adaptation approach to climate action. The report explores three main areas:

1. Strategic role of renewable energy in climate change adaptation and in mitigation-adaptation synergies

Renewable energy can significantly contribute to climate change adaptation and create opportunities for innovative practices to address climate change. Renewables-based adaptation solutions promote mitigation and reinforce adaptation efforts synchronously across many sectors. As a versatile energy resource, renewables can serve a broad range of adaptation needs and provide benefits that other resources cannot deliver. Specific adaptation needs and potential renewables-based solutions in five sectors/areas – water; food, agriculture and forestry; natural disaster response; oceans, coasts and small islands; and human health – are highlighted in this report.

Renewables allow implementation of energy-intensive adaptation solutions – such as air conditioning, desalination and irrigation – with net-zero emissions. Renewable energy enables "sustainable win-win" solutions, rather than trade-offs between mitigation and adaptation being inevitable, as they have been in the past.

Distributed renewable energy solutions (technologies that provide power outside a central grid) can create a resilient energy system, and therefore support vital adaptation measures, for the most vulnerable communities. For instance, the residents of coastal or rural communities, who are most affected by climate change, often face the most difficulty in adapting to and recovering from its impacts. In these locations, distributed renewable energy solutions can ease exposure to climate change impacts by providing "green infrastructure" in indispensable sectors (e.g. water, food, waste treatment), allowing these services to be supplied even when faced with climate change impacts and natural disasters. Moreover, long-term access to reliable energy through distributed renewable energy solutions builds services, self-resilience and adaptive capacity in the local society and decreases its vulnerability to climate change risks – all without requiring huge upfront infrastructure investment.

Renewables can also deliver non-energy services that contribute to climate adaptation. This multifunctionality enables renewable energy technologies to provide additional forms of resilience to climate change. For instance, the multipurpose nature of hydropower and bioenergy technologies is well recognised, and their non-energy services have been used in real adaptation projects, such as solar shading (e.g. honey production under solar panels to improve food security) to reduce evaporation on agricultural land; use of byproducts from biogas facilities to make organic fertiliser; and water harvesting from hydropower dams. Well-designed and integrated climate adaptation policies should take advantage of the energy and non-energy services that renewable energy technologies provide.

2. Planning and financing for renewables-based adaptation

Many countries recognise renewable energy as a synergistic mitigation-adaptation measure and incorporate it into their nationally determined contributions (NDCs) and long-term development strategies under the Paris Agreement. Of the 190 countries that had submitted NDCs by the end of 2020, 64 (34%) had incorporated renewable energy into the adaptation component. Although most of those countries describe renewable energy as an adaptation measure for the energy sector (diversifying energy mix and increasing the resilience of the sector), its use for adaptation in other sectors, such as water, food and agriculture, is also frequently mentioned. Many countries, particularly small island developing states and countries in the Middle East and North Africa region, use (or plan to use) renewables in the water sector to power desalination and wastewater treatment technologies and thereby combat climate change-induced water security concerns. Some countries' long-term development strategies include newer technologies, such as renewable-powered agro-photovoltaics and vertical farming, as adaptation measures for food security. Several countries plan to preserve forest by increasing access to renewable energy and eliminating the need to use wood for heating and cooking. Enhancing the adaptation components of NDCs will become a more urgent issue for countries in their upcoming 2025/26 NDC revisions.

Climate finance provided and mobilised for adaptation activities has significantly increased, rising to USD 16.8 billion in 2018 and accounting for 21% of total climate finance, up from 17% in 2016. **However, a considerable amount of adaptation finance remains untapped, and renewables-based adaptation could be a prime candidate for these funding opportunities.** For instance, the Green Climate Fund has been mandated since 2014 to deliver half its portfolio to adaptation projects, and in 2019 the World Bank announced it would boost its adaptation financing to USD 50 billion by 2025, ensuring that over half its climate finance will go to adaptation. **Projects involving renewable energy for adaptation are gaining ground: they already compose around 42% and 60% of projects for adaptation in the financial aid of the Adaptation Fund and the Green Climate Fund, respectively.**

With the rising interest in corporate environmental, social and governance practices, the emissions mitigation provided by **renewable energy technologies can help leverage private investors and propel the flow of private finance into climate adaptation projects.** In addition, recent progress in green finance, such as in climate finance taxonomy, may provide another income source and further spur the integration of adaptation and mitigation.

3. The way forward for renewables-based climate adaptation solutions

A holistic approach needs to be taken to integrate renewable energy into the climate change adaptation process at all levels of upstream and downstream decision making. This integrated and holistic approach would help identify the contribution of renewable energy to adaptation, promote synergies with mitigation and sustainable development, and maximise the overall benefits of renewable energy while minimising trade-offs.

A clear framework provides a strong basis for climate adaptation; it is therefore critical that countries establish a clear climate rationale, based on the best available science, through which renewable energy technologies can be embedded in adaptation policies, programmes and projects. A cross-sectoral approach is essential, and a range of stakeholders should be engaged from the early stage to identify synergies, avoid conflict, decrease implementation costs, and significantly improve project success.

Renewables may contribute more than one adaptation, mitigation or sustainable development objective, while producing greater impact with fewer resources. Careful and engaged cross-sectoral, multi-stakeholder planning can maximise these impacts within a given project. In addition, maximising and highlighting all the potential benefits of a renewable energy project could encourage financiers and stakeholders to invest, facilitating a greater flow of adaptation finance.

Renewable energy options must be integrated into short- and mid- to long-term decision-making and planning processes to mainstream, structure and scale up renewable energy adaptation projects. This integration can be best realised by (i) creating an enabling environment for private investors to catalyse private financing and supplement public spending, (ii) ensuring the engagement of finance ministries in adaptation planning, and (iii) engaging international climate finance.

As climate risks keep changing with time, and multiple sectors interact with one another, projects should include continually evolving processes for monitoring, learning and managing changes. Good practice-based policy, monitoring and evaluation will generate lessons learnt and present practical solutions for clean energy deployment in different sectors.

INTRODUCTION

THE SHIFT TO CLIMATE ADAPTATION STRATEGIES

Climate change has multidimensional impacts on human society and on natural systems. Climate change impacts, both direct and indirect and both short and long term, have become more evident – from extreme weather events to gradual changes in climate variables, such as temperature rise or altered precipitation patterns. By putting agriculture, water, human health, oceans, supply chains and infrastructure – all of which are vital to the socio-economic routines of human beings – at severe risk, climate change poses real threats to local communities and indigenous people. Developing countries in high mountain areas and small islands developing states (SIDS) are already observing visible climate impacts. To address these issues and reduce adverse impacts, the global community agreed a landmark joint pact, the Paris Agreement (2015).

However, recent global observations show that emissions trends are not on track to meet the Paris Agreement target and that significant warming trends will be impossible to escape, even if the global emissions target is achieved. The United Nations Department of Economic and Social Affairs (2019) reported that "2019 was the second warmest year on record and global temperature is projected to rise by up to 3.2°C by 2100", despite COVID-19 being predicted to result in a 6% drop in greenhouse gas (GHG) emissions in 2020 (United Nations, 2020a).

Under current policies, the world is struggling to reach the "well below 2°C" threshold, and even if mitigation targets are met, the effects of climate change are expected to be amplified in frequency and intensity. Countries are experiencing more climate-related impacts, such as floods, storms, extreme heat and extreme wind, putting pressure on supply chains of food, energy and water – the basic needs of human beings.

For this reason, adaptation has gained more attention in recent years as needs to address the negative impacts of climate change globally have increased. For many countries, especially developing countries, least developed countries and SIDS, adaptation has become an integral part of sustainable development. Various approaches to target, plan and implement adaptation initiatives have been taken, including in those countries' commitments to the Paris Agreement through their nationally determined contributions (NDCs) and national adaptation plans (NAPs).

Some countries, such as Antigua and Barbuda, have emphasised the provision of water and other essential services for rural communities. Costa Rica has given utmost importance to food security; Burundi has focused on agriculture and livestock production.

Renewables are often considered a climate change mitigation measure, while their importance to climate change adaptation has been overlooked. This report highlights some of the contributions of energy transformation through renewables to climate change adaptation. The report builds conceptual links between renewable energy and climate change adaptation to illustrate the opportunity renewable energy provides for well-designed, effective and comprehensive climate adaptation.

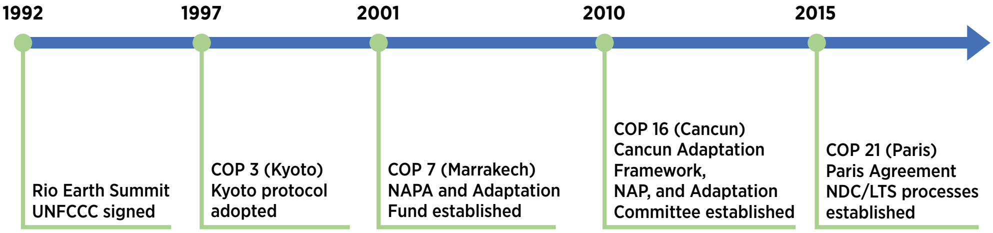
Chapter 1 provides background and concepts on climate adaptation. Chapter 2 establishes the contribution of renewables to adaptation in various sectors and through different renewable energy technologies. It explores how renewable energy opens adaptation pathways that also promote mitigation and reinforce adaptation efforts in other sectors synchronously. Chapter 3 examines current adaptation policies, identifies gaps in planning, and highlights opportunities and challenges for financing adaptation through renewables. Chapter 4 suggests ways for policy makers, researchers and practitioners to work towards wider deployment of renewable energy. This report does not discuss in depth the adaptation of the energy sector itself to climate change – such as the climate resilience of power systems. IRENA's upcoming NDC brief 'Supporting the enhancement of power system resilience in a changing climate with renewable energy' will explore this subject in more detail and provide insights into the role of renewable energy in building power system resilience.

PARIS, CANCUN AND UNFCCC: INTERNATIONAL FRAMEWORK ON CLIMATE ADAPTATION

Since the United Nations Framework Convention on Climate Change (UNFCCC) was signed at the Rio Summit in 1992, calls to address the adverse consequences of climate change have grown (Figure 1). The national adaptation programme of action (NAPA) was established at the seventh Conference of the Parties (COP 7) in 2001. The main objective of the NAPA was to support least developed countries in addressing the challenges of climate change. NAPAs consist of prioritised adaptation projects in each least developed country.

Countries agreed to enhance action on climate adaptation, recognising the increasing urgency of tackling climate change impacts. At COP 16 in 2010, the Cancun Adaptation Framework was adopted and commenced the process of formulating NAPs on a voluntary basis. The establishment of a new climate fund (currently the Green Climate Fund [GCF]) and a separate adaptation committee within the UNFCCC was also decided at Cancun. In the lead up to COP 21 in Paris in 2015, the Parties to the Convention agreed to submit NDCs and a long-term low emission development strategy (LTS), in which countries pledge their mitigation and adaptation targets.

Figure 1: International climate adaptation framework timeline



Source: UNFCCC (2019)

With the establishment of adaptation as an integral part of development planning, countries have taken different approaches to targeting, planning and implementing adaptation measures, documented in NDCs, NAPAs and NAPs. In the first submission of their NDCs, countries outlined their pledges to reduce GHG emissions and had the option to include targets for adaptation. NDCs were originally seen as a way to document GHG mitigation targets (AfDB, 2019a). However, many countries exercised this option and included adaptation targets (Paris Agreement, article 7.11; WRI and UNDP, 2019).

By the end of 2020, 190 Parties had submitted NDCs. Of those, around three-quarters of the countries had included an adaptation component, and 64 countries had recognised the contribution of renewables in climate change adaptation and resilience building. Renewable energy has come to the forefront of the climate change discussion, with a majority of NDCs including renewable energy as part of their mitigation and adaptation strategies. The number of countries that have included renewable energy in adaptation strategies within NDCs increased from 47 in 2017 to 64 in 2020. Many countries, especially those most vulnerable to climate change impacts, indicate in their NDCs that renewable energy can improve adaptation implementation measures and broaden the scope of adaptation.

ADAPTATION AND MITIGATION: TWO PILLARS OF CLIMATE RESPONSE

Mitigation and adaptation are the two essential pillars of response to reduce the negative impacts of climate change. While mitigation remains crucial to limit climate change, the negative impacts of climate change are already increasingly evident and, to some extent, inevitable. As a result, climate change adaptation has gained more attention in recent years, with its focus on minimising damage, predicting trends and impacts, and even tapping into opportunities.

To date, most mitigation and adaptation interventions have been implemented separately in projects and policies. The approach on mitigation has been largely economically and technologically oriented and has been put into action at a global level, whereas the approaches for adaptation have been more relevant to ecological and social dynamics and have been inherently associated with resolving local and short-term impacts of climate change. The notion that adaptation and mitigation are separate priorities has forced them to compete for investment, policy and planning resources (Greenhill, 2018).

However, the IPCC Fifth Assessment Report calls for mainstreaming "...adaptation and mitigation to realise the goal of sustainable development" (Denton et al., 2014, cited in Di Gregorio et al., 2017). Recent works looking at the links between mitigation and adaptation suggest that an integrated approach could be more beneficial than the implementation of two pillars separately (WRI and UNDP, 2019; Flores and Peralta, 2020).

CLIMATE ADAPTATION: THE BASIC CONCEPT

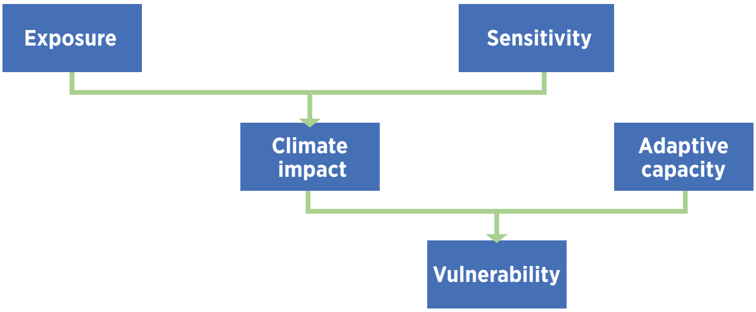
The concept of climate change adaptation is still evolving. Although no single unanimous definition exists, the following definition is used by the IPCC and the UNFCCC:

> "The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects. Adaptation would also include any efforts to address these components" (IPCC, 2014a)

While this concept is quite broad and can include a wide range of interventions, adaptation generally focuses on reducing vulnerability and impacts of climate change, and on enhancing adaptation capacity and resilience of societies (Paris Agreement, article 7.1). Among them, climate risk and vulnerability assessment are initial procedures to explore the climate adaptation needs. Their implementation includes the assessment of climate-related hazards, the vulnerability of human and natural systems, and their ability to adapt to climate change (IPCC, 2014a). As illustrated in Figure 2, **climate change vulnerability** is:

> "...the degree to which a system is susceptible to and unable to cope with adverse effects of climate change, including climate variability and extremes. **Vulnerability** is a function of the character, magnitude, and rate of climate change and variation to which a system is **exposed**, the **sensitivity** and **adaptive capacity** of that system." (IPCC, 2007)

Figure 2: Relationship between vulnerability, adaptive capacity, sensitivity and exposure



Source: Adjusted from GIZ and CCA RAI (2014); US NOAA (2020)

Thereby, climate adaptation actions aim to reduce climate vulnerability by increasing the adaptive capacity of a society and limiting exposure to hazards. For instance, a relocation (pulling back from the coast) could be a way to reduce exposure and sensitivity in response to sea level rise, and an early warning system and awareness-raising programme could increase the adaptive capacity of a community against flood or inundation risks.

The vulnerability assessment, a tool that identifies the sectors and areas most vulnerable to climate change impacts, helps establish decision-making criteria and baseline for climate adaptation strategies (IPCC, 2014a). Among others, scenario-based modelling can show how the project scenario contributes to adaptation by counterbalancing future negative impacts of climate change such as decreased water availability and crop production.

2. RENEWABLE ENERGY IN CLIMATE ADAPTATION

In this chapter, sections 2.1 and 2.2 will address the role of energy usage (including conventional energy) in climate adaptation, GHG emissions issue caused by energy-intensive adaptation activities, and how renewables can facilitate climate adaptation actions without resulting in significant GHG emissions. Sections 2.3 and 2.4 will analyse renewable energy technology options by sector. Section 2.5 will present distinctive adaptation benefits of renewable energy from various perspectives.

2.1. ENERGY USES IN CLIMATE ADAPTATION

Recently, there has been growing acceptance among academics and policy makers that energy and climate change adaptation are deeply interconnected. The most widely debated topic has been how the energy sector would adapt to climate change impacts. Clearly, energy as a sector itself is affected by climate change, as extreme weather events and gradual climate changes have increased the exposure of power systems to climate impacts. Generation diversification, distributed energy solutions and technical advancement to increase the resilience of physical assets have been the most commonly discussed measures to increase the adaptation capacity of the energy sector.

Despite the increasing demand for the energy sector to address climate change impacts, how the energy sector can facilitate and build climate resilience of the societies is a relatively new topic. Energy is a basic human necessity, and energy supply is an indispensable element in all economic activities. As the impacts of climate change grow, energy demand is expected to increase accordingly. Increases in global temperature have created significant upward shifts in energy demand for cooling, with implications for energy efficiency. For example, the International Energy Agency (2018a) estimates that a 1°C increase in global temperature could bring about 25% increase in cooling demand by 2050.

In this report, energy use in climate adaptation refers to all sorts of functions and actions that reduce vulnerability and exposure to climate change hazards. Because energy can enable basic services, including household lighting, cooling and heating, and electrical devices (mobile phones, computers, refrigerators, televisions, etc.), good energy service generally enhances the adaptive capacity of people, communities and remote regions with high vulnerability to climate change by improving their resilience and access to information (Davide et al., 2019; Hills et al., 2018).

The potential role of reliable, affordable and sustainable modern energy services in strengthening societies' capacities to better adapt to climate change impacts has not been widely acknowledged in either policy or practice (Sharma, 2019). Yet energy service is vital to many activities required to respond to climate change impacts, ranging from water supply and space cooling to emergency energy supply in natural disasters (Malekpoor et al., 2019). Table 1 provides some examples of energy-related adaptation interventions. This report will probe these links and argue for a critically co-dependent conceptual relationship between climate adaptation, mitigation and renewable energy.

Table 1: Examples of energy services for adaptation benefits*

EXAMPLES OF CLIMATE IMPACTS	KEY RISKS	ENERGY SERVICES	ADAPTATION BENEFITS
Drought	Water shortage	Desalination	Access to fresh water in coastal areas
	Water service disruption	Water distribution, pumping, transport (trucks, bottles), supply and distribution efficiencies	Water supply reliability for human and industrial use
	Degraded water quality	Wastewater treatment, water purification	Reduction of waterborne disease, water recycling
	Water shortage for agricultural use	Irrigation, pumping	Maintenance or increase of crop yield
Temperature rise	Reduction in food production	Fertiliser, water irrigation, horticulture, aquaponics	Crop yield increase
	Increased food loss	Food storage and refrigeration	Reduction in food loss
	Degraded air quality	Air filtration system, ventilators in hospitals	Reduction in respiratory diseases

* This is for an illustrative purpose. A climate adaptation option should take into consideration the variability of climate change impact that differ significantly depending on specific sectoral, geographical and social context.

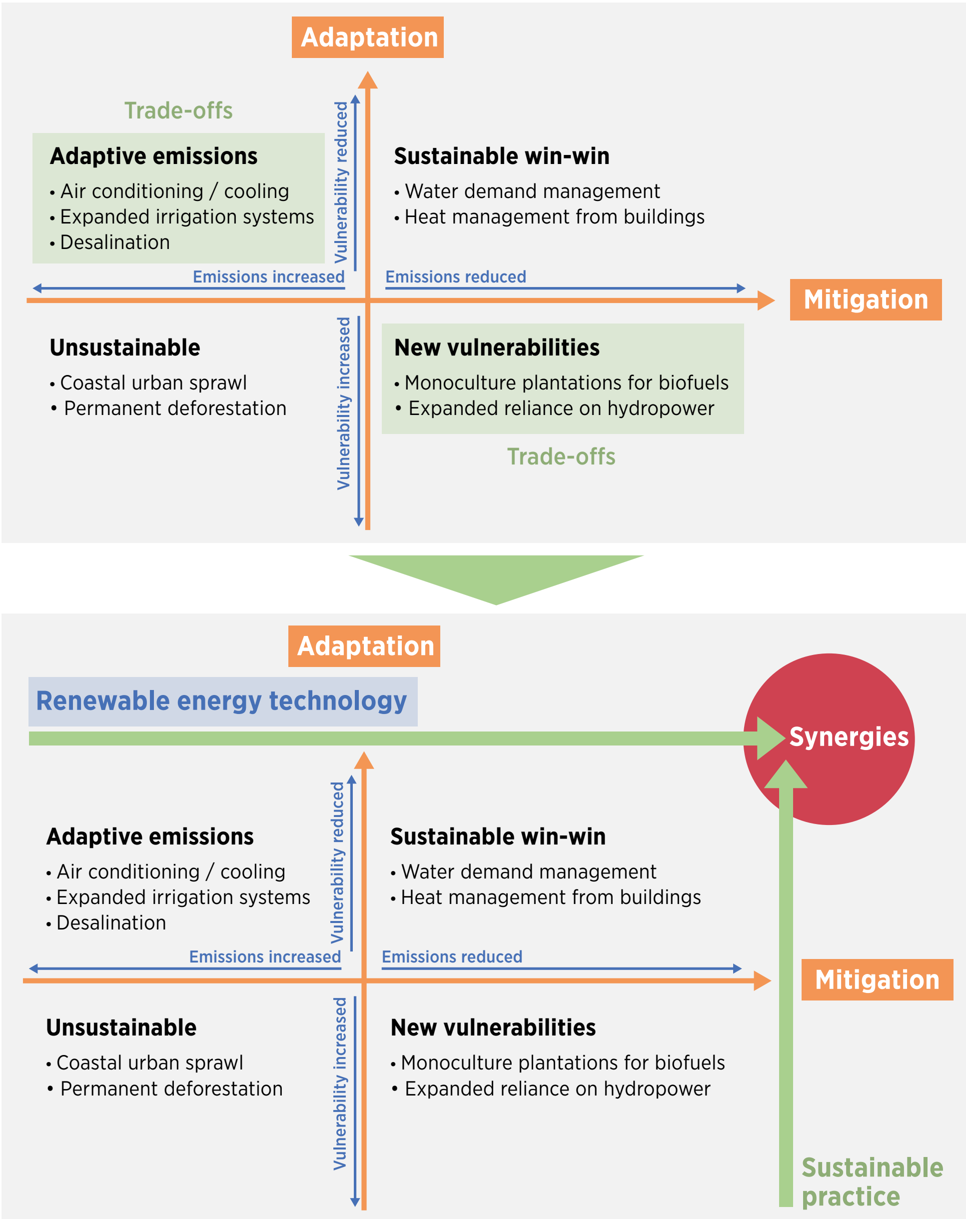
	Increased vector-borne diseases	Operation of health care facilities, refrigeration	Reduction in disease rate
	Heat or cold waves	Space cooling or heating, fans, heaters	Heat or cold fatality reduction in vulnerable population
	Increase in heat-related disease	Water chillers, freezers, ice-making plants	Alleviation of heat stress
Natural disasters, tropical storms, and floods	Mass casualty caused by disaster	Energy supply for medical services	Continued operation of medical service
	Increase in crime rate during disorder	Energy supply for lighting service	Improved safety, particularly for women and children
	Communication service disruption	Television, radio, Internet, telephone	Dissemination of information, communication
	Energy supply disruption	Emergency energy service for residential, commercial and industrial buildings	Energy recovery for disconnected facilities

2.2. NET-ZERO EMISSIONS AND ENVIRONMENTALLY SUSTAINABLE PRACTICES

As discussed in section 2.1, climate change is expected to increase energy demand to support adaptation measures, such as space cooling, water supply and cold chains. Energy-intensive adaptation solutions such as air conditioning, desalination and water irrigation systems have been acknowledged that they can make climate change impacts worse owing to their GHG emissions, while decreasing vulnerability.

As can be seen in the left-hand diagram of Figure 3, adaptation measures that lean on extensive energy consumption are inextricably linked to increased emissions; the trade-offs (vulnerability reduced but emissions increased) are shown in the upper-left quadrant. Monocultural plantations for biofuel and increased reliance on hydropower dams (lower-right quadrant) are some examples of consequent environmental degradation that could increase vulnerability through, for example, displacement of indigenous people, loss of biodiversity and degradation of water quality.

Figure 3: Examples of trade-offs and synergies between adaptation and mitigation



Source: Adjusted from IPCC (2014a)

Amongst various energy sources, renewable energy can facilitate climate adaptation actions without resulting in significant GHG emissions. Renewable energy enables "sustainable win-win" solutions, rather than trade-offs between mitigation and adaptation being inevitable, as they have been in the past. Through its net-zero-emission impact, renewable energy enables adaptations such as air conditioning and irrigations systems to move from being increased emissions solutions (upper-left quadrant of the left diagram) to sustainable win-win solutions (upper-right quadrant of the right diagram), where both vulnerability and emissions are reduced.

Likewise, the potential environmental effects of renewable energy technology (RET) in the bottom-right corner in Figure 3 can be addressed and minimised by adopting more environmentally sustainable practices, especially by incorporating climate change adaptation into decision-making processes and by making greater efforts to avoid environmentally and socially negative impacts. There is significant potential to build resilience by improving social and environmental practice to avoid unintended outcomes of engineering solutions (Hills et al., 2018). For instance, sustainable hydropower approaches – such as the International Hydropower Association's hydropower sustainability assessment protocol and the World Commission on Dams' guidelines – can reinforce the sustainability of hydropower projects. A properly designed hydropower project can ensure that economic development reduces negative impacts on the environment (IPCC, 2011). Taking into account the short- to long-term effects of climate change in the deployment of renewables is one way of safeguarding the sustainability of RET. For instance, small and run-of-the-river hydropower are technologically viable options that can evade negative ecological impacts and the need to build large dams.

Figure 3 illustrates how renewable energy-based solutions could increasingly take on a greater role in climate agendas to produce multiple benefits with the help of continued technological innovation. In addition to GHG emission reduction, rapid cost reduction and technological advancement are the main drivers in increasing the role of renewable energy. Adaptation requires innovative solutions to be implemented, however, it is important to ensure that the negative consequences of the implementation are minimised. Substantial contributions to climate adaptation can be gained from adopting RET together with other sustainable practices.

2.3. KEY SECTORS/AREAS FOR RENEWABLES-BASED ADAPTATION[1]

Energy provides input into almost all goods and services of an economy, facilitating and propelling activities in various sectors including water, food, agriculture and forestry, natural disaster response, oceans, human health. Energy can serve as an adaptation enabler for other sectors and areas, as many sectoral adaptation measures require energy provision. For instance, energy service is a fundamental input in industries such as water, agriculture and food. Energy service enables energy-intensive processes in the water sector (e.g. collection, purification, desalination, storage, distribution, treatment and drainage) and in food supply (e.g. land preparation, cultivation, irrigation, fertilising, processing, storage, transport, distribution and consumption), which are sometimes connected with large-scale energy infrastructure (Davide, 2018; IRENA, 2015).

This section focuses on illustrating renewable energy solutions; their potential challenges and limitations are then discussed. Some of these solutions could be delivered through the conventional energy sources; however, there exist benefits that only renewables can deliver (section 2.5) on top of net-zero emissions.

The following subsections discuss how renewables can prevent or mitigate negative climate change impacts in each sector. Each subsection introduces sector-specific climate impacts and risks, knowledge of which is critical in identifying the sector's adaptation needs and in establishing a climate framework. These adaptation solutions are illustrative rather than exhaustive. Nonetheless, it is important to note that all the renewables-based adaptation introduced in sections below may not be eligible for adaptation measures as adaptation is usually quite local context- and case-specific. It is essential for local government officials, project developers, and international development organisations to establish strong climate rationale on the ground for an implementation of mentioned projects.

1 These sectors have been recognised by many countries as crucial climate adaptation sectors in their plans, especially in NDCs in relation to RET (Chapter 3). The IPCC Fifth Assessment Report (IPCC, 2014) stated that "agriculture, forestry and fisheries may be particularly vulnerable to the effects of climate change and may encounter greater constraints on their capacity to adapt". Under UNFCCC's NAPA initiative, more than 50% of the projects are concentrated in three key sectors: food, terrestrial ecosystems and water resources. However, as noted, renewables-based adaptation also has the potential to be applied in climate mitigation sectors such as building, transport, industry and infrastructure (especially energy infrastructure).

Water[2]

Climate change risk and impact

The vulnerability of water resources to climate change can be clearly seen from hydrometeorological records and climate projections; the consequences for humans and human activities will be extensive (United Nations, 2009). Water itself is central to sustaining all economic sectors, lives and ecosystems and is as a critical part of the complex climate system that carries the impacts of climate change.

Freshwater resources are becoming increasingly scarce in some regions owing to climate change. Around 40% of the world's population is already affected by water scarcity, and this is expected to worsen as the impacts of climate change intensify (United Nations, 2020b). Increased unpredictability and variability in precipitation generally reduce the reliability and the operation cost of water services as well as raw water quality.[3] Degraded water quality negatively affects human health and ecosystems. Furthermore, water shortage itself diminishes water quality, exacerbating the climate impact.

These climate change impacts on water systems fall under three main categories: freshwater shortage, degraded water quality, and extreme weather events such as flood and drought. Yet climate change impacts on the water system are not confined to the water sector. The efficiency and availability of water services affects other sectors – such as food and energy production, human health, and oceans – directly and indirectly because of water's critical role in the hydrological cycle, potentially creating chain reactions.

Renewable energy opportunities in adaptation interventions

The water sector consumes 4% of electricity globally, which mainly consists of water supply (42%), desalination (26%), wastewater treatment (14%) and distribution (13%) (IEA, 2018). From new desalination and wastewater treatment techniques to air-to-water distillation systems, RETs are drivers of innovative approaches to secure, preserve and manage freshwater resources. Table 2 shows a range of renewable energy options in the water sector.

2 Each subsection introduces the potential of renewables-based adaptation in a specific sector/area. The list of renewable energy solutions introduced in this report are illustrative rather than exhaustive.

3 Some high-latitude and tropical regions may see increased rainfall and less exposure to water stress.

Table 2: Renewable energy solutions for adaptation in the water sector

CLIMATE IMPACTS	ADAPTATION NEEDS	ENERGY-RELATED MEASURES	RENEWABLE ENERGY SOLUTIONS
Water scarcity	• Stable freshwater supply • Water resource management	• Desalination • Distillation • Groundwater or aquifer pumping	• Renewable energy systems to power underground pumping • Renewable energy systems to power desalination plants
			(non-energy service) • Hydro dam to increase water reservoir capacity • Floating photovoltaics to reduce evaporation
Increased water pollution and contamination	Water quality enhancement	Water purification and sanitation	• Renewable energy systems to power water clearing pumps • Remote and small-scale water purification through renewable energy systems
	Wastewater treatment and recycling	Wastewater, sewage and sludge treatment	(energy + non-energy service) • Biogas plant for wastewater treatment and recycling
Flood or drought disruption	• Flood control and drainage • Water conveyance and distribution	Water distribution and drainage control	(non-energy service) • Hydro dam to control flooding
			• Solar or wind pumping

Renewable-based desalination

Although desalination is a mature and energy intensive technology, renewable-based desalination shows promise in addressing the water shortage caused by climate change. It is important to note that all the freshwater on earth is naturally desalinated and moved around by solar energy, itself and direct water collection using the solar heat has existed earlier than the invention of modern desalination technologies (Gude, 2018). Though renewables-based desalination was once considered commercially impracticable, it is now one of the most viable adaptation options, especially in small-scale projects. However, large-scale deployment is still at the early stage in many cases and need more government support, such as investment in research and development and an incentive scheme (World Bank, 2019a). Whilst water scarcity is a crucial issue in many countries' adaptation plans, 8 countries[4] specifically mention desalination technologies paired with renewable energy in the adaptation part of their NDC submissions (see section on nationally determined contributions) to move toward more efficient technology as well as to diversify water resources.

Complementarity also exists between variable renewable energy and water production. For instance, excess power generated by solar PV during the day can be used in desalination as water can be easily stored in a water tank or aquifers for later use, which may lead to reduced power curtailments.

Decentralised water supply solutions

Distributed renewable energy systems are increasingly being deployed to expand access to water services in remote communities. In remote areas without centralised water distribution systems, small-scale off-grid renewable energy water solutions are highly economical and implementable options.

Vapour (or fog) harvesting is an emerging innovative technology to collect water in the ambient air. The amount of water in the air is estimated to be equivalent to about 10% of surface fresh water that is not frozen in the Earth, although it presents great variability region by region (USGS, n.d.). This new technology uses this vapour resource and is suitable for small- to medium-scale water supply. For instance, desert safaris in Dubai have installed hydro panels that turn vapour in the atmosphere into drinking water using solar photovoltaic (PV) and solar thermal technologies.

Solar- and wind-powered systems for water purification

In many developing countries, decentralised solar- or wind-powered water purification systems are a more cost-effective solution than fossil fuels or a grid-connected system. The cost of such systems per litre depends on the degree and type of contamination. Small- or micro-scale solar purification systems would be a cost-efficient solution in remote areas with low population density and poor infrastructure for fresh water. Increasingly solar companies provide integrated solar and water solutions that desalinate brackish groundwater on a small scale. For instance, a solar purification system developed by non-governmental organisation (NGO) Givepower provides clean drinking water for 35 000 people per day in the off-grid area of Kiunaga, Kenya (Givepower, n.d.). The complexity and cost of water purification systems depend on the level of contamination and salinity.

4 Bahamas, Cabo Verde, Djibouti, Haiti, Qatar, Singapore, Tunisia, and UAE.

Water transmission networks upgrade

Water distribution services require significant amounts of energy for pumping, transmission and distribution (IPCC, 2014a). In places where water networks are ageing, experiencing significant water leakage and consuming excessive energy, combined water-energy solutions – such as upgrading equipment within water transmission networks (e.g. solar pumps, variable drive motors, energy management software) – can help alleviate water shortage risks.

Wastewater treatment and recycling

Wastewater treatment provides for the proper disposal and release of used water back into the environment. Without it, water availability would be reduced, and untreated water would pose significant risks to human health and the environment. While wastewater generally requires energy for treatment and disposal, the occurring biogas can be used for electricity generation and for sewage sludge and wastewater treatment. For instance, the national climate change secretariat of Singapore (2020) reports that the co-location of a water reclamation plant and food waste management facility in Tuas is expected to generate three times more biogas from water sludge and food waste than would be expected from conventional sludge treatment processes. Recycling water reduces water consumption and so can be beneficial for climate change adaptation.

Renewable energy-powered irrigation solutions

Energy consumption linked to conventional irrigation pumps is also significant. The potential for off-grid solar pumps depends on many factors, but if the technology continues to become more cost-effective, then the solar option could become as large in capacity as the existing stock of grid-connected electric and diesel pumps. This issue will be addressed more in the section on food, agriculture and forestry.

Water storage and vapour retention

Hydropower dams can increase water storage capacity, and the stored water can be used in low precipitation periods. Installing floating solar PVs on dam reservoirs is an increasingly adopted way of reducing water evaporation. This kind of adaptation option, which features a non-energy service from renewable energy, is discussed further in the section on multifunctionality.

Challenges and limitations

Without careful and advanced planning for water resource development, the possibility of maladaptation can be increased in the mid to long term. Possible maladaptation and trade-off cases may include the following (not limited to renewable energy but applying generally to water-energy solutions):

- overexploitation of groundwater by solar irrigation, without proper planning or a monitoring system
- lack of co-ordination with other sectors and possibility of negative impacts on the environment such as waste brine after the desalination process.

As water issues have multiple implications for other sectors, fragmented policies and lack of co-ordination could serve as a barrier to effective deployment of innovative solutions in the water sector. It should be ensured that the water sector adaptation solutions to which renewable energy contribute are planned, implemented and monitored in a way that prevents and lowers negative environmental impacts. Water sector climate adaptation policies should necessitate integrated water management encompassing water supply- and demand-side measures (IPCC, 2014a). Various kind of renewable energy can be coupled with different stage of water management options as shown above.

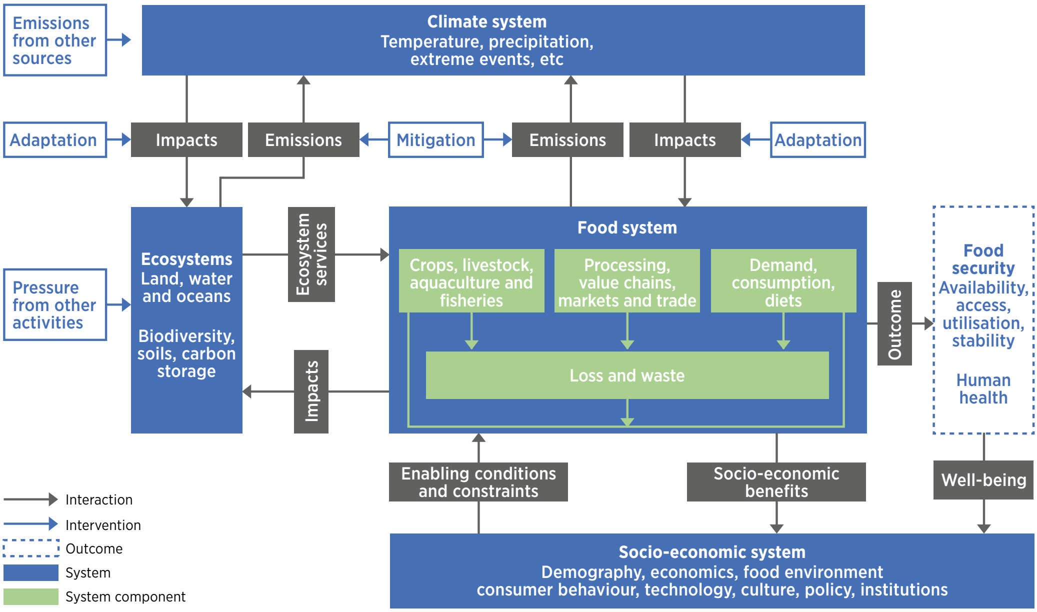
Food, agriculture and forestry

Climate change risk and impact

The Food and Agriculture Organization (2008) reported that food production is already being affected by rising sea levels and by increasingly frequent and intense extreme weather events and irregular rainfall patterns. Crop and livestock production systems are expected to be negatively impacted by climate change in most regions, although some countries have the potential to benefit from the changing climate patterns. While climate change has had positive impacts on some regions, especially those at high altitude with relatively low temperature throughout year, global crop yield is projected to decrease without effective adaptation measures. Increases in average temperatures may irreversibly damage soil fertility and water retention capacity, while favouring pests and plant diseases that thrive in warm conditions. Cattle health is also vulnerable to heat-waves; for instance, heat stress can lead to a reduction in the milk production of dairy cows (Zhao et al., 2017).

The climate change risk profile of the food, agriculture and forestry industry is complex. Because of multidimensional climate change impacts on the food sector, the Food and Agriculture Organization has established the "food system"[5] approach, which captures the entire range of food-related systems including land, water, oceans and human health (Figure 4).

Figure 4: Interlinkage between food, climate, ecosystem and socio-economic system



Source: IPCC (2019b)

Overall, climate change is projected to negatively impact crop production globally, especially in tropical and temperate regions with temperature increases of 2°C, while high-latitude regions may benefit from climate change effects. The loss of arable land due to increased aridity, groundwater depletion and sea level rise is likely to aggravate these impacts.

Livestock and aquaculture are also vulnerable to climate change. Temperature rise is likely to affect livestock production and reproduction negatively, while increasing both heat stress and water consumption.

5 The difference between the food system and the food chain is that the former is a more holistic process interacting with other systems, whereas the latter is the sequence through which people obtain food (FAO, 2008).

Food prices will rise and be increasingly volatile owing to the shortage of food production and extreme weather impact on harvest. Food availability will be further affected by the food spoilage in high temperature. Extreme weather events, such as severe floods, droughts and the spread of disease, can endanger both food availability and food system stability.

Renewable energy opportunities in adaptation interventions

A broad range of RETs are available to advance adaptation throughout the food system. An IRENA (2015a) report introduced a wide range of renewable energy solutions for the agri-food chain. In terms of food availability, the interaction between water, energy and food is expected to become increasingly important as climate changes. The agriculture and forestry sectors make important contributions to the development of renewable energy, especially bioenergy. Many countries are incorporating the multifunctional benefits of the agriculture and forestry sectors into their national plans, particularly in relation to those sectors' impacts on biodiversity, soils, air, water quality and the landscape (nationally determined contributions).

Decentralised energy solutions can provide affordable energy for irrigation pumping and post-harvest processing, which in turn can create employment opportunities for those who live in remote areas where water infrastructure is not yet developed.

Table 3: Renewable energy solutions for adaptation in the food, agriculture and forestry sector

CLIMATE IMPACTS	ADAPTATION NEEDS	ENERGY-RELATED MEASURES	RENEWABLE ENERGY SOLUTIONS
Reduction in crops and cattle production	(to stresses such as water and heat stress, salinity and new pests) • Enhanced food production • Animal health and disease control	• Air cooling system (indoor and outdoor) • Water spray for cooling • Soil fertiliser	• Clean cooling • Renewable energy system to power groundwater pumping • Agricultural waste fertiliser (non-energy service) • Agroforestry • Mixed farming with perennial energy crop
Food supply chain impact caused by high temperatures	• Food processing, storage, distribution and sales • Food utilisation (food nutrient, food safety) enhancement	• Cooling, chilling, freezing • Drying, pasteurisation • Cooking fuel supply	• Renewable energy-based food freezers, refrigerators, storage • Renewable energy-based food dryers or pasteurisers • Renewable energy-based clean cooking solution

Climate extreme events	• Food system stability enhancement	• Early warnings for pre-emptive crop protection • Greenhouse fuel supply	• Climate information service powered by renewable energy • Renewable energy-based greenhouse horticulture and vertical farming
Reduction in fishery production	• Fishery resource management and conservation	• Fuel supply for fishing ships	(non-energy service) • Fisheries and aquaculture in offshore wind farm • Marine protection areas around offshore wind farm
Water scarcity (indirect)	• Water supply for agricultural usage	• Groundwater or aquifer pumping and irrigation	• Renewable energy systems for groundwater pumping (energy + non-energy service) • Agro-photovoltaics

Solar irrigation pumps

Rain-fed agriculture is vulnerable to the increasing variability in precipitation. Climate vulnerability caused by reduced rainfall can be lessened through the expansion of irrigated areas and more efficient irrigation (Hettiarachchi and Ardakanian, 2016). If decreases in precipitation become more severe, a renewable energy pumping system can provide groundwater irrigation to improve agricultural productivity in rain-fed agriculture or to make cool-down water available to livestock. More efficient agricultural productivity can lead to reduced water demand and preservation, which enables excess electricity to be diverted to water storage tanks or battery storage, creating a synergistic impact.

Although the high upfront costs of the solar irrigation equipment, lack of maturity of the solar irrigation market, and water scarcity are barriers to large-scale adoption of solar irrigation practices (IISD, 2019), more and more private companies are expressing interest in the technology, and several local-level enterprises are developing and retailing solar pumping equipment.

Agro-photovoltaics

Like solar irrigation, agro-photovoltaics are gaining popularity. Recent studies suggest that solar sharing in the farm can create synergies between PV infrastructure and agriculture by cultivating crops under solar panels. Selecting crops that can grow well in partial shade is particularly important in agro-photovoltaics. Recent case studies identified that a large number of crops, vegetables, livestock, fish and shrimp can grow under solar PVs, although larger-scale demonstrations need to be carried out (Fraunhofer Institute, 2019).

Greenhouse horticulture and indoor vertical farming

Greenhouse horticulture is a way to produce plants (food as well as non-food) in a stable manner, regardless of weather conditions and seasonal temperature change. The combination of greenhouse horticulture and renewable energy can be a win-win solution. Renewable energy can provide heat and power – essential not only for greenhouses but for livestock buildings – efficiently and cost-effectively without GHG emission. Diverse RETs (solar, wind, biomass, geothermal) can be extensively applied for the operation of horticulture.

Indoor vertical farming using LED lights and hydroponic systems is a recent innovation. It is increasingly being adopted to maximise the efficiency of water and land use, while offsetting climate impacts. Indoor farming, itself, is an energy-intensive process, with large demand for lighting, climate control and IT systems. The energy needed for this is estimated at more than ten times that for conventional horticulture (Thompson, 2020). Therefore, coupling with renewable energy is essential to ensure the sustainability of indoor farming and lower its operation costs.

Like traditional agriculture, renewable energy-powered vertical farming will depend ultimately on the solar energy. Although vertical farming is still in its infancy, it can create synergies between water-food-energy resources by employing renewable energy.

Vertical farming

Food processing for reducing post-harvesting losses

The lack of proper post-harvest storage, processing and transportation facilities is estimated to cause losses of fresh food as high as 30 to 40% of production in developing countries (FAO, n.d.). A reduction of food loss in the food chain is a demand-side measure that could decrease the climate vulnerability of the food system. Temperature rise necessitates more cold storage, processing and logistics as adaptation measures. Enhancing food processing and storage facility capacity can increase climate resilience in the food supply chain. For food storage and processing, various kinds of RETs can be used, including solar, wind, bioenergy and geothermal. Agricultural drying, milk pasteurisation and fish drying using renewable energy are well-established practices in many countries.

Agricultural waste and by-product treatment

There are growing opportunities for food systems and value chains to provide clean and climate-friendly energy production, such as animal waste for biogas, crop residues for cooking (non-traditional uses such as biomass gasification-based cookstoves), agricultural waste treatment for rural electrification through biomass mini-grids, and agricultural waste from sugar and rice industries for power generation and biofuel production. Such solutions can provide not only renewable energy but also environmentally beneficial products such as biofertilisers and biochemicals.

As noted earlier, biogas plants not only generate gaseous energy but can be used for sewage sludge and manure treatment and for sludge recycling and incineration. Agricultural waste after treatment can be used as a fertiliser. The reuse of agricultural waste may increase crop yields, save energy and prevent soil erosion.

Agroforestry and mixed farming

Agroforestry and crop switching are options for adaptation to temperature and precipitation change. Agroforestry is a sustainable cultivation practice combining nitrogen-fixing trees and food crops. Whereas there has been criticism of biofuel's detrimental effect on food production in the past, agroforestry and crop switching to perennial energy crops can provide a solution to soil erosion and loss of soil nutrition and moisture caused by climate change, while increasing food crop production (IRENA, 2019b; Ministry of Food, Agriculture and Fisheries, 2010). Some developing countries, including Ghana and Vanuatu, are pursuing agroforestry using cacao or cocoa trees, of which shells or husks can be utilised as a bioenergy resource. Perennial energy crops are those that can grow well in marginal lands and provide ecosystem services without competition with food crops.

Challenges and limitations

With the appropriate adaptation measures, many of the risks to food, agriculture and forestry caused by climate change may be mitigated, and climate resilience can be improved. However, challenges in the deployment of renewable energy solutions still exist; they are not necessarily limited to renewable energy but apply to food-energy applications in general:

- high upfront costs and affordability in developing countries
- difficulties in establishing a reference case due to complexity in crop modelling
- evaluation of full life cycle costs and benefits of biomass production.

RET solutions in agricultural applications, including solar-powered irrigation systems, are already highly reliable and economically competitive, with rapid cost reduction. However, in many developing countries, small- and medium-size farms cannot afford renewable energy systems, mainly because the relatively high upfront costs and small-scale projects create hurdles in accessing the banking system. Supportive schemes, such as government subsidies, co-operatives or pay-as-you-go mechanisms, are necessary to enhance the deployment of renewables-based systems for food and agricultural applications. A variety of crop production models that accumulate climate, soil, water availability and salinity data can be used to justify the viability and effects of adaptation options.

Renewable energy solutions in food and agriculture sector could provide considerable adaptation benefits, such as increased food production; improvement in air, water or soil quality; and decreased waste (which may in turn impact air, water and soil quality). Producing both types of benefit requires sustainable management practice to be balanced especially with bioenergy production.

Natural disaster response

Climate change risk and impact

A record-breaking number of heat-related mortality and natural disasters are being reported around the world, such as historic wildfires in Australia, California and Siberia and massive river floods in China. In 2015, heat-waves claimed the lives of more than 2 000 people in Pakistan and 2 500 in India, in addition to those of countless livestock. Rising sea temperatures worldwide allegedly make tropical storms stronger and more destructive. The frequency, intensity and duration of certain extreme events continue to increase (IMF, 2019). Although any single extreme weather event can be hard to link directly to climate change, the influence of global climate change on extreme weather events is broadly accepted among climate scientists.

Natural disasters can disrupt physical infrastructure and critical social services, including water, food, energy, transportation, communication, health services and emergency response services (US GCRP, 2016). Increasingly hot weather triggered by climate change is witnessed globally. Prolonged heat-waves and increased humidity escalate energy demand for cooling dramatically and cause load shedding and blackout in many countries, which may lead to complete stoppage in critical infrastructure operations and emergency services. In these events, older people, young children, and people with disabilities suffer disproportionately. In rural areas, power and communication systems take longer to be restored from the blackout than those in urban areas (USGCRP, 2016).

Climate change is causing intense precipitation, which not only affects the infrastructure safety but increases disruption of transportation, displacement of people and damage to livelihoods. Drought increases natural disaster risks, such as wildfires, dust storms and reduced air and water quality. Extreme weather events have immediate impacts on migration and strain the capacity of public health systems. Natural disaster has not until recently been a major reason for migration, but as climate change leads to more intense natural disasters, environmentally induced migration is expected to increase notably. In 2016 alone, 24.2 million people were internally displaced by disaster globally (UNDP, 2018). The World Bank (2020) predicts that “over 143 million people in Latin America, South Asia and Sub-Saharan Africa could be forced to move to escape the impacts of climate change by 2050”.

Renewable energy opportunities in adaptation interventions

Natural disaster response necessitates cross-sectoral resilience-building and recovery measures. RETs can help reduce the vulnerability of societies to the impacts of disasters by enabling the provision of water, food and other public services (e.g. health, public facilities). In addition, decentralised energy systems – as self-reliant power systems – can provide more resilient power supply and protect critical infrastructure after these extreme weather events.

Table 4: Renewable energy solutions for adaptation in natural disaster response

CLIMATE IMPACTS	ADAPTATION NEEDS	ENERGY-RELATED MEASURES	RENEWABLE ENERGY SOLUTIONS
Life and health loss caused by climate catastrophe – flood, extreme wind	• Risk reduction and preparation against climate hazards • Disaster response and recovery • Emergency health service	• Early warning systems • Quick recovery infrastructure • Communication network power supply	• Weather forecasting and early warning systems for natural disaster: off-grid meteorological stations powered by renewables, etc. • Renewable energy for lighting and emergency housing • Off-grid renewable energy for infrastructure fixes and communication (energy + non-energy service) • Hydro dam
Life and health loss caused by climate catastrophe – heat-waves	• Protection and preparation for hazards	• Air conditioning • Freezing and chilling • Ventilators	• Renewable energy-based active cooling system • Freezers and chillers powered by renewable energy
Migration, displacement and relocation	• Disaster response and recovery • Mobility through timely, resource-efficient resettlement support	• Generation and distribution of electricity in emergency settlements	• Off-grid renewable energy generation in disaster-hit region • Off-grid renewable energy for infrastructure fixes and communication • Renewable energy for lighting and emergency housing
Energy system disruption caused by extreme weather events	• Climate-resilient energy system	• Energy system recovery and reconstruction	• Decentralised energy system

Flood control

Hydropower dams are an important adaptation measure that can protect human systems from severe weather events. Hydro dams can enhance overall flood management through river run-off monitoring and forecasting as an integral part of early warning systems.

Emergency communication and weather monitoring

Solar energy can provide valuable solutions for emergency communication and natural disaster control in remote areas. For instance, it can be applied to hazard forecasting at off-grid meteorological and agricultural stations in rural and island areas outside the grid's reach. These off-grid meteorological stations and equipment, powered by renewables, can collect data, create more reliable forecasting and automatically update related information for meteorological offices, water supply offices, and agriculture departments.

Renewable power plants also have the potential to help the operation of early warning systems. For instance, in times of high wind speeds, wind farms optimise their operation in advance with the help of accurate weather forecasting services. The regular weather information can be shared with local authorities/communities and it can enhance risk identification and preparedness, especially as climate information system is a prioritised adaptation area in many developing countries. Marine forecasting and early warning systems on offshore wind farms also can help reduce risks for fishery industry. In developing countries where weather monitoring systems are not well established, those local climate data collected by renewable energy generators can be valuable information which help identify local climate risks more accurately.

Energy system risk reduction

At the risk identification stage, policy makers need to identify proper RETs to deploy in the region in response to natural disasters. Heavy dependence on fossil fuels may result in power outages and associated health risks due to increased use of diesel generators, charcoal and kerosene (USGCRP, 2016). RETs reduce vulnerability to climate risks by diversifying power generation resources and introducing innovative solutions such as battery storage and smart IT systems. In Sub-Saharan Africa, decentralised energy systems – as self-sufficient power systems – have proven they can provide more robust power during these events than centralised power systems.

Emergency power supply

People displaced by natural disasters will still need appropriate energy and electricity provision in the relocation areas. However, conventional electricity generation technologies (e.g. large fossil fuel plants) and electricity transmission lines are hardly mobile or easily displaceable. Off-grid RETs such as solar PV, however, can be easily relocated with the community and then provide almost immediate energy access after relocation.

Renewable energy deployment for displaced people

In a similar way as described for emergency power supply, renewables can play a significant role in the settlements of displaced people, as depicted in IRENA's Renewables for refugee settlements report. The energy assessments of four refugee settlements noted in the report show the advantages that renewable energy solutions can provide in such environments (IRENA, 2019c). Sustainable energy based on renewables is required to enhance the well-being of displaced people and communities. At the recovery stage, small-scale solar PV generation could deploy emergency power more rapidly, while being easier to repair, than utility-scale generation systems. Solar PV systems could therefore help local communities recover from disaster more quickly.

Challenges and limitations

Disaster risk management typically requires a cross-sectoral approach and strengthened co-ordination due to its multiple impacts. Risk reduction, preparedness and recovery cannot be solved by only one sectoral effort. A disaster risk management framework is a useful tool to assist in making informed decisions throughout the whole disaster risk reduction process, which comprises (i) risk identification, (ii) risk reduction, (iii) risk preparedness, (iv) financial protection and (v) resilient recovery (World Bank, 2012).

Ex ante preparedness measures could provide more opportunities to address the underlying vulnerabilities than ex post recovery measures. Such ex ante measures include structural or physical policy measures and non-structural measures (Flores and Peralta, 2020). While close co-ordination will be essential, with clear responsibilities assigned among relevant authorities to identify and share risk information, integrating sustainable energy into national disaster response and recovery plans is an initial step in fostering resilience in terms of adaptation, mitigation and sustainable development.

The vulnerability of renewable energy to natural disaster is another challenge in renewable energy-based adaptation. The technology being used must be resilient to climate change effects. For instance, hydropower may not be effective in drought-prone regions, so it might be better to consider other renewable energy options. Climate change impacts can alter the expected benefits of hydro dams, so the design of water reservoirs for hydropower plants should account for climate variability. Variable renewable energy is also exposed to natural disaster risks that may aggravate supply intermittency. Disaster risk assessment must be conducted with care and then reflected in safety and land-use planning regulations.

Box 1: Making renewable energy technologies ready for climate change

Although this report explores the role of renewable energy projects in climate change adaptation, renewable energy projects are themselves impacted by climate change. Project developers must thus increasingly adopt risk mitigation strategies against extreme weather conditions to ensure that the renewable energy projects are resilient to climate change and suitable for deployment under harsh conditions.

The upcoming IRENA report Strategies to mitigate the impact of extreme weather events on renewable systems addresses this issue from the perspective of project developers and policy makers. In particular, it provides best practices on how to mitigate against extreme weather conditions based on comprehensive case studies. Here, some of the best practices for project developers are summarised in a three-step process that encompasses (i) the assessment of extreme weather conditions at the renewable energy project site, (ii) the assessment of the risks associated with these extreme weather conditions and the type of renewable energy project and (iii) the development of a risk mitigation strategy.

Step 1: Assessment of Extreme Weather Conditions

Project developers must determine the applicable extreme weather conditions for their renewable energy project. The report identifies eight clusters of extreme weather conditions that are relevant for renewable energy projects, including four short-term weather events (tropical cyclones, mid- and high-latitude cyclones, severe thunderstorms, and tornadoes) and four long-term climatic conditions (cold climates, desertic conditions, coastal conditions and high-altitude conditions). By examining macro factors (such as the climatic environment) and micro factors (such as local environment), project developers can establish a basis for risk assessment.

Step 2: Assessment of Associated Risks

Project developers must assess the risks for the renewable energy project based on the environmental impact assessment conducted in step 1. The physical risks vary widely by extreme weather condition and by planned renewable energy project. The financial risks encompass additional investments (capital expenditure, often known as CAPEX) in the project development and construction phase (e.g. quality and safety engineering, precautionary measures), additional operations and maintenance costs (operating expenditure, often known as OPEX) in the operation phase (e.g. reparations, replacements, cleaning), and lost revenues (e.g. downtime, degradation, premature decommissioning).

Step 3: Development of a Mitigation Strategy

Project developers can choose from a wide range of mitigation measures. In particular, they must make trade-offs between different measures across various renewable energy project phases. Project developers can either (i) make an upfront investment in the quality of the renewable energy core components, the mounting structure and the installation service, (ii) insure against certain unpreventable impacts or (iii) bear certain risks by taking measures during the operation phase if a renewable energy project has incurred damage from an extreme weather event. The best mitigation measure is highly dependent on the type of damage, the type of the renewable energy technology, the local environmental conditions, and the accessibility of high-quality components and experienced contractors in the local renewable energy ecosystem.

Oceans, coasts and small islands

Climate change risk and impact

Although the ocean plays a vital role in climate change itself, the ocean and coastal ecosystems are being severely impacted by climate change at an accelerated rate. Ocean acidification hampers growth of ocean organisms such as corals, plankton and shellfish, and warming oceans further decrease the amount and species of fish.

Coastal areas and SIDS are especially at risk of sea level rise, degradation of marine ecosystems and increased natural disasters. The IPCC (2019b) predicts a global mean sea level increase between 0.43 metres (m) and 0.84 m by the year 2100, in relation to 1986–2005, and levels may continue to rise over time.

Sea level rise and ecosystem degradation impact the availability of water and food (fishery and agriculture) in coastal areas and for small island populations, who are heavily dependent on coastal and marine ecosystem services. The intrusion of seawater due to sea level rise and changes in rainfall patterns exacerbates water shortages and increases soil salinity in coastal areas and atoll nations such as Kiribati, Maldives, the Marshall Islands and Tuvalu. These SIDS have dealt with water security concerns caused by climate change in their NDCs.

As geographically remote small island states are largely dependent on the import of necessities, increased extreme weather events further threaten their food and energy security, as well as human health. Small island states in the Caribbean, Pacific, Atlantic, Indian Ocean and South China Seas are suffering from natural disasters with annual average damage estimated at 2–3% of gross domestic product (IMF, 2019). In addition, these regions usually have large tourism sectors, which are sensitive to climate change impacts. These regions are easily exposed to climate change risks but usually have limited adaptive capacity and resilience to manage those risks.

Renewable energy opportunities in adaptation interventions

The importance of oceans in human and natural systems cannot be overemphasised, and maritime and ocean systems provide vast opportunities and challenges for adaptation. Risks associated with local vulnerability are often amplified by climate change. Renewable energy directly improves overall energy security and benefits energy independence in SIDS (Ioannidis and Chalvatzis, 2017).

Table 5: Renewable energy solutions for adaptation in the ocean, coasts and small islands

CLIMATE IMPACTS	ADAPTATION NEEDS	ENERGY-RELATED MEASURES	RENEWABLE ENERGY SOLUTIONS
Water scarcity caused by sea level rise	• Stable freshwater supply • Water quality enhancement	• Desalination • Water purification	• Renewable energy-based seawater desalination system • Solar pumps, solar water purifiers
Migration, displacement and relocation caused by sea level rise	• Defensive measures against sea level rise	• Generation and distribution of electricity in emergency settlements	(energy + non-energy service) • Coastal (tidal) barrage coupled with wave (tidal) power generation
	• Food security enhancement	• Fuel supply for agriculture and aquaculture	• Horticulture with renewable energy • Hydrothermal cooling
Reduction in food production (agriculture, aquaculture)			(non-energy service) • Fisheries and aquaculture in offshore wind farms • Marine protection areas around offshore wind farms
Deterioration of local natural resources	• Environment-friendly tourism as a main income source	• Fuel supply for tourism	• Renewable energy-based ecotourism – solar, wind, hydrothermal cooling, etc.

Decentralised seawater desalination and water supply

Water scarcity has become a severe challenge for most small island states in the Pacific Ocean owing to climate change. As noted in the water section, diversifying water sources by increasing the use of non-conventional sources is important in water management. Centralised water desalination and distribution systems require huge investment in infrastructure, making solar or wind desalination, purification and irrigation technology more viable options to decentralised water supply at the community level. Especially, small-scale decentralised solar-powered desalination is a suitable and competitive solution to increase both water and energy security in many small island states. Smart information and communications technology will allow such systems to be operated and maintained remotely to further increase efficiency; this raises the possibility of implementing an aggregator model in the water sector.

Horticulture with renewable energy

Horticulture combined with RETs can provide food and water in remote islands and build community resilience by reducing imports. For instance, the Resilient Island Foundation's horticulture project (2020) in Maldives was initiated to produce local food using renewable energy. The greenhouse system uses fresh water supplied by a solar desalination plant for crop cultivation, and there are plans to introduce a hydrothermal cooling system using seawater to overcome high temperature and humidity, which make many fruits and vegetables difficult to grow.

Hydrothermal heating and cooling

Hydrothermal energy is an innovative solution to introduce into passive houses and buildings and can provide an auxiliary energy source for cooling and heating in response to temperature rise. Hydrothermal cooling utilises large bodies of water such as aquifers, rivers, lakes and the ocean, and uses the relative temperature difference between ambient air and the water body, or between warm surface water and cold deep water to supply heat or cooling. Some projects show that it can save up to 73 % of energy consumption in buildings (K-water, n.d.). With technologies such as heat pumps, heat rejected from buildings can be dissipated in aquifers for storage, where it can be extracted again to provide heating. This also helps reduce the urban heat island effect. The UK government provides a nationwide water source heat map to help local authorities and communities deploy water heat pump technology at a larger scale (DECC, 2015). The Republic of Korea has been installing a 1 MW ocean thermal energy conversion plant in the Pacific Ocean in partnership with the government of Kiribati since 2010. It will be the largest such plant in the world and can be potentially used for freshwater supply, aquaculture and cooling as well (IRENA, 2020a). The stakeholders of this project include other Pacific island governments, such as those of the Marshall Islands and Tuvalu, and the Pacific Community.

Renewable energy-based ecotourism

Coastal areas and small islands usually rely heavily on the tourism industry which is often very susceptible to climate related effects. Increasing climate resilience of tourism sector has direct impact on local economy. Because coastal and marine ecosystems are key resources in tourism, ecotourism that does not harm the natural environment is becoming a key trend, especially in these areas. Increasingly large numbers of hotels and resorts in these areas are adopting renewable energy solutions to enhance climate resilience. The case study in Box 3 shows an example of zero-emission tourism in Mauritius using a solar desalination solution. In addition, geothermal resources support tourism in many countries such as in Iceland, where manifestations such as geysers and hot springs are tourist attractions. Furthermore, bathing and swimming facilities that use geothermal energy are very popular with tourists around the world. Because many other islands in the Pacific and Caribbean have also good geothermal resources, renewable energy can help build local capacity to respond to the negative impact of climate change. In the context of local capacity building, various socioeconomic aspects such gender, employment, environmental measures should be considered as well.

Aquaculture and marine protection zone in offshore wind farm

Offshore wind farms have the potential to be multi-use platforms, combining aquaculture and early warning systems. Weather forecast information for wind turbines can be especially useful for SIDS. A safety zone for offshore wind farms needs to be considered, together with marine protection areas for endangered marine species. This will be discussed further in the section on multifunctionality: renewables for non-energy services.

Coastal (tidal) barrages

To avoid relocation in response to rising sea levels caused by climate change, communities might decide to implement defensive measures. Such efforts could be coupled with renewable technologies for electricity production. One example is coastal (or tidal) barrages, which can be used to provide better control of the tidal flow of sea and river water. The barrages can be coupled with water turbines to produce hydropower (whose output can also be controlled through water flow management). Another example is sea-walls and revetments, which comprise shielding structures made of concrete, steel, stone or wood. Such structures protect coasts from erosion and act as barriers against flooding, through deflecting and dissipating wave energy. They can be coupled with technologies that harvest wave energy to produce clean and renewable electricity. Such measures would not only offer protection against surge flooding and rising water levels but also, to a certain extent, prevent salt infiltration in coastal areas. Nonetheless, both hard-engineering coastal protection measures and tidal and wave energy technologies are currently considered to be too expensive for wide deployment. Further research, application and economies of scale in the medium to long term might lower their cost enough to allow widespread applicability.

Box 2: Photovoltaic-based desalination plant project on Rodrigues Island

Overview: In 2018, Rodrigues Regional Assembly worked on the development of a solar desalination project on Rodrigues Island, Mauritius, with financial support from the Indian Ocean Commission, the European Commission, and the French Agency for International Cooperation. In 2019, the desalination plant demonstrated climate resilience by resuming operation just a few hours after a serious cyclone hit.

Climate risk, impact, vulnerability, adaptation options and outcome:

Step 1 (Scoping risks): Rodrigues Island, a small island of Mauritius in the middle of the Indian Ocean, has limited access to drinking water resources. According to the Central Water Authority, rainfall only partially filled the island's reservoirs in 2017, and the level of the reservoir at Midlands Dam has been one of the lowest ever observed and led to a lack of water resources and impacted water supply.

Step 2 (Climate impact modelling): Since 1960, the mean annual temperature has risen by an average of 0.13°C per decade, and the rainfall pattern has declined by an average rate of 7.7 millimetres (mm) per month, which is equal to an average 9% reduction per decade (57 mm) (Mauritius Meteorological Services, 2019). Over the period 1961–2014, rainfall records show a downward trend compared with the 1960s.

Step 3 (Vulnerability assessment): Rodrigues Island is currently highly dependent on the rainfall pattern. In Mauritius, 62% of water resources come from surface water and 38% from groundwater (KPMG, 2009). Since 2000, rainfall on Rodrigues Island has been decreasing annually, making the rainwater harvesting infrastructure investments inefficient, leading the island to face severe water shortages and drying of springs and rivers. In some regions of the island, people also have observed brackish water from the tap (UNDP, 2019), which might spread waterborne diseases.

Step 4 (Identifying options and implementation): For the production of clean water from seawater, Mauritius has been operating desalination plants powered by fossil fuels (diesel, oil and gas generators). Instead, Rodrigues Island has installed a solar photovoltaic desalination plant that provides 80 cubic metres (m^3) of fresh water per day using solar energy. A connection may be made to the grid at night during drought periods to produce an additional 200 m^3/day of fresh water (Mascara Renewable Water, 2019).

Step 5 (Expected outcome): Seawater desalination powered by renewables is expected to scale up on the island to secure drinking water availability with minimal impact on water tariffs. The figure below illustrates the change in the volume of desalinated water from the baseline to the project scenario.

Source: Sustainable Water and Energy Solutions Network (2020)

Challenges and limitations

Although ocean energy has great potential, many ocean technologies are still at the early stage of research and development. They are expected to take decades to become commercially available in some cases, so it would be difficult to evaluate the suitability of renewable energy options in climate adaptation. In addition, ocean technologies are not easy to deploy on a large scale in densely populated remote island states because of lack of demand. Given the climate urgency many small island states are facing, available options are currently expensive and technologically limited.

Human health

Climate change risk and impact

Climate change has multiple influences on human health. Direct impacts include losses caused by extreme heat and natural disasters. According to the World Health Organization (WHO) in 2018, these direct damage costs to health will amount to USD 2–4 billion per year by 2030, even without including climate-related impacts in other health-related sectors, such as water and food. Extreme heat-waves can cause wide-ranging health risks, which are amplified by heat island effects and air pollution, especially in urban areas.

Despite the severity and extent of the health effects, the complex pathways between climate change impacts and human health make it difficult to integrate human health into climate impact models. In addition to the direct effects already discussed, human health is endangered indirectly through climate change effects on social and environmental determinants of health: polluted air, water scarcity, insufficient food and unsafe shelter. WHO (2018b) estimates that climate change will cause approximately 250 000 deaths every year by 2050.

The recent spread of COVID-19 has made it evident that people with the least access to essential services like water supply feel the most dramatic health effects (Otto et al., 2020). Also, climate change has created changes in infectious diseases, including some vector-borne and water-borne diseases which are sensitive to climate conditions, their transmission patterns and their occurrences through a combination of factors, including (i) the adaptation and change of pathogens and (ii) the availability of hosts through changes in ecosystems, land use, and human demographics, behaviour and adaptive capacity (WHO, 2020a).

Renewable energy opportunities in adaptation interventions

Some of the most effective vulnerability reduction measures for human health are to supply basic human necessities, such as clean water, sanitation and sufficient nutrients; to provide essential health care services including vaccination and child-focused care; to prepared sufficiently for disasters; and to reduce poverty (IPCC, 2014b). As human health is inextricably intertwined with the energy, water and food sectors, the quantity and quality of supplies coming from these sectors are pre-conditions for healthy life, especially where vulnerability to climate change is very high or adaptive capacity and resilience is low. Human health and well-being cannot be sustained with a single factor. They require a combination of good food, water, energy, disaster relief and health services. Energy services can power the equipment that provides safe water and sanitation, refrigeration for vaccines and reduction of indoor pollutants; these services, in turn, reduce health risks (Venema and Rehman, 2007) – although the sensitivities to climate change impacts vary for each measure.

Table 6: Renewable energy solutions for adaptation in the human health sector

CLIMATE IMPACTS	ADAPTATION NEEDS	ENERGY-RELATED MEASURES	RENEWABLE ENERGY SOLUTIONS
Increase in intense heat-waves	• Adequately maintained temperature • Ice and cool drink supply • Emergency health service	• Indoor and outdoor space cooling systems • Freezing, chilling • Ventilators	• Renewable energy-based active cooling systems
Loss in labour productivity			(non-energy service) • Solar blinds to provide passive cooling through shading
Increase in disease and fatality, especially in vulnerable groups	• Enhanced health care service	• Energy service for health care facilities	• Enhanced medical service by renewable energy

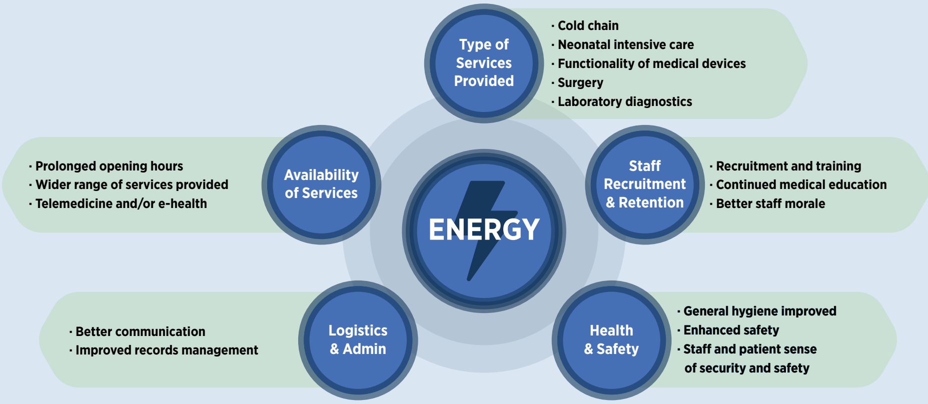
Impact of high temperature on health care system	• Climate-resilient health system	• Health cold chain system (vaccine, samples, etc.)	• Renewable energy-based cold chain system • Renewable energy power supply
(Indirect) Human health impact from water sector	• Water quality control • Water treatment and recycling	• Water sanitation and purification • Wastewater, sewage and sludge treatment	• Renewable energy-based water purification and sanitation system • Small-scale water purification through renewable energy
(Indirect) Human health impact from food sector	• Food system stability and utilisation enhancement	• Greenhouse fuel supply • Cooking fuel supply	• Renewable energy-based greenhouse horticulture and vertical farming • Clean cooking solutions

General electricity provision for health facilities

Renewable energy solutions can play a critical role in the functioning and quality of health care facilities and service delivery, especially in places where climate change negatively affects human health. In many remote and isolated areas, reliable electricity supply can not only limit sensitivity to climate change but enhance adaptive capacity against harsh climate conditions through the provision of basic health care and power for medical devices (e.g. solar PV-powered refrigerators for samples and vaccines to replace kerosene-powered refrigerators). The ongoing COVID-19 pandemic has increased the urgency of addressing these issues. Renewable energy can provide the means to operate health care facilities. In addition, improved access to electricity enables enhanced public health education and communication. Box 3 illustrates the various needs for general electricity provision in health facilities.

Box 3: Renewable energy for health service

IRENA has partnered with the energy and health ministries of Burkina Faso and the SELCO Foundation to conduct an assessment of electrification needs of rural health facilities looking into the policy, institutional, financial and technical aspects. This project will develop technical design of primary health facilities with decentralised renewable energy solutions and will consider building designs, energy efficiency, medical appliance uses and communication technology, along with lighting. Renewable energy solutions enable a wide range of health service operations in many urban and rural health centres:Climate risk, impact, vulnerability, adaptation options and outcome:



Source: WHO presentation given at the 3rd International Off-grid Renewable Energy Conference and Exhibition, IOREC 2016, in Nairobi, Kenya.

Clean cooling solutions

In addition to direct support to health facilities, renewables can contribute to climate adaptation by supplying clean cooling solutions. One such solution, solar cooling, is gaining in global market share as it helps users reduce ambient temperature through cooling home appliances, enabling adaptation to higher temperatures. As temperatures rise through climate change, solar cooling technology will become an increasingly viable solution in many regions.

In places where diesel-powered cooling solutions are too large and capital intensive to be feasible, off-grid or solar thermal scale solutions are being developed for small communities. With increasing demand for cooling, innovative business models for air conditioning and chilled water use, such as district cooling and cooling-as-a-service, are emerging and can deliver more than 40% energy savings compared with standard air conditioning and chiller models (K-CEP, 2018).

Clean water solutions

As noted earlier, raw water and drinking water quality is expected to be degraded further by climate change impacts. Public health could be significantly impaired by reduced water quality issue. Increased access to water sanitation and hygiene plays a significant role in enhancing the health sector. In underserved remote areas, small-scale solutions such as solar desalination, water reuse and recycling, water and sanitation for clinics and hospitals, and communal sanitation facilities would be priority policy measures to be considered. Cross-sectoral financing schemes such as the Green Health Fund could help incentivise innovative approaches between public health and renewable energy.

Clean cooking solutions

In 2018, 2.8 billion people still had difficulty accessing clean cooking solutions in many developing countries (IEA, IRENA, UNSD, World Bank and WHO, 2020). Clean cooking solutions can provide multifaceted benefits in health, food, and forestry sectors as well. It reduces the risk of food spoilage and contamination enables people suffered from temperature rise to can. Therefore, improved access to clean cooking solutions can reduce increasing health risks associated with eating contaminated or raw food. In remote communities that rely on traditional biomass (wood, charcoal, etc.), deforestation exacerbated by climate change impact make it harder to get access to energy resource. Clean cooking solutions can safeguard forest resource as firewood is no longer required for cooking and biogas solution can improve waste recycling. It also could enhance adaptive capacity of local people, especially women and children by allowing them to engage in more productive economic activities. In this regard, several countries mention renewable energy in cooking as a tool to save woods and to reduce vulnerability of their people.

Challenges and limitations

Because human health is affected by various individual, social and environmental conditions, it is very difficult to evaluate and monitor the impact of a certain project on the health sector. Quantifying the relationship between climate change and human health is even more challenging. For instance, the link between clean cooking solutions and lower respiratory disease and mortality rates seems intuitively obvious, providing a basis for statistical comparisons and analysis. Sooty particles from polluting fuels and cook stoves are also short-lived air pollutants and adversely affect climate change (WHO, 2018a). However, estimating the precise health effect of a clean cooking solution remains difficult. For a cross-border issue like climate change, moreover, precise estimations of health impacts are elusive. Even with clearly defined terms and parameters, such estimates would depend on sophisticated statistical research, which is lacking globally.

The complexity and interrelated characteristics of health issues necessarily require cross-sectoral measures. For example, to supply clean water with renewable energy solutions, it is necessary to put in place adequate policies and regulations to manage the quality of groundwater and the related health risks. Regular inspections on aquifers at risk of pollution and periodic water quality monitoring should be enforced. Environmental regulations should be placed on the agricultural and industrial sectors in areas such as pesticide, petrochemical and manure use.

Ensuring an integrated approach in conjunction with approaches in other sectors, such as food, water, energy and natural disaster response, is essential; coordinated efforts to create synergy and complementarity should be pursued.

2.4. INTERACTIONS AMONG SECTORS: INTEGRATED APPROACH BETWEEN ADAPTATION AND MITIGATION

Because these sectors outlined in this report are very closely interlinked and interact with one another, cascading impacts of climate change in one sector simultaneously affect the other sectors. In the context of conventional energy systems, interdependency and interaction with these sectors have been relatively unimportant – this is not the case for renewable energy systems. For instance, specific regional metrological conditions such as solar radiation and precipitation levels, which greatly affect the capacity factor of solar and hydropower generation, are closely linked to the availability of water resources as well as food production. Some cross-sectoral measures for synergy effects are illustrated in Table 7; these measures could also play a role in promoting the circular economy.

Table 7: Examples of cross-sectoral measures for resource complementarity

PAIRING RESOURCES	MEASURES FOR MAXIMISING RESOURCE EFFICIENCY
Water-energy	• Efficient use of multipurpose dams • Energy recycling in the course of desalination • Hydrothermal energy project • Hydropower from water treatment outfalls • Water treatment for agricultural sewage
Energy-food	• Technology development in bioenergy • Agroforestry for food production and biofuels • Reduction of food waste during the production and consumption phase
Food-water-energy	• Biogas water treatment for agricultural sewage

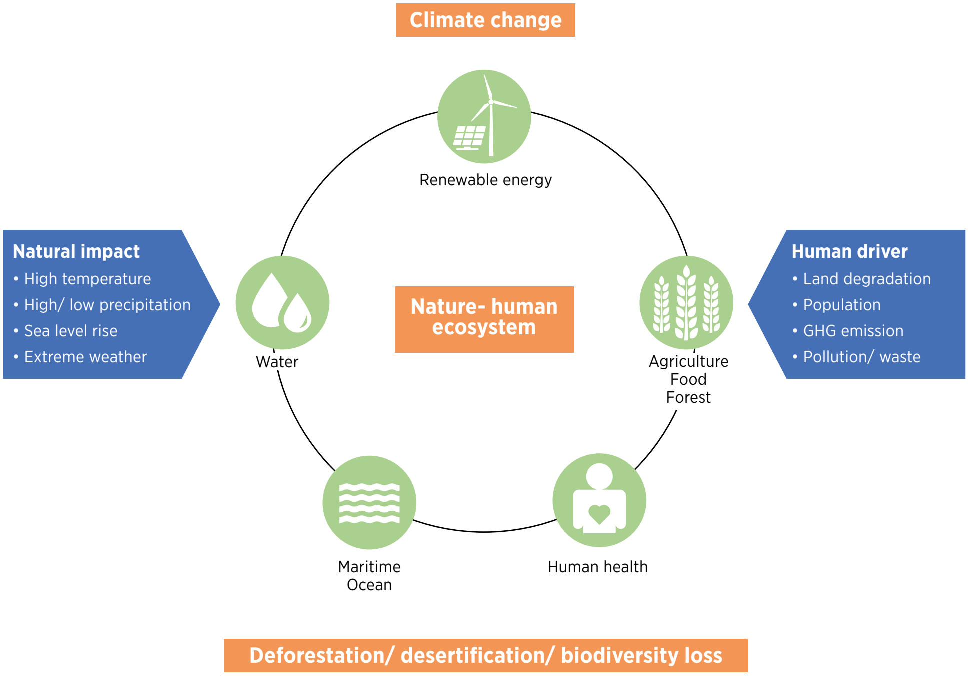
Source: Adjusted from UNESCO and UNESCO i-WSSM (2019)

Hence, management of vulnerability in one sector can limit or enhance the adaptation capacity of other related sectors. Failure to manage these sectoral systems in a synergistic fashion can result in increased vulnerability changes in other sectors. This kind of close interconnection and interdependence within different sectors has been explained by the concept of a "water-energy-food-health" nexus. The nexus approach underscores that the security of water, energy, food and health are inextricably linked and reiterates the importance of cross-sectoral integrated approaches (IRENA, 2015; Rasul and Sharma, 2015). This paper shows that water, energy, food and health issues are at the core of climate vulnerability in some cases and it is necessary to expand the concept of the nexus to include climate adaptation.

Reducing climate vulnerability in these sectors can strengthen climate resilience of local people by enabling access to indispensable goods and services and increased outputs to address adverse effects of climate change. In doing so, renewables-based adaptation measures can serve as 'green infrastructure' to provide these essential services and promote more sustainable and innovative adaptation in these areas.

A cross-sectoral integrated adaptation approach enables renewable energy to maximise its presence as 'green infrastructure' that is conducive to the environment. This can be partly accomplished by linking sectoral policies with renewable energy as a catalyst. Policy makers and project managers need to take integrated approaches, incorporating renewable energy as an adaptation enabler. This kind of cross-sectoral approach also can help organise community priorities and maximise the diverse benefits from the implemented projects such as water supply in addition to energy generation, hence, improving local acceptance of projects.

Figure 5: Renewables and the water, agriculture/food/forest, human health, ocean ecosystem



Source: adjusted from WHO (n.d.)

Box 4: Integrated approach to restore water resources with solar water pumping in Djibouti

Overview:* Between 2010 and 2016, the United Nations Environment Programme and the Global Environment Facility supported the government of Djibouti in planning and implementing an ecosystem-based adaptation project at two sites: Khor Angar in the north (population 3 500), where floods are increasing after loss of mangroves, and Damerjog (population 600) in the south, where rising sea levels and saltwater are destroying crops.

Climate risk, impact, vulnerability, adaptation option and outcome:

Step 1 (Scoping risks): Djibouti is a small arid country; the low availability of water constrains development and negatively impacts crops and livestock. Of the country's population of 890 000, 85% of Djiboutians live in urban coastal areas. These regions are by particularly hard hit by the environmental implications of climate change.

Step 2 (Climate impact): Djibouti is considered "severely water poor" and is prone to multi-annual droughts, flash floods and cyclones. In fact, more than half of all reported human mortalities between 1990 and 2014 were caused by climate extremes. Saltwater intrusion on farms and aquifers, caused by rising sea levels, is destroying crops and water supplies. Water shortages are exacerbated by flood damage to critical water pumps.

Step 3 (Vulnerability assessment): Djibouti's coasts contribute significantly to its economy, and its coastal ecosystems (reefs, estuaries and mangroves), if in strong condition, should not only guard against floods but provide the population with food and other resources. Steep population growth in the country is increasing demand for water resources, deepening the challenges caused by climate change. People who have lived in the desert for generations are moving away – in part because of increasing degradation of freshwater supply. Those remaining need to find funds to either power generators to pump fresh water from the groundwater (but this supply in turn has been increasingly unreliable owing to salt water intrusion into aquifers) or pay for water delivery from other regions (UNEP, 2018a). Farmers have used petrol motor pumps to pump water from deep wells (6–12 m). The excessive pumping was contributing to the intrusion of seawater into the water table, with the pumped water becoming saltier over time. In some areas, the soil has become non-cultivable and has been abandoned.

Step 4 (Implementation): To counter the impacts of drought, 60 crop gardens in Damerjog received with improved access to water through solar water pumping, upgraded wells, and boreholes. The desalination system was given a new pump, pipes and generator (it had previously had a diesel water pump), providing the community with a better quality and cheaper supply of fresh water.

Solar panels connected to water pump for deep wells, replacing old diesel water pump

Vegetable garden, with solar panels in the backyard

Newly installed micro-dams control water flow; the resultant slowing of erosion and strengthening of water supplies allows local people to grow vegetables for themselves or to sell, thereby improving health and livelihood. The project also taught locals how to build energy-efficient cook stoves, reducing the usage of fuelwood and, therefore, deforestation. "No-take zones" were implemented in particularly sensitive forest areas to reduce timber removal further. In addition to restoring the vitality of coastal ecosystems like mangroves, project activities were intended to incentivise ecosystem service management (sources of biomass, sustainable fishing techniques, and ecotourism development).

Step 5 (Outcome): Sixty households benefitted from crop gardens and solar water pumps. Solar water pumps have a lower water extraction rate than fuel pumps, thereby reducing water wastage and the salinisation of water resources. The project also provided training on solar power equipment maintenance to the community.

The president of the Local Association in Damerjog, who manages the community programmes said that having access to solar energy has redynamised gardening activity, with some abandoned gardens being put back into production.

Source: UNEP (n.d.)

2.5. BENEFITS OF RENEWABLES-BASED ADAPTATION

As a versatile energy resource, renewables can serve a broader range of adaptation needs and provide benefits that other resources cannot deliver. This section explains how renewables can be mobilised for climate adaptation purposes, as well as the benefits this can deliver, including net-zero emissions, relatively low capital investments, and non-energy services.

Distributed renewables as climate-resilient adaptation options

Distributed renewable energy solutions (DRES) bear significant relevance to climate change adaptation in creating a resilient energy system as they can provide access to indispensable energy service (Blechinger et al., 2019) to where urgency in the need to adapt to climate change is highest. In developing countries with large unelectrified populations, often located far from the power grid, DRES offer the cheapest and quickest energy solutions when grid infrastructure costs are considered. As remote communities tend to have very low power demand, they are often not prioritised when it comes to grid expansion plans. Renewable energy as a distributed energy resource can contribute to climate-resilient and less-capital-intensive adaptation.

Firstly, DRES can ease local adaptation ecosystems' sensitivity and exposure to climate change impacts by harnessing local energy resources and enabling less dependence on centralised services in other areas (water, food, healthcare, etc.) as well. The universal and inexhaustible availability of renewable resources makes it possible to access renewable energy even in isolated areas or troubled situations by making use of local resources. Thus, DRES can alleviate sensitivity to climate change when used as back-up power resources in the event of emergency. This feature enables indispensable services to be supplied without interruption. It can also provide essential redundancy in providing these services when faced with climate change impacts and natural disasters, as discussed in the section on natural disaster response.

Secondly, access to renewable energy generally decreases a region or community's vulnerability to climate change risks and builds the self-resilience of local people and communities. Small-scale distributed energy systems have traditionally served local society in multiple ways (e.g. street lighting, irrigation, food processing). As renewable energy resources, these systems can meet various adaptation needs of local communities and provide a way for local people to engage in climate adaptation autonomously.

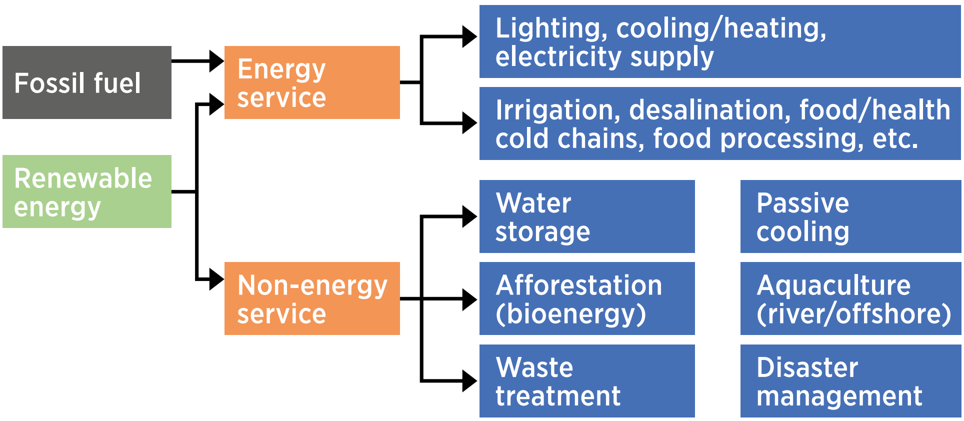
Lastly, in addition to the rapidly decreasing cost of renewable energy, DRES can avoid huge upfront infrastructure investment (e.g. water distribution). This feature makes it possible to build self-reliant and climate-resilient systems and to provide greater accessibility to indispensable services (water, food, health care, etc.) for local people.

Multifunctionality: Renewables for non-energy services

RET builds and relies on the energy sources present in the environment, such as waves, wind, solar radiation and geothermal energy. While energy generated from these sources still requires processing to become usable, renewables are intrinsically linked to the natural ecosystem and therefore often produces additional functions that can be beneficial or detrimental to the environment.

This distinct and multifunctional nature of renewable energy has been previously introduced as "non-energy service" by some studies (IEA, 2012; Flores and Peralta, 2020). For instance, hydro dams in many cases would not have been built without the intent to provide flood prevention, water storage, irrigation and inland waterway navigation. This multipurpose nature of hydropower has been well recognised in many countries. A biogas plant built to produce electricity for cooking and water heating has multiple additional benefits, such as the treatment of wastewater, which can be used as fertiliser and therefore help communities build adaptive capacity through increased productivity. These non-energy services occur when RET reduces vulnerability and builds resilience to climate change risks through measures other than energy supply. On top of its energy service, this multifunctionality has potential to place renewable energy in a unique position to providing solutions to climate adaptation needs.

Figure 6: Multifunctional aspects of renewable energy contribution to climate change adaptation



Non-energy services may not be the core purpose of implementing a specific renewable energy project; they have been mostly considered additional benefits. However, non-energy services could be crucial features when renewables are considered for climate change adaptation as they hold enormous potential. For instance, water for agriculture or aquaculture activities in dam reservoirs enables an important economic activity, and sun-shading PV blinds on buildings may affect the structure's total energy consumption through passive cooling. Although non-energy services might be accounted for as one of a project's objectives or be internalised in the planning and implementing process, they are often ignored and not highlighted well as it is difficult to quantify them in monetary terms; the knowledge base is in this area is currently very limited.

Figure 6 shows that renewables can have multifunctional impacts, as they can deliver both energy and non-energy services. In regions where adaptation needs for non-energy services are high, these services can validate the implementation of renewable energy projects.

Bioenergy

Bioenergy encompasses a diversity of energy sources, giving it more multifunctional benefits than any other form of renewable energy, including waste treatment, fertiliser production, water treatment and eco-recycling. Bioenergy is usually classified into two categories: traditional and modern. Traditional uses of bioenergy, such as fuelwood and charcoal, have direct impacts on deforestation and desertification as well as air pollution.

Modern bioenergy can replace traditional uses of biomass and can address environmental concerns such as deforestation and degraded land caused by unsustainably exploiting biomass resources. Reducing unsustainable uses of traditional biomass would reduce land degradation while providing social and economic co-benefits (IPCC, 2019b).

Land use for bioenergy crops is another renewable energy option that can contribute to climate change adaptation. Degraded land can be used for bioenergy crops to reverse ecosystem carbon depletion. Planting perennial bioenergy and symbiotic bioenergy crops on abandoned and degraded farmlands increases evapotranspiration and albedo and, during their growing season, could result in cooling effect on the surface (IPCC, 2019b). Integrating perennial grasses and woody bioenergy into agriculture could increase soil productivity and reduce shallow landslides, local flash floods, and wind and water erosion (IPCC, 2011). IRENA (2017) found that through the African Forest Landscape Restoration Initiative, which is aiming to restore 100 megahectares of forest, around 1.8–6 exajoules of bioenergy could be yielded per year on the deforested and degraded land of the African continent.

Bioenergy production on a watershed can improve soil and water conservation, thereby benefitting land and water management. These practices can reduce vulnerability to floods and droughts, whilst some negative impacts of bioenergy production such as deforestation due to monoculture plantation can be minimised when using abandoned or degraded lands (IRENA, 2019b). These measures need to be implemented together with careful management and planning of land use and of food and water resources. Restoring deserted or degraded lands has the potential for carbon sequestration as well. Agroforestry systems can be a tool to increase yields and build soil fertility. In such co-existing systems, nitrogen-fixing woody trees would be planted alongside food crops on the same piece of land because these woody trees can improve soil moisture, reduce soil erosion and provide natural fertiliser for the food crops.

If the source of bioenergy is waste, it can produce overall positive impacts on the environment. Biogas from anaerobic treatment and gasification of solid biomass can not only generate energy but also provide water treatment and agricultural waste treatment services. Dewatered sludge and bio-char in the treatment process can be used as fertiliser. In the case of processed fresh water, it can be not only used for irrigation but released back into the environment. When used in agriculture, the liquid fertiliser and compost from sewage sludge can replace chemical fertilisers and bring nutrients back into the soil in a natural way. This helps communities reduce vulnerability to and build resilience against land degradation.

Agroforestry using banana tree and eucalyptus

Hydropower

Most of the world's 54 000 large dams were built to control floods and to store and divert water for multiple uses. Only about 18% of these large dams generate electricity, and hydropower is main purpose of just 60% of that (IHA, 2019).

While protecting from flood and drought, hydro dams can supply fresh water and facilitate irrigation to agricultural activities along the waterways. With increased demand for freshwater resources, the importance of water management in hydro dams is becoming more prominent. Hydropower developments can also include measures to improve irrigation systems, access to drinking water and, in some cases, support aquaculture in the river basin. In the adaptation part of its NDC submission (2016), Lao People's Democratic Republic set out hydropower as one of its integrated adaptation and mitigation solutions, which it stated was "an opportunity to reduce GHG emissions and also meet other objectives such as flood, irrigation and water supply management" (see section on nationally determined contributions). The benefits of non-energy service, such as navigation, flood control and tourism, are often difficult to secure financing for by themselves, and hence power generation plays an important role in multipurpose project development.

Run-of-the-river hydropower usually has limited non-energy services (e.g. water storage) as it does not involve building dams with reservoirs. However, small run-of-the-river hydropower with pondage can provide electricity and water supply for the local community without altering the local ecosystem much.

Box 5: Co-benefits, synergies and side-effects in hydropower and water resource management

The synergy approach, which values the whole more than the parts, emphasises integration, whereas the complementarity (co-benefit) approach places more value on one measure (major) than another (minor), and the minor one does not carry significant importance (Duguma et al., 2014). Therefore, the synergy approach goes one step further, and the benefits of the complementarity approach are limited. The Intergovernmental Panel on Climate Change in its Fourth Assessment Report (2007) defines synergies as "the interaction of adaptation and mitigation so that their combined effect is greater than the sum of their effects if implemented separately".

An integrated approach is essential to achieving multiple objectives simultaneously. It can promote co-benefits as well as synergy effects through identifying potential multiple benefits at the early planning stage. Similarly, unintended side-effects also can be minimised through cross-sectoral planning and project development processes.

Hydropower dams show the importance of policy co-ordination and how it can occur. An integrated approach and policy co-ordination between water and energy authorities can achieve multiple benefits through optimising and striking a balance between water use and electricity generation while minimising harmful effects on the environment and livelihoods.

The energy authority regulates the electricity demand (off-takers), siting, design and capacity, transmission, and operation of hydropower. The water authority regulates water demand, water supply management, flood management, and so forth. Because hydro dam development takes a long time, with all its components decided at the early planning stage, developers need to cultivate co-operation between authorities and ensure that both the energy plan and the water management plan reflect the project as early as possible. A national development plan may facilitate the process too.

Hydropower generation may be limited by downstream flow constraints, such as irrigation and environmental issues. If reservoir storage capacity is not sufficient, the hydro plant would generate power only for the time of high demand (as a peaking operation) in contrast to baseload generation (IPCC, 2011). Such constraints affect operation and power sales revenue. With the implementation of climate adaptation programmes, governments should commit to developing balanced approaches between water management and power generation.

Geothermal energy

Geothermal energy is mainly used for power generation or for direct use applications, including heat pump technology. Possible contributions of geothermal resources to climate change adaptation have been identified in many areas, mainly through the direct use of geothermal energy (e.g. heating greenhouses, food drying). Diverse geothermal applications in the agri-food sector can be found in the IRENA (2019a) report Accelerating geothermal heat adoption in the agri-food sector. Integrated systems with geothermal energy, such as greenhouse and aquaculture heating, have been built for enhanced food security in many countries, such as Kenya (IRENA, 2019a). Geothermal applications in greenhouses can generally reduce food system vulnerability by lessening exposure to rapid weather changes and possible diseases.

Low-temperature geothermal resources such as hot spring water have been used by humankind since ancient times. Twenty percent of geothermal energy used today is still used for bathing and swimming, while more than 50% is used for heating and cooling (IRENA, 2019a). Hot spring water can be used as a freshwater source; other water uses for geothermal resources include desalination, for example by coupling with filtering systems. In coastal regions, groundwater can be pumped and then desalinised through heat exchangers, while the thermal energy of the same water is used for various processes.

Besides water and agri-food applications, geothermal resources can also be used for space heating and cooling. In addition, unconventional geothermal sources such as abandoned coal mines are increasingly being exploited for heating and cooling, as heat source and sink, thereby minimising the urban heat island effect.

Whereas extraction of geothermal resources may result in negative environmental effects such as depletion of the resource and contamination during the disposal of wastewater, these effects can be mitigated through reinjection of the waste or treated water.

Solar energy

Solar energy has positioned itself as the fastest growing RET in electricity generation with the help of rapidly falling prices. Solar energy's potential is not limited to power supply: it can bring synergy effects to other sectors, like agriculture and water, by introducing innovative models such as solar sharing.

Solar sharing is the sharing of land or water surfaces between electricity generation and other uses. It allows limited space to serve multiple purposes, thereby maximising co-benefits while minimising land-use change. Mounted solar PVs and floating solar PVs are emerging as new solutions. Many developers have interest in multipurpose land use through cross-sectoral agricultural activity in which crops or livestock grow under solar panels.

Floating solar panels can also provide adaptation capabilities that include water shielding to decrease evaporation in hot climates and improve the panels' performance owing to the cooler environment . Dam reservoirs usually lose a significant amount of water due to evaporation. Water losses by evaporation range from 20% to even 40% in arid and semi-arid climates, and floating solar panels can deter 80% of water evaporation where they operate (Ferrer-Gisbert et al., 2013).

Many researchers suggest that solar sharing is a promising practice. However, the limited track record, uncertainty about the long-term environmental impact, and old-fashioned regulations on land use or management may inhibit the deployment of solar sharing projects (World Bank, 2019).

Box 6: Solar shading

Solar shading is an inevitable feature of photovoltaic (PV) panels because they absorb solar energy. Several researchers have recently examined this non-energy contribution of solar energy and shown that rooftop solar panels not only produce electricity but also cool roofs and buildings, which may lower cooling costs and reduce the energy consumption of a building. However, the effect of solar shading varies by circumstance. Solar PV installations reduce local surface albedo, giving a small positive radiative forcing, which can affect the surrounding microclimate in warm, highly populated areas (Burg et al., 2017). In some local circumstances, such as in tropical or hot and arid regions, positive effects of solar shading may be a consideration; in comparison, solar panels can have a warming effect in winter in high-altitude regions.

Shading is a very effective means of maintaining thermal comfort in both outdoor and indoor environments (Lee et al., 2018). For instance, smart solar blinds currently in production can provide constant shading to decrease the need for indoor air conditioning, while at the same time tracking the sun movement to generate electricity. Shading is a valid solution for cooling outdoor spaces that are experiencing increased evaporation.

Solar shading can serve versatile purposes such as at farms, car parks, buildings and reservoirs where solar panels, rather than aluminium or plastic sun shades, can be used to provide shade effects. An increasing number of studies show that agro-photovoltaics can help reduce water and energy demand by limiting evaporation and providing cool shade conducive to various kinds of plants and livestock (Barron-Gafford, 2019; Kaushik, 2020). Even though solar PVs generally produce no air or water pollution, safety measures are needed to minimise the possibility of solar PV pollution in agro-photovoltaic and floating solar PV applications. Safety measures may include regulation on the use of pollutants, such as lead and cadmium, and manufacturer buy-back or repair guarantee programmes in the events of panel cracking.

More research is needed to demonstrate the impacts of solar shading on energy efficiency and agricultural activities because different results could be achieved in different simulation conditions.

Wind energy

For thousands of years, wind energy has been used by humankind for activities such as sailing, milling, grinding, water pumping and seawater drainage. Now, windmill technology has evolved to generate electricity, and wind power has become one of the fastest growing RETs. In 2019, wind power capacity expanded to 586 GW. It accounts for 25% of total renewable energy capacity, second only to hydropower. IRENA (2016) analysis predicts that offshore wind power will be a leading power generation source by 2030. Offshore wind farms have positive and negative environmental effects. The major environmental issues of concern are bird collision and potential impact on marine species. However, offshore wind projects also have the potential to conserve endangered marine biodiversity.

Offshore wind farm foundations may work as artificial reefs, providing a surface to which shellfish can attach. That may, in turn, increase the number of fish and marine animals that feed on them, creating biological hotspots. The World Wildlife Fund (2014) has also suggested that offshore wind farms can be integrated with aquaculture or other multi-use concepts. More importantly, marine ecosystems can benefit from the safety zone around the wind turbines. The zones' main purpose is to prevent collision with ships, but they may serve as marine reserves where some or all types of fishing are, de facto, restricted, while also reducing the risk of bycatch in fishing gear.

Table 8: Summary of multifunctionality of renewables in adaptation

RENEWABLES	NON-ENERGY SERVICES
Bioenergy	• Afforestation on abandoned and degraded land • Increased crop productivity • Agricultural waste or wastewater treatment • Fertiliser use (recycling)
Geothermal energy	• Tourism (bathing and swimming in some places) • Spring water reuse (sometimes, with filtering)
Hydropower	• Water supply and storage • Protection from flood and drought through improved water management • Improved irrigation systems • Waterways and local tourism • Aquaculture
Solar energy	• Cooling effect and increased soil humidity from solar shading • Food production (agro-photovoltaic via land sharing)
Wind energy	• Preservation of marine ecosystems in safety zone for turbines

3. THE ENABLING FRAMEWORK FOR RENEWABLES-BASED ADAPTATION

In Chapter 2, this report identified synergistic areas and innovative practices in renewable energy-based climate adaptation. To explore and scale up the deployment of renewable energy in climate adaptation, this chapter identifies the current state and the major gaps and challenges in climate adaptation planning and finance.

3.1. ADAPTATION TARGETS AND PLANNING

A renewable energy-based integrated approach between mitigation and adaptation at the international and national levels can bring synergistic effects in tackling climate change (Nordic Council of Ministers, 2017). This section examines, through analysis of international and national documents (NDCs, NAPs, etc.), how countries are including and using renewables in their adaptation planning, beyond their impact on mitigation, and identifies the missing gaps.

Nationally determined contributions (NDCs)

The Paris Agreement (2015) recognises the mitigation co-benefits resulting from adaptation actions (article 4.7) and that greater levels of mitigation can reduce the need for additional adaptation efforts (article 7.4). Yet, while the Paris Agreement encourages action to implement and support joint mitigation and adaptation approaches, it does not explicitly deal with synergy effects between mitigation and adaptation in the energy sector. However, as discussed earlier in part, many countries recognise renewable energy as a synergistic measure and incorporate it in their NDCs.

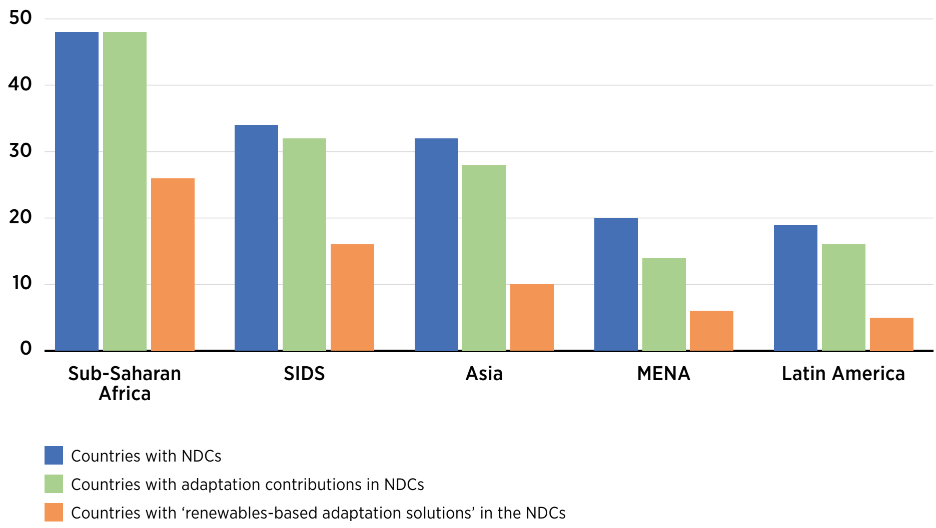
As can be seen in Figure 7, there is an important variation among adaptation measures mentioned in NDCs, as not all countries are equally vulnerable to climate change. Of the total 190 NDCs submitted by Parties by 2020 (including new and updated NDCs by 31 December 2020), the majority included adaptation goals (whether quantified or non-quantified): 28 out of 32 Asian countries have an adaptation component in their

NDCs; in Sub-Saharan Africa the number is 48 out of 48 countries, and for SIDS it is 32 out of 34 countries.

Altogether, 64 countries have mentioned RET in the adaptation component of their NDCs as a technological option for climate resilience in various sectors. Figure 7 shows the number of NDCs with an adaptation component (in orange) and the number of Parties that submitted an NDC with an adaptation component that includes RET (in grey) by region. Most developing countries in Sub-Saharan Africa, Asia and the Middle East and North Africa region, as well as SIDS, have a strong interest in and focus on adaptation.

Sub-Saharan African countries and SIDS particularly stand out for their specificity in needs and plans to use RET. Almost half the countries in these regional groups include RET in their adaptation actions. The countries share common climate change challenges, such as high exposure to climate change impact, lack of local adaptive capacity and dependency on traditional fuels. As such, leveraging synergies between renewables and other sectors has great importance for these countries, and “good examples” can be shared among them.

Figure 7: Renewables-based adaptation in nationally determined contributions (NDCs) by region



Source: Based on UNFCCC (n.d.c)

Sectors in which renewable energy contributes to adaptation

The preceding literature on countries' adaptation policies in their NDCs has already shown a set of adaptation strategies and options strongly related to energy use, and many countries include these energy-related options in their national plans (Davide et al., 2019). The followings are analyses of ways countries include renewable energy specifically among adaptation measures in their NDCs.

In total, 131 adaptation activities mention "renewable energy" in the NDC adaptation components (counted multiple times if countries mention it in more than each sector). In the largest number of cases, totalling 36, countries describe renewable energy as a way to reduce the vulnerability of the energy sector, because renewable energy can diversify the energy mix and increase energy security by reducing dependence on fossil fuels. Renewable energy is also mentioned as a means to ensure the resilience of the energy sector as part of adaptation, especially in the NDCs of SIDS.

Table 9: Examples of countries that specify renewables as a measure to address energy resilience

COUNTRY	NATIONALLY DETERMINED CONTRIBUTIONS (NDCs)
Burkina Faso	"Diversification of energy sources (solar, wind, biogas)" is included as one of the country's priority actions for adaptation.
Cambodia	"Climate proofing existing and future solar/hydropower infrastructure" and "increase storage capacity by adjusting water release schedule to maximise generation" are included in the NDC.
Ethiopia	The NDC includes "expanding electric power generation from [renewable energy] sources (geothermal, wind and solar) to minimise the adverse effects of droughts on energy sector, predominantly hydroelectric."
Haiti	Haiti states "the need for resilience to climate change by reducing its energy dependence on fossil fuel
Kenya	While Kenya recognises mitigation co-benefits in adaptation interventions, the country also includes renewable energy in the adaptation section of its NDC: "Enhance climate proofing of energy infrastructure along the renewable energy supply chain."
Nauru	Energy is listed "as one of the priority sectors for adaptation: One such improvement will be transition to untapped clean energy sources, such as renewable resources."
Nigeria	"Expansion of sustainable energy sources and decentralised transmission to reduce the vulnerability of energy infrastructure to climate impacts" is listed as part of the country's Adaptation Policy Framework.
Seychelles	Renewable energy is mentioned as a means to ensure energy security as part of adaptation ("particularly considering the reliance on fossil fuels").
United Arab Emirates	The United Arab Emirates is "expanding clean energy based installed capacity, in order to address potential increase in power demand due to extreme temperatures."

Source: UNFCCC (n.d.c)

Many other NDCs go further and include indications of the most vulnerable sectors prioritised for adaptation, such as water and agriculture. Analysis of these NDCs and their adaptation targets reveals that the key sectors with potential for adaptation (i.e. that are most applicable for adaptation) are water supply, agriculture, forestry, and disaster risk reduction and response.

Other sector-related adaptation activities are identified in connection with renewable energy as below:

- agriculture, food and forestry sector (29 countries, including 7 that mention wood saving)
- water sector: for example, freshwater supply or irrigation (27 countries)
- disaster risk reduction and response (6 countries)
- waste management (8 countries) and human health (2 countries)
- other: tourism, land use, mining (3 countries).

Table 10: Examples of sectors in which renewables contribute to adaptation

COUNTRY	NATIONALLY DETERMINED CONTRIBUTIONS (NDCs)	SECTOR
Angola	Angola aims to promote renewable energy to avoid deforestation, "reducing the demand for firewood is, therefore, an important strategy to reduce drivers of deforestation and an exhaustion of Angola's natural resources", and pursues an integrated approach through its "energy and water sector action plan" and "construct[ing] flood protection barriers along major rivers."	Forestry Disaster reduction and response
Antigua and Barbuda	"By 2030, 100% of electricity demand in the water sector and other essential services (including health, food storage and emergency services) will be met through off-grid renewable sources."	Water Human health
Cambodia	Agriculture] "Scaled up climate-resilient agricultural production through increased access to solar irrigation systems and other climate resilient practices." [Water] "Strengthen flood resiliency capacity of communities around lake Tonle Sap (access to clean water, off grid renewable energy and waste management)."	Agriculture Water
Cabo Verde	Under adaptation contributions, Cabo Verde seeks "to build several new desalination and water pumping units. With progressive increase of [renewable energy] penetration in the grid, overall energy costs are expected to reduce, decreasing also potable water supply and irrigation costs." In addition, "decentralised renewable energy solutions and more efficient technologies will also be considered and tested."	Water

Costa Rica	"The country will promote a system of circular economy of agricultural farms comprehensively considering the process of biodigestion and re-carbonisation of the soil through the use of technologies to increase the levels of soil organic carbon (SOC)." By 2030, "at least two studies of the food, energy and climate change impact on food security" are to be conducted.	Agriculture
Cuba	"By treating waste waters and using biogas to produce heat and electricity, 100% of waste waters is to be treated in the Cuban swine sector. For all the mitigation actions considered, potential co-benefits in adaptation will be evaluated."	Agriculture
Dominica	"Establishing community off-grid mini-grid or micro grid [renewable energy] electrical supply systems in vulnerable communities that are periodically without electricity as a consequence of storm and hurricane events." "Establishing early warning systems, multi-use disaster shelters (powered by [renewable energy] and back up bio-diesel generators) and emergency preparedness training programs in vulnerable communities."	Disaster reduction and response
Equatorial Guinea	"Installation of early warning systems for climate risks and other natural disasters", "installation of rainfall stations in hydroelectric plants to monitor changes in rainfall"	Disaster reduction and response
Haiti	"Development of thermal energy from the seas for production of fresh water" in the agriculture/food sector and "water supply of communities by building dams and storage ponds" in the water sector.	Water
Jordan	In its adaptation component, Jordan mentions, "renewable energy and its uses in the agricultural and food production sector for cooling and heating purposes, for example in poultry production, greenhouses and olive mills" as a part of "Climate Intelligent Agriculture".	Food Agriculture
Kiribati	Kiribati listed "the KJIP (Kiribati Joint Implementation Plan on Climate Change and Disaster Risk Management)" as part of its section on adaptation: "The goal of the KJIP is to increase resilience through sustainable climate change adaptation and disaster risk reduction." The promotion and use of renewable energy sources are listed as a major strategy under the KJIP.	Disaster reduction and response
Maldives	"Enhance the resilience of health infrastructure through increased climate proofing and incorporating green and energy efficiency measures."	Health
Papua New Guinea	"Development of renewable energy initiatives to combat climate change-induced water insecurity."	Water
Qatar	"Moving towards more efficient forms of desalination and is investigating in R&D of new technologies, including renewable energy to power desalination plant."	Water
United Arab Emirates	[Food] "The flagship project of the Sustainable Bioenergy Research Consortium is to grow both food (fish and shrimp) and fuel (salt-tolerant halophyte plants) using desert land irrigated by sea water."[Water] "…making efforts to expand the share of renewable energy in desalination."	Food Water

Source: UNFCCC (n.d.c)

While water, food and agriculture are sectors which mention renewable energy most frequently, several countries[6] include the promotion of renewable energy to preserve forest in their NDCs as renewable energy can replace the use of traditional biomass for heating and cooking purposes and hence safeguard forest resources.

Meanwhile, of the countries that have specified the use of renewables for climate change adaptation, seven[7] refer to renewable energy as contributing to overall adaptation targets within their NDCs without specific sectoral linkage.

Integrated approach between adaptation and mitigation

While most countries make a clear distinction between adaptation and mitigation in their NDCs, some explicitly recognise the importance of an integrated approach between the two. In addition, some countries have mentioned the adaptation contributions of renewables under the section on mitigation, implying acknowledgement of the co-benefits. For instance, Bolivia (Plurinational State of) proposes a "joint approach which includes renewable energy". Uruguay mentions that "renewable energy technology (RET) actions have adaptation benefits", which can reduce the vulnerability of all sectors of the economy.

Table 11: Examples of countries that take an integrated approach

COUNTRY	NATIONALLY DETERMINED CONTRIBUTIONS (NDCs)
Burkina Faso	"Production and distribution of improved cook stoves" (including biomass) is mentioned as part of mitigation/adaptation actions in the energy/waste recycling sector. "The use of biodigester in husbandry sector and wood saving" is also mentioned in the adaptation part.
Dominican Republic	While the NDC includes mitigation co-benefits resulting from the actions of adaptation, it mentions an integrated approach in the following sectors: [Agriculture] "...promote integrated food, water and energy systems in smart agriculture and resistant to climate change." [Energy] "...promote water-energy-land interaction with renewable energy sources."
Ethiopia	As part of its initiatives to reduce vulnerabilities to adverse climate impacts, "Ethiopia will be able to increase energy access in rural areas as addressing both climate adaptation and mitigation objectives."
Somalia	Renewables – namely solar, wind, hydro and geothermal – are mentioned as potential solutions addressing both mitigation and adaptation. For example, hydro is mentioned in the context of power generation and irrigation.

Source: UNFCCC (n.d.c)

6 Angola, Benin, Burkina Faso, Comoros, Malawi and Senegal

7 Comoros, Costa Rica, Haiti, Nepal, Somalia, Uruguay and Zambia.

Distributed renewable energy solutions to adaptation

Distributed renewable energy solutions are also identified by 13 countries as cross-sectoral solutions to build overall community resilience to climate change. Direct and simple causal links with climate impacts can be hard to identify. Even so, many countries recognise that access to energy can help reduce climate vulnerability and build resilience in rural communities.

Table 12: Examples of countries that specify the use of DRES to adapt to climate change

COUNTRY	NATIONALLY DETERMINED CONTRIBUTIONS (NDCs)
Ethiopia	"…increasing energy access in rural areas" is a measure to address the country's adaptation and mitigation objectives.
Nigeria	"Decentralised transmission to reduce the vulnerability of the energy infrastructure to climate impacts" is listed as part of the Adaptation Policy Framework.
Togo	Togo lay outs the "establishment of incentives for renewable energy use; creation of a national rural electrification agency".
Uganda	"Expanding use of off-grid solar system to support value addition and irrigation, promoting [renewable energy]" is listed as a long-term goal for adaptation.

Source: UNFCCC (n.d.c)

Non-energy services from renewable energy

Although the practice is not widespread, some countries include the non-energy services of renewable energy in the adaptation part of their NDCs.

Table 13: Examples of countries that specify non-energy service

COUNTRY	NATIONALLY DETERMINED CONTRIBUTIONS (NDCs)
Lao PDR	"Hydroelectricity has great potential in Lao PDR providing clean energy and also meet other objectives such as flood, irrigation and water supply management."
Morocco	"Construction of three dams per year on average" as part of building resilience for water storage rather than power generation.
Seychelles	Includes a waste-to-energy facility (biogas) in the waste management sector and dams as a tool to increase water storage capacity.
Sudan	"Small hydro plant, especially in combination with irrigation-sites, energy recovery by generation of electricity or gas from waste, introduction of agroforestry in areas vulnerable to climate change to enhance agriculture production" are included.
Tonga	Biomass and biogas facilities are included in waste management sector.
Uganda	"Ensuring the best use of hydropower by careful management of the water resources" is listed as a long-term goal for adaptation.
Zambia	Zambia includes adaptation and mitigation co-benefit areas and "protection and conservation of water catchment areas and enhanced investment in water capture, storage and transfer (linked to agriculture, energy, ecological, industrial and domestic use purposes) in selected watersheds."

Source: UNFCCC (n.d.c)

As can be seen from the analysis and cases listed above, renewables are evidently being recognised as more than just measures for GHG emission reduction or alternative resilient sources of energy. More countries could include renewable energy in the adaptation strategies outlined in their NDCs; this would be particularly valuable for the countries most vulnerable to climate change. Enhancing the adaptation component in NDCs is an issue that many countries may consider when they embark on the 2025/26 NDC revisions. If more countries adopt RETs into their NDCs, they could scale up renewable energy deployment in climate adaptation as well. Enhancements need to be concrete, as well as coherent with existing initiatives and processes such as NAPs.

National Adaptation Plans (NAPs)

While NDCs focus on ambitions to address climate change and on targets, NAPs present countries' concrete adaptation planning. NAPs enable countries to identify their adaptation needs over different time frames (typically, medium to long term) as well as appropriate adaptation measures to meet those needs (Burmeister et al., 2019).

The NAPs were established in 2011 under the Cancun Adaptation Framework. The main objective of the NAPs is to reduce countries' vulnerability to climate risks through building capacity and facilitating national planning processes for adaptation actions. NAPs aim to support countries with their climate adaptation planning over both the medium and long term (Daze et al., 2019). The NAP process also provides technical guidelines, which assist developing countries with adaptation planning.

Of the 64 countries that included renewable energy as an adaptation component of their NDCs, four have their NAPs available on the UNFCCC website. All four specify renewable energy implementation within the list of adaptation actions.

Table 14: Consideration of renewable energy in national adaptation plans

COUNTRY	REGION	BUILDINGS	ELECTRICITY ACCESS	ENERGY RESILIENCE	WATER AND SANITATION
Burkina Faso	Africa	■	■		
Ethiopia	Africa		■		■
Sri Lanka	Asia			■	
Togo	Africa	■		■	

■ Renewable energy implementation mentioned in sectoral activities

Source: UNFCCC (n.d.c)

Long-term low emission development strategy

The long-term low emission development strategy (LTS) in the Paris Agreement (article 4.19) is a national plan that outlines a long-term vision for GHG emission reduction, its pathway and follow-on climate actions. The LTS time frame spans more than 30 years, whereas the NDC typically addresses 10–15 years. Because an LTS is a long-term plan, it can provide opportunities for more active dialogues among different sectors, which could help reach synergies in sustainable resource use, climate adaptation and mitigation.

By the end of 2020, 28 countries have submitted an LTS, so there exists potential for more countries to participate in the strategy building. Currently, the Paris Agreement does not require Parties to deal with any specific issues other than a low GHG emission strategy, and countries have tended to focus more on GHG emission reduction in their LTS than in their NDC, in which many countries already include their NAP. Only a few countries have placed a separate climate adaptation chapter in their LTS.

The LTSs mostly address socio-economic development plans as well as some climate adaptation plans. Many countries have identified agriculture, forestry and waste management as priority sectors that are vulnerable to climate change and have therefore included climate adaptation measures in the LTS. Countries also state that their LTS should cover both mitigation and adaptation, especially in these sectors. The use of RET for adaptation is frequently specified in relation to agriculture, forestry, water and waste sectors, rather than intensive sectors, and bioenergy is an area of primary focus in the LTSs). Some countries, including Canada, Germany, Mexico, Slovakia and Ukraine, underscore synergies between the agriculture and forestry sector and RET.

In some countries take a more forward-looking approach and underline the role of innovative technologies in the long term. For instance, Japan and Singapore include, respectively, agro-photovoltaics and vertical farming technologies in their LTS. France specifically elaborates on cross-cutting and innovative issues of a bio-based economy, such as the development of bio-materials and green chemistry using not petrochemicals but eco-friendly agricultural products (see the Appendix for details). Though some technologies are currently premature and not commercially available, an LTS, as a long-term national plan, features more future-oriented and innovative renewable energy solutions than are typically found in NDCs.

3.2. FINANCING RENEWABLES-BASED ADAPTATION

The landscape of climate finance is rapidly developing and growing in volume. Pledges to support adaptation and resilience have significantly increased in amount, with growing acknowledgement that further delays to adaptation actions will result in increasingly costly measures to adapt to climate change (UNEP, 2021). The climate finance provided and mobilised for adaptation activities rose to USD 16.8 billion in 2018, which accounts for 21% of total climate finance, up from 17% in 2016 (OECD, 2020).

According to the Global Commission on Adaptation, the global investment required for climate adaptation could reach USD 180 billion annually from 2020 to 2030, and investing USD 1.8 trillion globally in just five adaptation areas could yield USD 7.1 trillion in net benefits (GCA, 2019). Similarly, the United Nations Environment Programme (2018b) estimates that the annual cost of adaptation could be USD 140–300 billion between 2025 and 2030 and USD 280–500 billion between 2030 and 2050 if temperature rise is controlled under 2°C from the pre-industrial level. While financing adaptation has significantly scaled up, these estimations indicate a huge adaptation investment gap that needs to be met by public and private finance.

This section presents the potential opportunities of adaptation finance that flow from the scale-up of renewable energy deployment. It particularly focuses on the current gaps and barriers in financing adaptation and how renewable energy can serve as an effective option to mitigating or resolving them.

Public sources of adaptation finance

Several key actors provide financing for adaptation, including national, international, public and private institutions. While there is an interplay between private actors driving adaptation investments from the bottom up and public actors facilitating this structural change, the role of the public sector has been emphasised because adaptation is often associated with public goods and services. Within the scope of public financing for adaptation, a wide range of financing schemes – including bilateral financing from country to country, MDBs, and climate funds – have been established.

While adaptation finance channelled through bilateral official development assistance can serve as a complementary option, its share in overall official development assistance has hardly increased since 2013 (UNEP, 2021), and the landscape of adaptation financing is hard to imagine without MDBs. MDBs had committed USD 61.6 billion to climate finance by 2019 (EBRD, 2020). Climate finance from MDBs is particularly important in aligning global financial flows with the Paris Agreement objectives.

The GCF, the GEF and the Adaptation Fund provide significant shares of international adaptation finance and are helping to shape wider investment trends and initiatives. The GCF, especially, has been mandated since 2014 to deliver half its portfolio to adaptation projects, with half of that share meant to be allocated to least developed countries, SIDS, and African countries (ODI, 2019). In 2019, the World Bank, which also serves as the GEF trustee, announced it would boost its adaptation financing to USD 50 billion by 2025, ensuring that over half its climate finance will go to adaptation (World Bank, 2020).

Since climate adaptation measures do not always guarantee earnings that can pay off the investments made, public finance is essential as a catalyst. This report analyses what kind of adaptation projects which involve RET are actually implemented by the funds. These renewables-based adaptation projects show more diverse and innovative usages of RET than in the NDCs, (e.g. honey production using solar shading, aquaculture using solar power, weather observation network using renewable energy). Table 15 gives a summary of the projects approved by the Adaptation Fund, and the GCF; the number of projects involving renewables; and examples of the renewable energy projects financed. The analysis shows that the water sector and the food/agriculture/forest sector are focused areas in renewable energy usage, then it is followed by energy access/resilience, waste treatment, and disaster risk reduction projects.

Table 15: Analysis of renewable energy implementation for adaptation in funding proposals

	ADAPTATION FUND	GREEN CLIMATE FUND
Total number of adaptation projects	112 (2010 – 2020)	106 (2015 – 2020)
Total share of projects integrating RET	47 (42% of adaptation and mixed projects)	64 (60% of total adaptation/cross-cutting projects (both adaptation and mitigation))
Water	• Solar and wind energy desalination / purification systems • Pumping station in piped network • Solar dehydrator	• Solar off-grid distillation / desalination reverse osmosis plants • Solar off-grid desalination reverse osmosis plants
Food production	• Post-harvest processing (solar dryers and cold storage / cooling units) • Solar shading (honey production under solar panels) • Solar powered surface aerators for aquaculture in ponds	• Post-harvest processing (Solar food drier/refrigerator/storage • Bio-digester to maintain temperature in food storage
Cooking	• Biogas cookstove to combat deforestation	• Cooking systems with biogas / improved biomass to enhance forest management • Solar ovens for cooking
Irrigation	• Solar and wind irrigation pumps and water storage pumping system	• Solar PV pumps and boreholes for drip irrigation • Biomass / wind pumping technologies
Weather prediction system (Disaster risk reduction)	• Automatic weather station powered by solar PV or wind turbine	• Hydrological station with sensors, data collection, communication system by solar power • Groundwater monitoring system/ weather observation network • Climate information service for renewables • Solar power supply in case of disaster

Waste treatment	• Biogas plant for effective waste management	• Bio-digester to reduce sewerage • Waste water reuse complex
Heating/cooling	• Solar water heaters/Solar wall to address increased climate variability in highland communities	• Heating systems with biogas / methane usage • Solar water heaters
Energy access/ resilience	• Hydropower dam • Solar PV for lighting and electricity production (including solar lamps, solar chargers, solar batteries etc.)	• Solar PV for lighting and electricity production (including solar lamps, solar chargers, solar batteries, etc.) • Scaling up hydropower dam climate resilience • Pumped hydropower plant using the ocean as reservoir • Replacing fossil fuels with renewable energy

Source: Adaptation Fund (n.d.), GCF (n.d.)

The Adaptation Fund had approved 112 concrete adaptation projects for developing countries between 2010 and 2020, totalling USD 768 million in grant (Adaptation Fund, n.d.). Analysis of the funding proposals shows that the projects involving renewable energy for adaptation compose 47 projects (42%) of the total projects and these 47 projects include total 88 renewable energy applications.[8] Among those 88 renewable energy applications, the agriculture/food/forest sector accounts for 34 renewable energy solutions and the second focus is the water sector with 28 applications, and the third one is energy access with 10 applications.

The GCF has approved 106 adaptation and cross-cutting projects from 2015 to 2020, with the total amount of financial support equalling USD 2.47 billion (GCF, n.d.). Of those adaptation and cross-cutting project proposals, almost 64 projects (60%) include in their description RET integration for adaptation needs. Among them, 125 renewable energy applications are identified. 37 measures with renewable energy have focused on agriculture, food and forest sectors and 30 measures for the water security. These are followed by 19 energy access and resilience solutions. 13 waste treatment and 9 disaster reduction measures involve the implementation of renewable energy. Disaster reduction projects include hydrological monitoring system and climate information service equipped with data collection sensors, antennas, and renewable energy feeding system to strengthen early warning network in developing countries.

8 It is counted multiple times in case a project includes several sectoral renewable energy applications.

The GEF was established in 1992 and manages three subsidiary organisations: the Least Developed Countries Fund, the Trust Fund and the Special Climate Change Fund. As of 2020, the total number of projects for adaptation action approved by the GEF is almost 400 with USD 2 billion in financial aid (GEF, n.d.). Especially, GEF supports cross-cutting impact projects with synergistic mitigation impact through integrated and comprehensive approach.

Investment from MDBs has also been part of initiatives to mobilise private sector finance. Notably, the Pilot Program for Climate Resilience and the GCF have established specific co-finance schemes to leverage private investment in adaptation. However, most private finance mobilised by public climate finance goes towards mitigation activities (OECD, 2020). It has often been believed that projects and businesses aligned with sustainable development do not provide the high financial returns that attract private investors.

In addition to the initiatives of MDBs, there are now multiple efforts to integrate private actors into climate actions. State investment banks such as Green Investment Bank in the United Kingdom set to leverage private capital by generating learning effects for the finance sector in managing the climate adaptation project risk; this can reduce the cost of capital and make investment in innovative business models and technologies much more attractive (Geddes et al., 2018).

Particularly, progress also has been made in green finance regulation, such as efforts to steer investments into projects aligned with pollution reduction, GHG emissions reduction (low-carbon finance), biodiversity protection (biodiversity finance) and climate change adaptation (climate finance). Among these initiatives, UNDP's SDG Finance Taxonomy, the Climate Bond Initiative's Taxonomy and the European Union (EU) Sustainable Finance Taxonomy are some examples of efforts to minimise the negative and maximise the positive non-financial impacts of business. Specifically, the EU taxonomy requires public and private investors, banks, and companies to report their investment and economic activities under the EU taxonomy regulation. This regulation, which was introduced in 2020, is expected to contribute to achieving the goals of the Paris Agreement, while ensuring more a climate-resilient economy.

Box 7: Climate adaptation and development finance

Climate change impacts pose severe threats to sustainable development. To be sustainable, socio-economic development can only be pursued in line with climate resilience and low carbon emissions. The Paris Agreement (2015) affirms this intrinsic relationship between climate change actions and sustainable development (articles 2 and 4). Adaptation and sustainable development share some common ground.

International climate funds have adopted the concept of "additionality" in this regard. "Additionality" implies that new climate finance mechanisms should be a separate funding source solely for climate change issues, provided in addition to existing official development assistance funds; in other words, countries should not have to sacrifice other assistance for the sake of climate change. As such, for the GCF and the Adaptation Fund, which are only mandated to support climate projects, proposals must prove the "climate rationale" – that the results of the investment can be shown to build resilience to climate change (GEF, 2018). Therefore, how to encourage synergy and co-benefits between climate adaptation and development remains an important question.

Drivers of private financing for renewables-based adaptation

Although the major focus of the private sector to date has been on supporting mitigation activities, private actors can be an important source of climate finance, and it is essential that investment and technological innovation fills the adaptation finance gap.

Many companies are increasingly concerned with protecting their business, operations and supply chains from the risks presented by ever more frequent extreme weather events and slow-onset climatic changes. Companies are also seeing support for climate resilience as a new business opportunity, expanding private actors' interest beyond mitigation to adaptation. The recent effect of the coronavirus pandemic has reiterated the need to prepare for long-term future risks – and climate change sits at the centre of such a goal. As investors and businesses increasingly weigh climate change risks into investment decisions and strategic directions, financing adaptation is steadily escalating its presence in private sector investments. The emergence of initiatives such as the Financial Stability Board Task Force on Climate-related Financial Disclosures and the Carbon Disclosure Project are obliging businesses to allocate additional resources to managing climate change risks.

Private actors such as corporations, banks, and insurers have begun to implement adaptation as commercial and purely private activities. Investment in climate resilience is already being made by the private sector, in the form of insurance for risk mitigation and as forms of debt and equity, without being labelled “climate adaptation”. Renewables can help resolve the existing challenges for private actors investing in adaptation projects and propel the flow of private finance into new investment opportunities that have adaptation impacts.

One of the main challenges for investing in adaptation projects has been the repayment of funding. While the benefits of investing in adaptation can outweigh the costs in long-term (UNEP, 2021), these benefits are often concerned with non-monetary returns or avoided costs that are difficult to measure. However, renewable energy production can make adaptation projects more attractive to private investors than other, usually uncertain and long-term, outcomes or savings associated with climate adaptation actions. In addition, the power generated may support new or increased production of other goods and services. In the Middle East and North Africa region, independent power provider projects, sometimes coupled with independent water provider projects, are being built using renewable energy. These projects are a form of public-private partnership (PPP), a well-established financing model in construction projects where large-scale investment is required. The power sector has been actively engaged with the private sector, especially in power generation, and the PPP mechanism is now gaining awareness in a wider range of sectors, such as water supply and waste treatment, as well as for rehabilitation projects after natural disasters. PPP investment can contribute to climate adaptation when public investment is not sufficient and lead to a reduced burden on the national budget. A revenue guarantee scheme from the government, such as minimum functional spend or minimum revenue guarantee, can attract more private financing.

Another form of PPP that can contribute to climate adaptation comes in the form of energy service companies that can leverage private capital in the initial investment. In the Middle East and North Africa, energy service companies usually optimise energy consumption and enhance water conservation through equipment retrofits, pumping optimisation, and demand monitoring and control (UNESCO and UNESCO i-WSSM, 2019). Government supports at the national level can help capitalise private funds and expand service areas in other sectors.

Carbon finance may provide another income source when relevant climate policies such as carbon pricing and emission trading schemes are in place by selling carbon credits, as renewable energy can contribute to GHG emission reductions In climate-sensitive sectors like agriculture and water, this kind of carbon market is not well established, but by giving a clear signal to market participants and investors it can provide not only an incentive for initial investments but also long-term returns over its lifetime.

A second challenge is that the energy sector has been a traditionally capital-intensive industry. Therefore, most businesses are state-owned or operated by large-scale companies. However, DRES have transformed the industry to one where small-scale businesses can also step in. This has driven the rise of quick and affordable adaptation solutions for rural and remote populations, even without capital-intensive electricity and water infrastructure.

As a consequence, renewable energy companies are finding new business opportunities in climate adaptation areas such as solar irrigation, water purification and solar cooling. Micro, small and medium enterprises are becoming especially active in renewable energy-based climate adaptation solutions and making increasing investment in this emerging market. Renewables are enabling a wider range of adaptation options and can make adaptation projects more appealing to investors.

MDBs, bilateral development banks and multilateral climate funds, recognising the potential contributions of the private sector to climate adaptation, are increasingly engaging with the private sector and stimulating their investments through various measures. Early in a project's life cycle, investment equity, loans and concessional funds can play an important role in anchoring the private sector, especially in developing countries, and hence public finance institutions usually require co-financing from the private sector. Government guarantees and grants are also important sources for mobilising private finance.

Innovative financing models emerging in the renewable energy sector, such as the pay-as-you-go model and micro-financing, have the potential to channel more finance resources towards climate adaptation. One such example is the Adaptation Benefits Mechanism, an innovative adaptation finance mechanism developed by the African Development Bank to encourage private finance to invest in climate adaptation projects in accordance with the Paris Agreement, article 6.8. Under this mechanism, on the successful completion of an adaptation project, such as clean cooking and electricity access from DRES, the project developers can receive adaptation benefit credits as per established methodology and sell credits to development aid agencies, investors and philanthropic organisations (AfDB, 2020).

There is also growing awareness of responsible investment in the social sphere, where the Adaptation Benefits Mechanism can be used. A growing number of investors now evaluate corporate environment, social and governance factors in investment assessments and have announced 100% renewable energy usage in their energy consumption. Environment, social and governance risks include those related to climate change impacts, and as a result, there is a movement towards establishing mid- to long-term plans to save energy and promote the use of renewable energy in various sectors and industries.

Table 16: Examples of mechanisms propelling private finance in renewables-based adaptation

Adaptation benefit mechanism (ABM)	The ABM is a result-based finance mechanism to enable enhanced climate change adaptation action. It was developed by the African Development Bank and is based on the Paris Agreement (article 6.8, non-market mechanism). It has the potential to create synergy among climate adaptation, mitigation and sustainable development by attributing monetary value to various benefits.
Green bonds	The green bonds market has expanded rapidly, and most bonds are issued for renewable projects, followed by energy efficiency projects. Of the more than 4 300 green bonds analysed by IRENA (2020b), half (by volume) specified RET as one of the use-of-proceeds. More recently, green bonds have become a tool to attract private finance; the private sector accounts for a significant proportion of adaptation-related green bond issuance, with corporates having issued 13% of the green bonds categorised as adaptation in the period March 2010 to April 2019 (Tuhkanen, 2020).
Insurance instruments	The amphibolic nature of climate change amplifies the uncertainties of risk occurrences, and the difficulty in measuring the impacts of adaptation measures often implies reduced cost-effectiveness of investments. Insurance and other risk-transfer or risk-sharing approaches can serve all relevant stakeholders, for instance by enabling them to complement ex ante risk mitigation by ensuring swift access to financing after an extreme event, which can stimulate productive investments (ODI, 2019).
Micro-financing	Micro-financing can provide affordable, long-term finance to the populations most vulnerable to climate change, while encouraging private investment. Local micro-financing institutions can support local training and empowerment of communities to ensure the sustainability of the project.
Public-private partnership (PPP)	PPP is a financing mechanism to leverage the private sector's finance and its expertise in public service areas. While PPP projects are often long-term, risky and sometimes non-profitable, a well-structured PPP model can deliver public service successfully. Government mostly supports private companies through subsidy, guarantee and co-investment to mitigate financial risk.

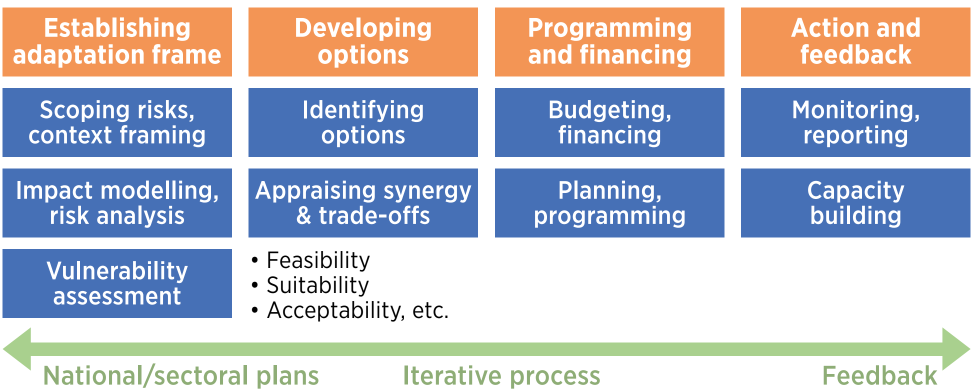
4. THE WAY FORWARD

A changing climate landscape poses significant risks as well as new investment opportunities globally. The opportunities for synergy and co-benefit in mitigation and adaptation are vast. A range of climate planning instruments already include renewable energy components, and private investors are looking into new business opportunities in adaptation. As it becomes increasingly accessible, RET can be used to enhance climate adaptation as well as mitigation efforts in developed as well as developing countries.

In Chapters 1 and 2, this report introduced a conceptual basis for the renewables-based integrated approach and a range of renewable options that can contribute to climate adaptation. Chapter 3 highlighted the well-established climate planning instruments (NDCs, NAPs and LTS) that already exist at the national level. A wide range of public finance instruments and drivers for private investment were also presented as key considerations in advancing climate change adaptation.

To leverage these instruments, foster synergistic linkages and mainstream climate adaptation efforts using renewable energy options, it is essential that all instruments be aligned and integrated into the climate adaptation decision-making process (Figure 8). Climate change adaptation involves the whole adaptation decision-making process and related activities: scoping, framing, developing options, budgeting and financing, programming, implementation, monitoring and evaluation, and feedback. A holistic approach needs to be taken to integrate renewable energy into the climate change adaptation process at all levels of upstream and downstream decision making.

Figure 8: Climate adaptation decision-making cycle



Source: Adjusted from UNFCCC (2019), IPCC (2014a)

This chapter provides recommendations for renewable energy-based adaptation through the overall climate adaptation policy and decision-making process. The integrated and holistic adaptation approach would help identify the contribution of renewable energy to adaptation, promoting synergies with mitigation and sustainable development, and maximising overall benefits while minimising trade-offs. Furthermore, renewable energy-based climate adaptation will facilitate cross-sectoral approaches by reinforcing the existing policy framework and project implementation process.

ESTABLISHING THE FRAMEWORK FOR RENEWABLES-BASED CLIMATE ADAPTATION

Establishing a framework provides the basis for adaptation intervention; therefore, it is critical to establish a clear climate rationale by using robust climate methodologies and the best available science. Climate adaptation strategies should build on this rationale, and impact modelling and vulnerability assessment should be used to identify and prioritise the most vulnerable sectors. If a climate rationale is not clearly articulated, an action could be implemented that insufficient to be counted as a climate adaptation action.

However, renewables are often included in the planning and project levels without proper adaptation rationale, and the role of renewable energy in climate adaptation shows considerable variation in each country. This may signify that further studies and good practices need to be established globally. In particular, good practices can be shared with other countries facing similar climate risks in the current context, where renewable energy is becoming more important in establishing the adaptation framework.

Multisector assessments are also needed, with the energy sector being taken into account. Climate scenarios and vulnerability assessments must also encompass social, economic and institutional aspects, necessitating on-site or bottom-up processes to engage a broad range of local and regional stakeholders.

Embedding RET into sectoral adaptation policies, programmes and projects across local, national and global levels expands the range of opportunities for reducing vulnerability, ensures a more efficient use of scarce resources, helps all key stakeholders (policy makers, public and private investors, and local communities) find synergies and avoid conflicts, and leverages larger financial flows. A cross-sectoral approach is essential, with various stakeholders being engaged from the early stage of scoping and defining risks. Institutionalising sectoral policy co-ordination and multi-stakeholder engagement at the early stage could decrease the implementation cost. Well-established climate change planning frameworks such as NDCs and NAPs can facilitate sectoral co-ordination.

Different perceptions on climate vulnerability can affect policy priority, which varies by region. For instance, in many African and Middle Eastern countries, energy and water sectors are governed by a single authority and freshwater supply is of the utmost importance. With increasing water shortages, the engagement of the energy and water authority at the early stage of the adaptation process may not be an option but a must. Setting up cross-sectoral adaptation planning tools as well as programme and policy guidelines would also help facilitate co-ordination. The Global Health and Energy Platform for Action launched in 2019 by WHO is an example of co-ordination at the international level.

As energy related mitigation policy is easy to understand and can produce tangible outcomes, an integrated approach between adaptation and mitigation could make an adaptation policy more acceptable and bridge the gap between the two types of policy (Lee et al., 2020; Grafakos et al., 2019; Hwang and Kim, 2017). This, in turn, may provide stronger motivations for local communities to engage in mitigation actions more actively.

DEVELOPING RENEWABLES-BASED ADAPTATION OPTIONS

Renewables can provide multiple benefits simultaneously, while addressing adaptation, mitigation and development needs. A technology needs assessment may support exploring technology options and identifying opportunities for synergies among different adaptation options. While technology-centred adaptation approaches can contribute to climate adaptation, they need to address social, environmental and institutional issues, as climate adaptation depends on not only physical but social dimensions.

When appraising various options, all potential synergies, co-benefits and trade-offs must be considered in order to increase efficiency and amplify their complementarity at multiple levels. Renewable energy provides mitigation advantages, and this usage needs to set the ground for renewable energy-based adaptation projects. Depending on the specific context of each project (baseline situation, project area, etc.), renewables may contribute more than one adaptation, mitigation or sustainable development objective, while producing greater impact with fewer resources.

Given the difficulties in capturing and evaluating the synergy and multiple benefits of renewable energy-based adaptation options, developing a tool that evaluates the adaptation benefits of renewable energy projects would encourage financiers and stakeholders to invest in the project, facilitating a greater flow of adaptation finance.

PROGRAMMING, BUDGETING AND FINANCING

National and sectoral plans are of critical importance in allocating resources and coordinating different interests. Renewable energy options must be integrated into short- and mid- to long-term decision-making and planning processes (e.g. NDCs and NAPs) to mainstream, structure and scale up renewable energy adaptation projects. This is required by many climate finance facilities as a prequalification for finance proposals.

Renewable energy can play a key role in improving business models and attracting greater investment, especially private finance, into climate change adaptation, as is happening in the climate change mitigation area. As the private sector plays a large part in mitigation, especially in the energy sector, the focus for public finance, particularly, is being slowly shifted towards adaptation projects, which are more difficult for private actors to engage in.

To ensure the participation of the private sector, and therefore gain the advantage of its expertise and capital, policy makers need to establish synergistic budget programmes for innovative projects and new business models such as solar sharing, agro-photovoltaics and vertical farming. Currently, further empirical studies on these practices are necessary to provide robust evidence of which practices work, where, and what their costs and expected co-benefits or dis-benefits are. Creating an enabling environment for private investors is a critical factor. Government support programmes (e.g. national funding programmes, consumer finance, subsidies, tax incentives) for renewable energy deployment are critical in that public spending can be supplemented by private investment to catalyse private financing.

Many financial institutions and private companies are not fully aware of climate adaptation impacts, adaptation options and their benefits yet. Governments should encourage financial institutions to provide incentive schemes such as public guarantees, loans, subsidies, micro-financing, and green bonds for renewable energy solutions, which could attract more investment in adaptation policy and actions and therefore increase their impacts. Ensuring the engagement of finance ministries in adaptation planning as well as streamlining the allocation, evaluation and audit process for budget expenditure are necessary conditions in securing budget. International climate finance should play an important role in ensuring greater financing flow for renewable energy-based adaptation solutions.

To tackle climate finance challenges in many developing countries, the Climate Investment Platform (CIP) has been established by IRENA, UNDP and Sustainable Energy for All, in cooperation with the GCF. It aims to help countries access climate finance and channel it where most needed. The objective is to mobilise capital towards developing countries to accelerate the scale of RE technologies deployment to meet Nationally Determined Contributions (NDCs) targets and achieve compliance with Sustainable Development Goals (SDGs). The Climate Investment Platform covers the entire clean energy investment chain and works for scaling up not only clean energy investment but also the health-energy nexus, energy systems for drinking water, sanitation, and other productive applications.

MONITORING, EVALUATION AND CAPACITY BUILDING

Multiple objectives and iterative management are key characteristics of adaptation programmes and projects. These complexities of adaptation projects necessitate the development of common goals, the creation of operational guidance and the proper management of project implementation. Good practice-based policy, monitoring and evaluation will generate lessons learnt and present practical solutions for clean energy deployment in different sectors.

During the adaptation decision-making process, various types of assessment must be conducted to help policy makers, project developers and financial institutions evaluate different options and make the best choices for delivering impact. Synergistic and standardised metrics for the assessment of broader renewable energy contributions to climate adaptation, mitigation and sustainable development are important for assisting decision-makers as well as for mobilising climate finance Also important is increasing public awareness of climate adaptation solutions, providing access to scientific information and sharing good practices. Raising awareness of the role of renewable energy in climate change adaptation could add real benefits for many countries.

To conclude, a number of renewable energy plans and projects in climate adaptation have been identified in this report, while their importance and potential adaptation impacts are often overlooked. This is partly caused by lack of awareness of the integrated approach between adaptation and mitigation.

Recognising the interplay among different sectors can help harvest all potential benefits as well as mitigate the possibility of maladaptation. Renewable energy as a cost-effective and innovative input can improve climate resilience in multiple sectors and this integrated approach can make renewable energy greener infrastructure conducive to the environment. The integrated approach can unlock new investment opportunities and channel more investment into climate actions by taking advantage of both climate and carbon finance.

The pandemic situation highlighted the urgent need to address essential services for human beings, such as water, food and health services, especially in developing countries. Post-COVID recovery efforts might need to be directed more towards climate adaptation, while addressing GHG emission reduction at the same time.

This report attempts to clarify the synergistic relationship between renewable energy and climate adaptation, and taps into the potential role of renewables as climate adaptation strategy. However, many areas remain to be explored with further studies, theoretical and practical, in order to scale up the deployment of renewable energy in climate adaptation. These may include identifying further synergy areas with renewable energy in adaptation and developing enabling conditions to mainstream renewables into climate adaptation policy at the national and international levels.

APPENDIX

Examples of the contribution of renewables to climate adaptation in LTSs

COUNTRY	LONG-TERM LOW EMISSION STRATEGIES
Canada	“There is an opportunity to convert growing agricultural waste, as well as agricultural by- and co-products into eco-efficient, bio-based products with direct benefits for the environment, the economy, and consumers, for example, sustainable bio-energy, bio-fertilisers and bio-chemicals. Co-benefits include: Greater food security, increased supply of renewable natural gas and electricity, creation of a soil amendment (i.e., compost); and a reduction in volatile organic compounds emissions, smog formation and unpleasant odours.”
Costa Rica	“To develop and scale-up the meat and milk value chains with a circular economy approach for the generation of biomass from Organic Agricultural Waste (in particular, excreta and slurry in the production of biogas and fertilisers).”
Fiji	Climate adaptation plans “serve as the foundation for promoting adaptation and resilience for Fiji, and these should be implemented in close coordination with the mitigation strategies outlined in Fiji’s LEDS and NDC.” Renewable energy “may be at risk from damage from extreme events. There will be a need to assess operation of hydropower and other renewable energy sources to maximise output under new climate conditions. Long-term strategies include: diversifying renewable energy generation to improve resilience and diversifying distributed generation options.”
France	In the agriculture/forestry/waste sector, France explores new synergies for adaptation and mitigation in innovative ways. They include: “In the long term, the agricultural sector will make a significant contribution to reducing GHG emissions in four main ways: • circular economy (organic fertilisers, by-products for livestock feed, 2nd generation biofuels etc.), • bioeconomy, with bio-based products replacing fossil resources (bio-based products for bio-materials, green chemistry and energy products.) This transition must also take into account the crucial challenge of adapting to climate change (crop varieties, water management, environmental risks etc.).” “The diversity of agricultural production and the promotion of agroforestry can help us to boost the economic performance of farms while also replacing fossil fuels with more widespread use of biomass for energy and materials. The agricultural sector can also help to supply the energy, materials and chemical sectors with biomass materials. We need observational tools which cover all forms of biomass resources. In addition to soil fertilisation and animal feed, as much as 8 MtDM, of leftover agricultural produce could be available each year.” “The use of combustibles from renewable sources instead of fossil fuels, and the use of bio-based materials in lieu of more energy-intensive materials, can help to reduce greenhouse gas emissions from other sectors.” “For agricultural land which has been temporarily abandoned or is no longer used for food production, we need to find innovative solutions, capitalising on their productive potential for high-value-added food and non-food-related purposes and/or uses which can directly or indirectly replace fossil fuels.”

Germany	"…wood is used as a source of energy within the limits of sustainable forest management, while recognising positive effect on climate adaptation"
Japan	Japan specifically mentions "an integrated approach in building a resilient society to adapt to climate change." It includes: "…introduction of self-sustained and distributed energy including renewable energy is a mitigation measures, and, at the same time, helps revitalise the local economy and secures energy in the event of disaster, thus beneficial for adaptation." "Farming-photovoltaics, installing photovoltaic equipment above farmlands, in a manner that allows farming to go along, renewable energy to be expanded and businesses to be profitable and contribution to be made the sustainability of the local community." "…cultivating symbiotic fuel crops on abandoned farm land, to contribute to the preservation of the ecosystem unique to each region." "The Government aims to manufacture plastics and biofuels by using biomass resources such as microalgae and plants absorbing CO_2."
Mexico	[agriculture/forestry sector] "…encourage agriculture practices that preserve and increase carbon capture in soil and biomass. These practices replace monoculture with polyculture or perennial crops." "…implement actions for energy efficiency and use of renewable energy in agriculture, livestock, and fishing projects. This may include the encouragement of biodigesters." "…substitute cooking over and open fire for efficient, low-emission stoves and disincentive the unsustainable use of wood." [energy sector] "…harness existing electric power potential by installing new large hydropower plants. Likewise, to use water stored in these installations for other uses such as irrigation, protection against floods, water supply for cities, roads, recreation, environmental services, landscaping, and tourism."
Singapore	In Singapore's LTS, there exists a separate chapter for adaptation action. It addresses water supply and food security issues. It includes the introduction of desalination and indoor farming, "Tuas Desalination Plant is the first in Singapore to be fitted with solar panels, The 1.2 megawatt peak (MWp) solar PV system will meet all of the energy needs of the plant's administrative building." "USD 144 million has been allocated for the Singapore Food Story R&D Programme to support R&D in sustainable urban food production, future foods, as well as food safety science and innovation." It also mentions that "indoor farming is a part of the growing community of urban farmers."
Slovakia	Slovakia aims "to promote synergies between adaptation and mitigation measures" in the adaptation policies and measures section of LTS. Slovakia's LTS introduces "sustainability criteria for forest biomass according to the Directive on the promotion of the use of energy from renewable sources" and also mentions "the use agro-forestry systems aimed at carbon sequestration through wood biomass." In the waste sector, Slovakia will establish "the obligation to reuse purified water from wastewater treatment plants, purified process water mainly for energy use (e.g., biodegradable waste and waste from wastewater treatment plants) with regard to the use of digestate for land, its subsequent transformation into biogas/biomethane."

Ukraine	Ukraine's LTS in agriculture/forestry sector states "synergy in climate change prevention and adaptation thereto.", "Promotion of generation and energy consumption from RES by entities of all forms of ownership (incorporation) in agriculture and forestry. It is envisioned to encourage introduction of practices and use of equipment contributing to reduction in GHG emissions in production of agricultural produce and foods owing to increased output and use of RES, including, installation of solar or wind energy devises; use of hydroelectricity generators for irrigation purposes."

LEDS = low emission development strategy; LTS = long-term low emission development strategy; RES = renewable energy sources; R&D = research and development.

Source: UNFCCC (n.d.a)

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