IRENA

International Renewable Energy Agency

Renewable energy in climate change adaptation:

METRICS AND RISK ASSESSMENT FRAMEWORK

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About IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.
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Disclaimer

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ABBREVIATIONS

CO_2	carbon dioxide
CPI	Climate Policy Initiative
EU	European Union
GDP	gross domestic product
GIS	geographic information systems
GIZ	German Agency for International Cooperation
GWh	gigawatt-hour
IPCC	Intergovernmental Panel on Climate Change
NDC	Nationally Determined Contribution
RCP	Representative Concentration Pathway
REIS	Regional Exchange Information System
SDG	Sustainable Development Goal
SPEI	Standardised Precipitation Evapotranspiration Index
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States dollar
WMO	World Meteorological Organization

EXECUTIVE SUMMARY

The necessity of renewable energy in any transition towards a climate-friendly future is undisputed. Often overlooked is the role that renewable energy can also play in climate change adaptation. Examining the intersection of renewable energy and climate change adaptation presents a critical opportunity to examine the dual challenges of mitigating climate impacts and supporting sustainable development. Promoting renewable energy as a strategy for adaptation requires increasing visibility of its benefits, including reduced greenhouse gas emissions, improved energy security, enhanced socio-economic outcomes, and greater resilience[1] to climate impacts.

Climate change adaptation is a dire need for many countries that are increasingly experiencing the impacts of changing climatic conditions. The World Meteorological Organization reports that the frequency and intensity of climate extremes, from record-breaking heatwaves to devastating floods, are on the rise and that between 1970 and 2019 the number of climate-related events increased fivefold (WMO, 2021, 2023). Furthermore, inaction on climate change could cost the world's economy USD 178 trillion in present value terms between 2021 and 2070 (Philip *et al.*, 2022), while under a middle-of-the-road scenario of future income development (SSP2, Shared Socio-economic Pathway), Koltz *et al.* (2024) assessed that it will be around USD 38 trillion (likely range of USD 19–59 trillion)[2] in 2049. This highlights the urgent need to embrace adaptation measures not only to alleviate the immediate impacts of climate change but also to pave the way towards a more resilient and thriving future.

After the Cancun Declaration in 2010 (UNFCCC, 2024a), the process of formulating and implementing national adaptation plans was established. As of May 2024, 56 national adaptation plans have been submitted to the UNFCCC (United Nations Framework Convention on Climate Change) secretariat (of which 21 are from African countries, including 11 Francophone countries), 17 between 2010 and 2019 and 39 between 2020 and May 2024, indicating a growing recognition and formalisation of adaptation needs across countries (UNFCCC, 2024b).

Although these policy frameworks provide a structured foundation for climate adaptation, a significant challenge remains in financing these initiatives. In 2021/2022, average annual climate finance flows nearly doubled – to almost USD 1.3 trillion – compared with 2019/2020 levels (CPI, 2023). This increase can be attributed to two main factors. One, an actual rise in mitigation finance amounting to USD 439 billion; two, improved methodology and new data sources that led to newly identified financing of an additional USD 173 billion annually. Despite this surge in overall financing, *adaptation finance* remains marginal, amounting to only USD 63 billion, which falls far short of the estimated USD 212 billion needed annually by 2030 for developing countries alone (CPI, 2023).

1 *Resilience is the capacity of social, economic and environmental systems to cope with a hazardous event or a trend or a disturbance by responding or reorganising in ways that maintain the systems' essential functions, identity and structure, while also maintaining the systems' capacity for adaptation, learning and transformation (IPCC, 2014). Resilience can refer to the technical resilience of energy systems (e.g. climate-proofing infrastructure) and to other types of resilience, such as individual or household resilience to climate shocks or the general resilience of systems and their ability to "bounce back", which renewable energy systems may contribute to.*

2 *In 2005 international dollars.*

Policies and finance play a key role in climate change adaptation, but their effective implementation requires understanding of the specific climate change risks they are intended to address. Therefore, an important part of climate change adaptation planning is identifying the risk, the exposure and the vulnerability to climate change in the respective country. Quantitative indicators need to be developed to make the implementation of the plans monitorable, reportable and verifiable. However, measuring adaptation ex ante is challenging, as it involves estimating the amount of damage that will be avoided by the respective adaptation measures.

Risk assessment is the first step of the process in climate adaptation, which will lead to evaluating potential impacts and vulnerabilities and developing effective strategies. The literature has deployed various methodologies for improved understanding of risk, each with unique approaches and tools. In this report, the vulnerability assessment methodology has been adopted for several reasons. Because it combines both quantitative and qualitative data, including stakeholder consultations (a participatory approach), the methodology captures local knowledge and context-specific details. One of the tools under this approach, the impact chain method, also serves the key purpose of this study, which is to assess any potential impacts and specific vulnerabilities and to pinpoint critical areas that require renewable energy measures for higher adaptive capacity. This ensures that the assessment is tailored to the unique characteristics and needs of the area being studied, particularly in Francophone African countries. Figure S1 shows the step-by-step guide to applying the impact chain method, and the steps are discussed in detail within the report.

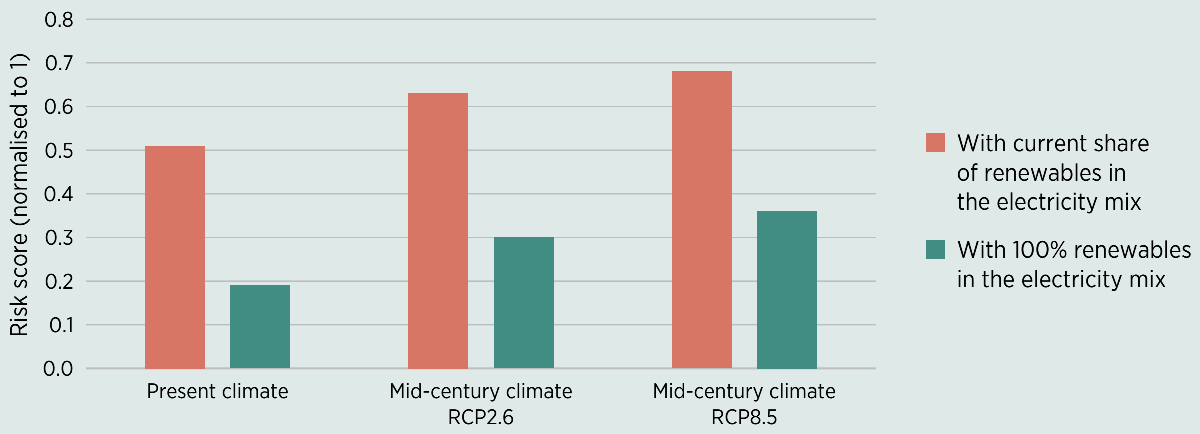
Figure S1 Impact chain method

Source: Adapted from *(GIZ et al., 2014)*.

Of the sectors in critical need of climate adaptation measures, desalination to produce potable safe water is one of the most important for many countries, in particular for island communities. Water scarcity is a crucial issue in many countries' adaptation plans; 16 countries specifically mention desalination technologies paired with renewable energy in the adaptation part of their nationally determined contributions as of June 2024 (ClimateWatch, n.d.). The case study of desalination in the Canary Islands (Spain) has been used in this report to illustrate and provide step-by-step guidance on the different steps of the impact chain method, primarily due to data availability. This methodology is also adaptable to any Francophone African country and can be applied to a wide range of adaptation projects involving renewable energy, subject to the availability of relevant data. The first step is risk identification, followed by identification of associated dimensions of hazard, vulnerability and exposure. The third step is to list relevant indicators related to each of the associated dimensions. Since all indicators will have different units of measure, the fourth step is to scale the indicators to have dimensionless metrics.[3] The fifth and the final step is to present the findings with the harmonised metrics and demonstrate the potential impacts of renewable energy interventions across various risk measures.

This method allows for the use of quantitative techniques, expert assessments and participatory approaches to quantify risk. One of the key advantages is the high level of stakeholder involvement throughout the process. As indicators are identified and methods for quantitative or qualitative risk measurement are developed, the adaptation gap and challenges become more clearly defined and communicable.

IRENA adopted the methodology to assess the risk of increased energy demand (due to increased desalination and pumping needs) and greenhouse gas emissions, and the contributions of renewables in lowering the risk. In the Canary Islands, electricity for desalination is mainly taken from the grid, and electricity production on the Canaries is mainly based on diesel fuels. Less than 10% of electricity generation is based on renewable energy. The more the energy mix becomes renewable, the less it will depend on non-renewable sources, lowering the risk of greenhouse gas emissions and avoiding maladaptive pathways. Figure S2 shows the risk index for the electricity mix with the current share of renewables and in the scenario mainly based on renewable energy. The values of the risk index are between 0 and 1, indicating risk levels from very low to extremely high. It is evident that the adoption of renewables leads to a significant reduction of risk under different scenarios.



[3] *The metric itself therefore becomes unitless. This makes the metrics comparable (when they would otherwise have different units of measure).*

Figure S2 Risk score incorporating the weights of the current share of renewables and 100% renewables in the electricity mix in the Canary Islands under different climate scenarios

Note: RCP = Representative Concentration Pathway.

Future studies should give priority to improving the methodologies and metrics used to assess the effect of renewable energies on climate adaptation. It is essential to broaden the scope of pilot projects and case studies to encompass a wider range of geographical locations (*e.g.* Francophone African countries), sectors (*e.g.* agriculture), technologies (*e.g.* hydropower) and situations. This will provide useful information on the different ways in which renewable energies can be applied for adaptation purposes. Developing a synergistic metric that encompasses adaptation, mitigation and sustainable development benefits is a step forward in quantifying the comprehensive impacts of renewable energy-based adaptation initiatives. Such metrics could be essential for tracking progress, informing policy and securing funding from multilateral organisations. Another approach could be to expand and deepen the methodology adopted in this report to examine how long-term impacts affect key risk dimensions, such as exposure and vulnerability, through macro-econometric models. Such models provide critical insights when considering the socio-economic impacts of adaptation measures taken over time. The model could cover the links between the economy, the energy sector and emissions and thus help in identifying sustainable policies. Such a comprehensive framework will also have great potential to foster inter-ministerial co-operation and discourse through the exchange of relevant policy issues, key assumptions and model results. In addition, embedding these projections in regional or sector data would allow the models to show a much more detailed picture of the cumulative impacts on social and economic resilience and on the sustainability and equity of adaptation strategies.

1. INTRODUCTION

The necessity of renewable energy in any transition towards a climate-friendly future is undisputed. According to IRENA's flagship reports, *World Energy Transitions Outlook* 2023 and 2024, the largest shares in the carbon dioxide (CO_2) emissions cuts needed to achieve net-zero emissions by 2050 under the 1.5°C pathway will come from the use of renewables in power generation and, directly, in heat and transport, combined with energy conservation and energy efficiency. These measures would account for over half the necessary cuts in global CO_2 emissions. An additional 19% of the cuts would come from direct electrification of end-use sectors, and 12% from using hydrogen and its derivatives, including synthetic fuels and feedstocks (IRENA, 2023, 2024a). Renewable energy thus features largely when it comes to climate change mitigation.

Often overlooked is the role that renewable energy can also play in climate change adaptation. Climate change adaptation is a dire need for many countries that are increasingly experiencing the impacts of changing climatic conditions. The World Meteorological Organization reports that the frequency and intensity of climate extremes, from record-breaking heatwaves to devastating floods, are on the rise and that between 1970 and 2019 the number of climate-related events increased fivefold (WMO, 2021, 2023). If current emission reduction efforts remain unchanged, we are on track for a 2.8°C increase in global temperature by the century's end – a recipe for catastrophic climate change and irreversible damage. Furthermore, inaction on climate change could cost the world's economy USD 178 trillion in present value terms between 2021 and 2070 (Philip *et al.*, 2022), while under a middle-of-the-road scenario of future income development (SSP2[4]) Koltz *et al.* (2024) assessed that it will be around USD 38 trillion (likely range of USD 19–59 trillion)[5] in 2049. This highlights the urgent need to embrace adaptation measures not only to alleviate the immediate impacts of climate change but also to pave the way towards a more resilient and thriving future.

At COP28 (the 28th Conference of the Parties to the United Nations Framework Convention on Climate Change), the Global Stocktake urged countries to enhance their climate change adaptation ambitions, underscoring the urgent need to accelerate global adaptation efforts and chart a robust path for the next five years. While the COP28 decision acknowledged significant strides in adaptation planning and implementation, it also recognised the substantial gaps and challenges that persist. The decision rightly emphasised the importance of integrated, multisectoral and gender-responsive solutions and called for the establishment of national adaptation policies by 2025. A total of USD 792 million has been pledged for loss and damage funding arrangements, of which USD 662 million is for the Loss and Damage Fund, including USD 100 million from the United Arab Emirates (COP28, 2024).

National adaptation policies, though discussed and agreed on at the global level, must be designed and implemented at the local or regional level. Like any other policy, adaptation policy design will benefit from a sound and science-based estimate of its effects. This entails identifying adaptation solutions before the policy and monitoring them after implementation to be able to compare the changes, costs and benefits from the policy. Policy frameworks are essential not only for responding to climate impacts but also for ensuring that adaptation strategies are implemented efficiently and effectively. However, while climate mitigation interventions can be easily measured and tracked, adaptation is harder to measure and often requires rigorous scientific knowledge. As the world increasingly turns to renewable energy solutions to address climate change, understanding how these solutions contribute to climate adaptation efforts is a critical gap that needs to be bridged.

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4 *Shared Socio-economic Pathway 2, as defined in the Intergovernmental Panel on Climate Change Sixth Assessment Report.*

5 *In 2005 international dollars.*

After the Cancun Declaration in 2010 (UNFCCC, 2024a), the process of formulating and implementing national adaptation plans was established. Annex 1 describes the role of United Nations and international bodies in highlighting the role of adaptation. As of May 2024, 56 national adaptation plans have been submitted to the United Nations Framework Convention on Climate Change (UNFCCC) secretariat (of which 21 are from African countries, including 11 Francophone countries), 17 between 2010 and 2019 and 39 between 2020 and May 2024, indicating a growing recognition and formalisation of adaptation needs across countries (UNFCCC, 2024b).

Although these policy frameworks provide a structured foundation for climate adaptation, a significant challenge remains in financing these initiatives. Climate finance is increasingly moving to the centre in the public discussion on climate change, bolstered by discussions of climate equity and a just energy transition (IRENA, 2024b). In 2021/2022, average annual climate finance flows nearly doubled – to almost USD 1.3 trillion – compared with 2019/2020 levels (CPI, 2023). This increase was largely due to a USD 439 billion rise in mitigation finance and an additional USD 173 billion annually due to improved methodologies and new data sources, enhancing the accuracy of tracked flows. The rise in global climate finance is primarily due to substantial investments in clean energy within a few key regions. Brazil, China, Europe, India, Japan and the United States accounted for 90% of the increased funding. Despite this overall surge, adaptation finance remains insufficient, amounting to only USD 63 billion, which falls far short of estimated USD 212 billion needed annually by 2030 for developing countries alone (CPI, 2023). Box 1 provides more information on the current adaptation financing landscape and gaps.

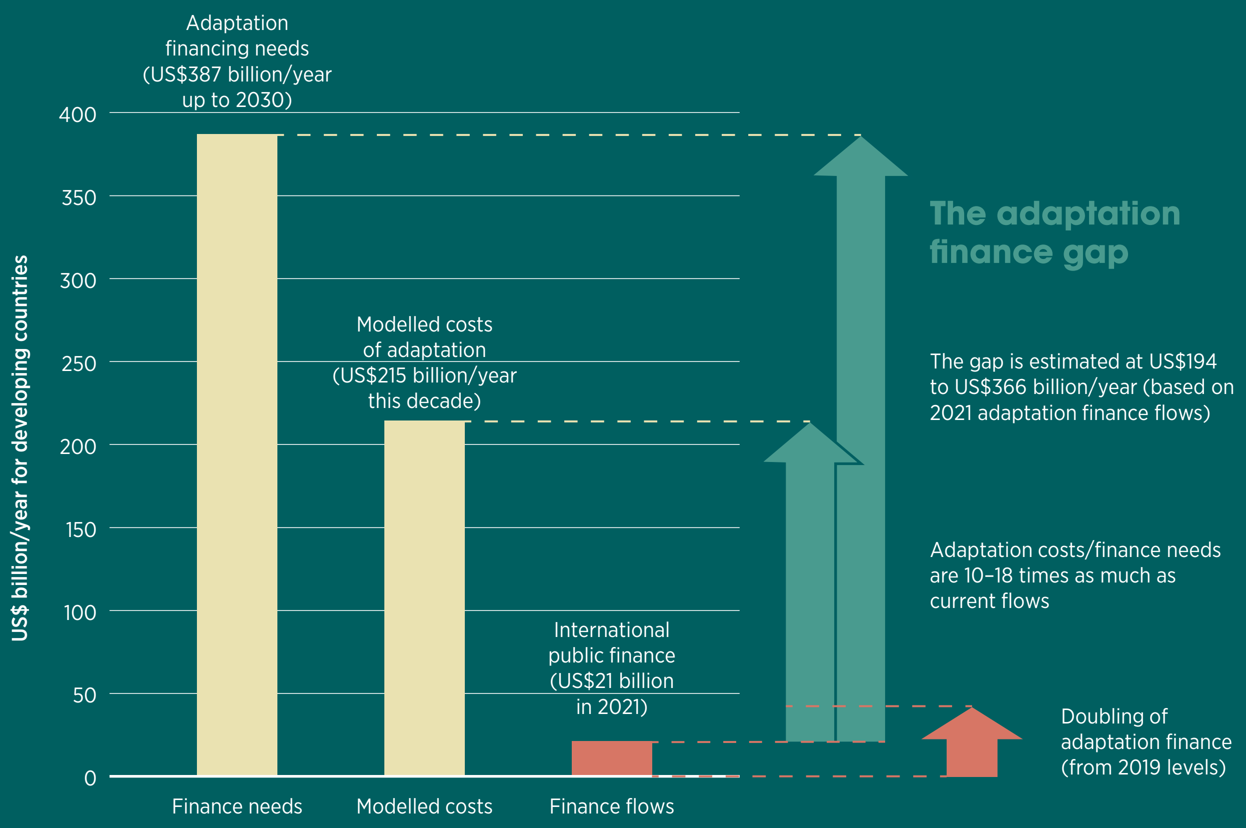
Box 1 Global adaptation financing landscape and gaps

International public climate finance to developing countries fell by 15% to USD 21.3 billion in 2021, after rising to USD 25.2 billion between 2018 and 2020 (UNEP, 2023). The adaptation finance gap – that is, the difference between estimated adaptation financing needs and costs (USD 215 billion (modelled costs) to USD 387 billion (adaptation finance needs))[6] and finance flows (USD 21.3 billion) – has grown. Highlighting this gap, the United Nations Environment Programme's *Adaptation Gap Report 2023* indicates that the finance needs of developing countries are 10-18 times greater than the current international public finance flows, a more than 50% increase from previous estimates (UNEP, 2023) (Figure 1). The report also notes a halt in adaptation planning and implementation, exacerbating possible losses and damage, particularly in the areas most vulnerable to the impacts of climate change. To address these challenges and help close this gap, the report provides seven potential strategies to enhance adaptation financing, including increasing domestic expenditures, leveraging international and private sector finance, and developing new financial channels through the new Loss and Damage Fund.

At COP26, several institutions raised the issue of an underfinanced adaptation, mainly for developing countries or least developed countries. The African Development Bank points out that rapid and massive investment in initiatives that build resilience and strengthen climate adaptation across the continent is needed and demands at least 50% of global climate financing be directed towards adaptation (Adesina, Akinwumi A. and Sukhdev, Pavan, 2021). The Adaptation Fund, established to finance concrete adaptation projects and programmes in developing countries under the Kyoto Protocol, has been formally serving the Paris Agreement since 2019.

[6] *Modelled adaptation costs estimate the expenses needed to reduce climate risks without considering financing; country adaptation finance needs refer to the funds required from international and domestic sources to implement national adaptation plans. These needs are influenced by current ambitions and socio-economic conditions. The methods differ: modelled costs focus on general risk reduction, whereas finance needs are based on specific programme and project costs, leading to discrepancies between the two approaches (UNEP, 2023).*

Figure 1 Comparison of adaptation financing needs, modelled costs and international public adaptation finance flows in developing countries



Source: (UNEP, 2023).

Resources for climate action are being raised, channelled and deployed by an increasingly complex constellation of public and private institutions. Multilateral climate funds play a large and growing role in this system, with multilateral funds dedicated to renewable energy deployment, and others focusing on reducing emissions from deforestation, supporting adaptation, or pursuing a mixed mandate. However, renewable energy deployment, as reiterated throughout this report, is often seen from the financing side only as a mitigation strategy.

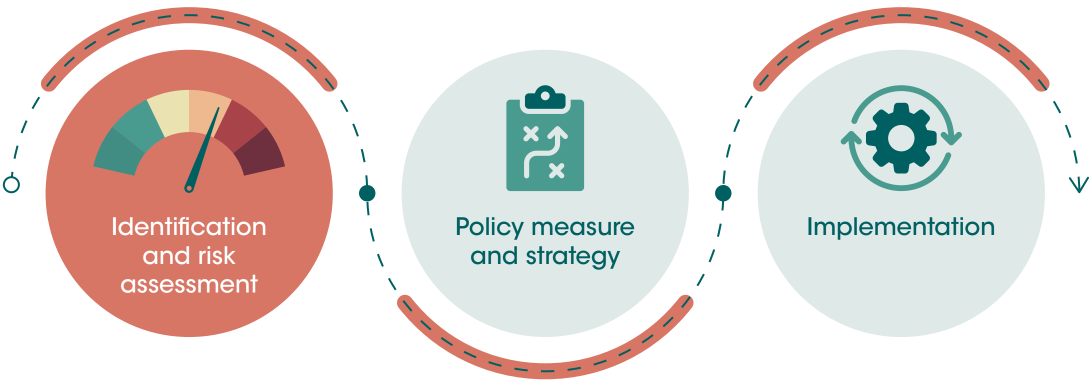
However, private sector finance is becoming increasingly attentive to adaptation. As an example, the G7 development finance institutions, working together under the Adaptation and Resilience Investors Collaborative,[7] have declared a practical plan to the G7 on actions to accelerate investments in adaptation and resilience (DFC, 2021). The Coalition for Climate Resilient Investment, a private sector-led initiative, encourages businesses and countries to apply climate risk pricing tools; 120 institutions have joined the coalition, holding over USD 20 trillion in assets.

[7] *The collaborative is a "working shop" that aims to accelerate and scale-up investments, particularly from the private sector, to achieve the adaptation goals of the Paris Agreement. The collaborative aims to improve collaboration and action to help overcome barriers and market failures hindering investments in climate adaptation and resilience.*

Policies and finance play a key role in climate change adaptation, but their effective implementation requires understanding of the specific climate change risks they are intended to address. Therefore, an important part of the climate change adaptation planning is identifying the risk, the exposure and the vulnerability to climate change in the respective country. Quantitative indicators need to be developed to make the implementation of the plans monitorable, reportable and verifiable. However, measuring adaptation ex ante is challenging, as it involves estimating the amount of damage that will be avoided by the respective adaptation measures.

Since 2021, IRENA has laid out the relationship between renewable energy and climate adaptation, highlighting the ways in which renewable energy can provide dual adaptation pathways while also contributing to mitigation and enhancing efforts across other sectors (IRENA, 2021, 2024c). This report presents a framework for identifying adaptation needs and evaluating the risk mitigation effects of renewable energy. It aims to establish essential definitions and methods, providing examples of applications, potential outcomes and subsequent recommendations. Developing adaptation measures comprises three phases: the identification and quantification of the need for adaptation, the formulation of policies, and the implementation of those policies. This report mainly focuses on phase 1, of which the central component is the risk assessment (in red in Figure 2).

Figure 2 Phases in development of adaptation measures (red indicates the focus of this report)



Renewable energy-based adaptation solutions – the various ways through which the inclusion of renewables into local systems could decrease systemic climate risks and improve resilience – are discussed throughout the report.[8] Renewable energy-based adaptation solutions could reduce exposure, sensitivity and vulnerability to high temperatures, low or high precipitation, extreme winds, and sea-level rise as well as increase adaptive capacity (Annex 2). The effective implementation of these renewable energy solutions requires a strong risk assessment framework. In the next section, we explore how this framework is relevant in the context of adaptation and, specifically, show that a holistic view of risk assessment can inform the strategic deployment of renewable energy technologies. The framework serves as a basis to shortlist the most relevant adaptation options for long-term analysis. This will help ensure that adaptation is "smart"[9] and climate-friendly, tackling the unique risks from a changing climate faced in different locations and by different communities. Section 3 concludes and presents other potential work that would expand the scope of this report.

[8] *Resilience is the capacity of social, economic and environmental systems to cope with a hazardous event or a trend or a disturbance by responding or reorganising in ways that maintain the systems' essential functions, identity and structure, while also maintaining the systems' capacity for adaptation, learning and transformation (IPCC, 2014). Resilience can refer to the technical resilience of energy systems (e.g. climate-proofing infrastructure) and to other types of resilience, such as individual or household resilience to climate shocks or the general resilience of systems and their ability to "bounce back", which renewable energy systems may contribute to.*

[9] *Fits into a specific, measurable, achievable, realistic and timely (SMART) criterion (McCarthy et al., 2012; Seyisi et al., 2023).*

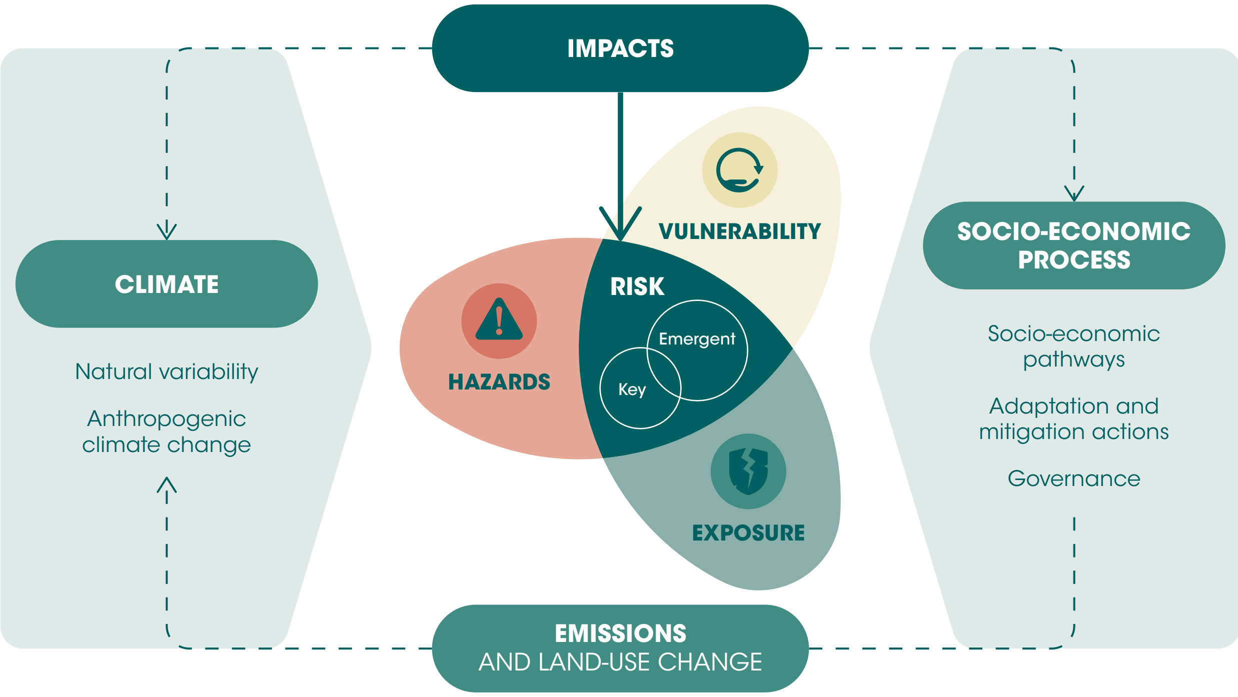
2. RISK ASSESSMENT IN THE ADAPTATION PROCESS

This section will explore the concept of risk and its various dimensions, review different frameworks for risk assessment, and detail the methodology selected for this report. A case study is presented in boxes to illustrate the different stages of the process and demonstrate its practical application and effectiveness in providing understanding of and managing climate adaptation risks. This approach of supporting the theoretical framework with examples from a case study can be used to gauge the most relevant adaptation options for long-term analysis, which is often a data-intensive process.

2.1 RISK IN THE CONTEXT OF IPCC REPORTS

For climate adaptation, understanding and managing the risk of climate-related effects is fundamental. The definition of risk lies at the core of climate change analyses. The Fifth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC) defines the risk of climate-related effects as the interaction of climate-related hazards,[10] vulnerability and exposure, against the background of climate and socio-economic processes (Figure 3)(IPCC, 2014).

Figure 3 Risk definition in IPCC Fifth Assessment Report



Based on: (IPCC, 2014).

[10] *Hazards are potential occurrences of a physical event (e.g. extreme weather), trend (e.g. warming) or physical impact (e.g. drought) that may impact life, health, property, infrastructure, livelihoods, services, ecosystems and environmental resources. Hazards cannot be influenced by adaptation; they depend on the status of climate change and respond to differences in emission levels and other climate variables. For the discussion of adaptation, hazards may be considered exogenous.*

The IPCC Sixth Assessment Report refines the risk concept (IPCC, 2022). IPCC uses the risk concept to refer to negative (adverse) consequences, as this is the way "risk" would be understood by most people. Moreover, the IPCC reports only consider the risk applicable to human or ecological systems. The IPCC risk concept also covers the impacts and responses to climate change, hence including the potential negative consequences of climate change response, a discussion particularly relevant when considering a just energy transition.

The Sixth Assessment Report further elucidates the key dimensions of climate-related hazards, vulnerability and exposure:

- **Hazards:** Climatic drivers and climate events are referred to as hazards. The identification of hazards relies on an assessment of the potential consequences of a climatic change, not just an assessment of the observed or projected climatic change on its own.

- **Exposure:** Exposure relates to the presence of valuable entities – such as human populations, infrastructure, or ecosystems – in areas that could be adversely affected by climate-related hazards.

- **Vulnerability:** Vulnerability refers to the propensity or predisposition of these valuable entities to suffer adverse effects due to their inherent or situational characteristics. Vulnerability encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt (IPCC, 2014).

For example, for a coastal city, its probability of flooding or drought would be considered a hazard, its population density would indicate its level of exposure, and the infrastructure it has to deal with such hazards (or the lack of such infrastructure) would be considered a vulnerability.

Adaptation actions should be geared towards reducing vulnerability and increasing resilience by improving climate-related knowledge and strengthening socio-economic systems and livelihoods (Lewis, 2024). A rural farming community facing recurrent droughts, for example, demonstrates vulnerability through factors like poor soil quality and limited water availability. However, the implementation of diversified cropping systems (*e.g.* planting drought-resistant crops), solar irrigation pumps and efficient water management practices could transform this community into a model of resilience, capable of sustaining agricultural productivity despite challenges.[11] This foundational interplay between vulnerability and resilience forms the foundation of adaptation strategies. However, to understand any aspect of such interplays, assessment of climate-related risk must be the first step.

2.2 RISK ASSESSMENT FRAMEWORK

Understanding risk – how it can be measured or assessed and what are the suitable ways to encompass the manifold uncertainties stemming from the development of hazards, the development of societies and the development of capacities to deal with climate change impacts over time – is vital at the start of the risk assessment process. Risk assessment in climate adaptation involves evaluating potential impacts and vulnerabilities to develop effective strategies. The literature has deployed various methodologies for improved understanding of risk, each with unique approaches and tools. Some of the commonly adopted tools, methodologies and approaches are:

- **Vulnerability assessment**, which focuses on identifying and analysing the susceptibility of systems to climate impacts, using tools such as the ***impact chain method***, socio-ecological frameworks and rapid assessment tools. This method is crucial for prioritising adaptation actions through an understanding of the most vulnerable sectors and communities (Smith and Peatley, 2009).

[11] *If energy products and services do not address the root causes of vulnerability – such as poverty or social norms – there is a greater risk of maladaptation. Maladaptation occurs when the actions taken to reduce vulnerability to climate risks adversely increase, reinforce or redistribute the vulnerability of social groups, the environment, institutions or sectors (Johnstone and Greene, 2024).*

- **Scenario analysis**, which involves creating and analysing different future scenarios based on different climate projections and socio-economic pathways. Tools like general circulation models, downscaling techniques and integrated assessment models are used to understand potential future conditions and plan long-term adaptation strategies (TCFD, n.d.) Cost-benefit analysis evaluates the economic feasibility of adaptation measures by comparing costs and benefits and employing economic modelling, cost estimation frameworks and benefit quantification methods. This approach assists policy makers in making informed decisions by highlighting the most cost-effective adaptation options (Markanday *et al.*, 2019).

- **Multicriteria analysis**, which integrates various criteria, including environmental, social and economic factors, to assess adaptation options. Decision support systems, stakeholder analysis, and scoring or ranking methods are used to facilitate comprehensive evaluation by considering multiple dimensions of adaptation measures (USAID, 2013). Risk mapping and spatial analysis uses geographic information systems (GIS) to visualise and analyse the spatial distribution of climate risks. GIS software, remote sensing data and spatial modelling techniques enhance understanding of the spatial patterns of vulnerability and guide location-specific adaptation planning (Papathoma-Köhle *et al.*, 2016).

- **Participatory approaches**, which engage stakeholders in the risk assessment process to incorporate local knowledge and preferences. Workshops, focus groups and participatory mapping ensure that adaptation strategies are context specific and socially acceptable (Restrepo-Mieth *et al.*, 2023). These methodologies provide a comprehensive toolkit for assessing climate risks and developing robust adaptation strategies. By combining different approaches, practitioners can address the multifaceted nature of climate change impacts and enhance resilience across sectors and communities.

In this report, the vulnerability assessment methodology has been adopted for several reasons. This comprehensive approach helps in identifying the most at-risk populations, sectors and systems. Because it incorporates both quantitative and qualitative data, including stakeholder consultations (a participatory approach), the methodology captures local knowledge and context-specific details. One of the tools under this approach, the impact chain method, also serves the key purpose of this study, which is to assess any potential impacts and specific vulnerabilities and to pinpoint critical areas that require renewable energy measures for higher adaptive capacity. This ensures that the assessment is tailored to the unique characteristics and needs of the area being studied.

By focusing on the most vulnerable aspects, the vulnerability assessment methodology enables the development of targeted adaptation strategies that can enhance resilience to, and sustainability in the face of, climate shocks. In addition, the methodology integrates exposure, sensitivity and adaptive capacity, providing a holistic view of how different factors contribute to vulnerability. It also helps in prioritising adaptation actions by highlighting the most vulnerable aspects of a system. It can be applied across various scales, from local to national levels, and can be adapted to different sectors such as agriculture, water resources and infrastructure. This flexibility makes it a versatile method for diverse applications. Importantly, the participatory nature of the methodology involves stakeholders in the assessment process, fostering collaboration and ensuring that the adaptation strategies are socially acceptable and supported by the community.

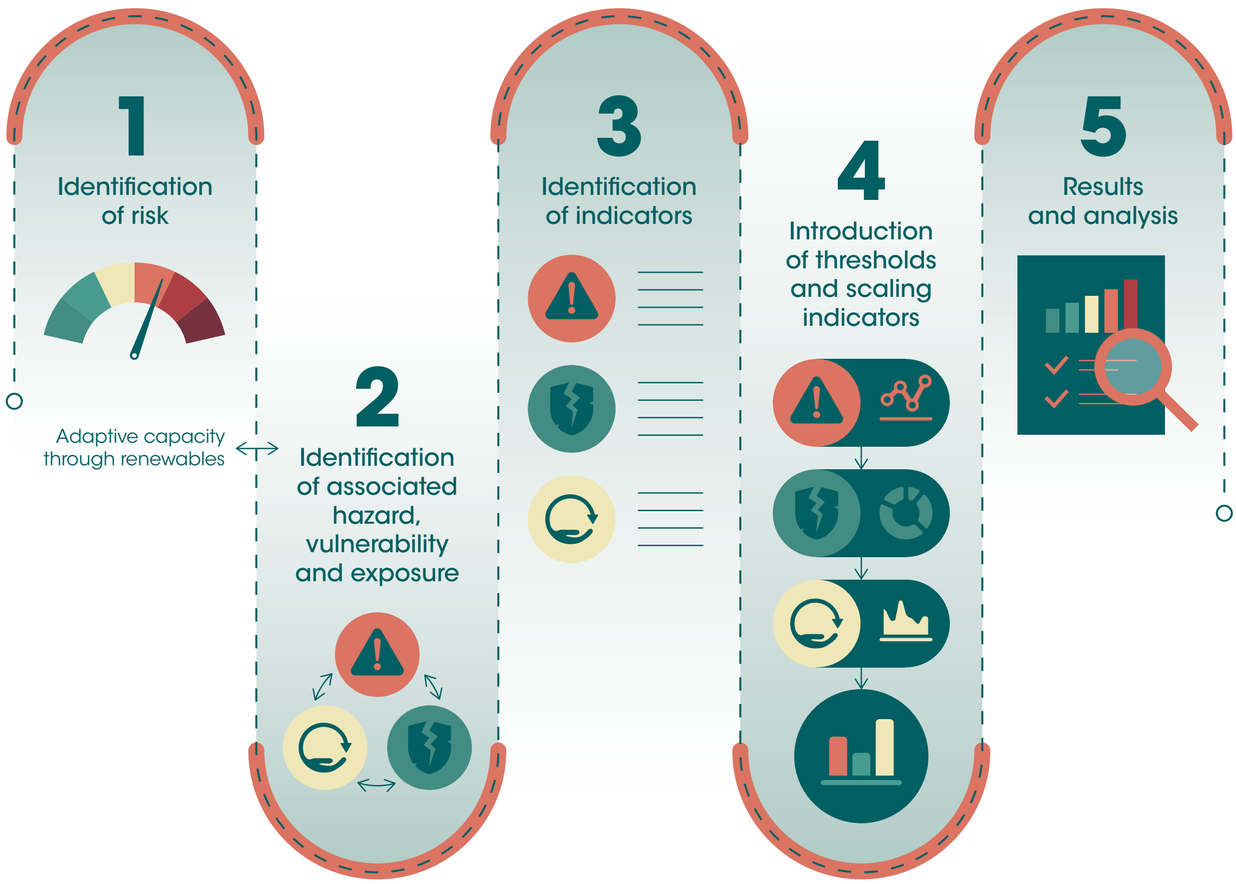
The approach has become increasingly established for measuring the impacts and benefits of adaptation to climate change and has been applied to pilot projects in Bolivia, Burundi, Mozambique and Pakistan and to full-scale assessments in the Mediterranean as well as Bangladesh and Germany. *The Vulnerability Sourcebook* presents a standardised methodological framework for climate change vulnerability assessments (GIZ *et al.*, 2014). The NDC Partnership acknowledges the *Vulnerability Sourcebook* approach as a practical and scientifically sound methodological approach to vulnerability assessments and their application for the monitoring and evaluation of climate adaptation. This section builds on the methodology and shows how the impact chain method can be used to assess the risk from climate change and quantify the risk mitigation from using renewable energy in adaptation.

2.3 INTRODUCING THE IMPACT CHAIN METHOD

An impact chain is an analytical tool that helps in better understanding, systemising and prioritising the factors that drive risk in the system of concern. The structure of the impact chain developed according to the IPCC Fifth Assessment Report approach is based on the understanding of risk and its components (IPCC, 2014). The framework incorporates the three components discussed earlier: hazard, vulnerability and exposure. The hazard component includes factors related to the climate change impacts and direct physical impact; the vulnerability component consists of sensitivity and capacity factors; and the exposure component comprises one or more exposure factors (no subdivision within this component).[12]

The framework of hazard, vulnerability and exposure components is critical for an assessment of climate-related risks to renewable energy systems. One must examine the evidence of climate outcomes and direct physical impacts on renewable infrastructure (hazard), tell how sensitive these systems are likely to be, introduce metrics for adaptive capacity within the renewables sector, and establish siting and resilience criteria for the project. Based on the results, appropriate policy designs and strategic project planning can be implemented to improve the sustainability and reliability of renewable energy sources over time. Figure 4 shows the step-by-step guide to applying the impact chain method, and the steps are discussed in detail in following sections.

Figure 4 Impact chain method



Source: Adapted from *(GIZ et al., 2014)*.

12 *Intermediate impacts are not a risk component by themselves but merely an auxiliary tool used to fully grasp the cause-effect chain leading to the risk. They are a function of both hazard and vulnerability factors, which means that the impacts identified do not depend only on the climate signal but also on one or several vulnerability factors. There are several principles to consider when collecting the various factors needed to generate an impact chain. The factors allocated to one component (be it hazard, vulnerability or exposure) should be – at least predominantly – independent of the factors of the other components. Factors influenced by the factors of at least two different components should be treated as intermediate impacts.*

This section demonstrates the implementation of the impact chain method step by step. The method will be applied to a case example (Box 2), primarily due to data availability and follow the process of assessing potential impacts and identifying specific pathways through which climate change could affect a chosen system, enabling the development of targeted adaptation strategies to enhance the system's resilience and sustainability.

Box 2 Implementation of the impact chain method in water desalination

Desalination to produce potable safe water is a very important adaptation strategy in many countries, in particular for island communities. Although desalination is a mature technology, it is energy intensive (IRENA, 2021). Water scarcity is a crucial issue in many countries' adaptation plans; 16 countries specifically mention desalination technologies paired with renewable energy in the adaptation part of their nationally determined contribution as of June 2024 (ClimateWatch, n.d.).

A detailed analysis covering desalination, among many other adaptation strategies in the blue economy sectors,[13] has been carried out recently under the European Union's Horizon 2020 programme (SOCLIMPACT, n.d.). The analysis focuses on European islands in the Mediterranean Sea, the Atlantic Ocean and the Caribbean Sea. The results can be transferred to islands in other regions, other island States or small island developing States. Hence, in this report, the Canary Islands (Spain) are used to illustrate the different steps of the impact chain method (SOCLIMPACT, n.d.).

This section will delve into the implementation of the impact chain method in the blue economy. The first step is risk identification, followed in the second step by the identification of associated dimensions of hazard, vulnerability and exposure. The third step is to list relevant indicators related to each of the associated dimensions. Since all indicators will have different units of measure, the fourth step is to scale the indicators to have dimensionless metrics.[14] The fifth and final step is to present the findings from the analysis of the risk and its mitigation through renewable energy use.

STEP 1: Identify risk

Climate-related risk can be associated with slow changes under climate change or extreme weather events. The data situation for these two types of risk will be different: not as much data are available for gradual changes, whereas extreme events, be they climate change driven or not, have occurred over decades and more data are therefore available. Obviously, the risk selection will be driven by the perceived danger of the risk and not by data availability, but it is important to keep in mind how the type of hazards involved in the risk might affect the quantification of vulnerability and exposure. Box 3 shows an example of risk identification associated with increased desalination as an adaptation strategy in the case of the Canary Islands. A detailed study on desalination and other aspects of adaptation strategy in blue economy sectors on European islands has been made recently under the European Union (EU) Horizon 2020 research programme (SOCLIMPACT, n.d.). The impact chain method is indicator based, so the data collected in this study provide valuable resources for a risk assessment. For this reason, the Canary Islands, which are

13 *The blue economy, roughly speaking, comprises economic sectors and related policies that together determine whether the use of oceanic resources is sustainable (World Bank and United Nations Department of Economic and Social Affairs, 2017). Paralleling the green economy concept, the blue economy promotes economic growth, together with inclusion and better livelihoods, while respecting the integrity of oceans and coastal areas. The blue economy has several components: established ones like fisheries, tourism and maritime transport, and new ones like renewable energy, aquaculture, or biological services from marine life forms.*

14 *The metric itself therefore becomes unitless. This makes the metrics comparable (when they would otherwise have different units of measure).*

faced with increased challenges of water scarcity under climate change, and which were included in the Horizon 2020 study, were chosen to depict the various steps of the impact chain method in this report. This methodology is also adaptable to any Francophone African country and can be applied to a wide range of adaptation projects involving renewable energy, subject to the availability of relevant data.

Box 3 Identification of risk – the water desalination in Canary Islands case study

The Canary Islands[15] face situations that are common to many islands; that is, their water supply is highly determined by seasonal factors. Owing to natural limitations (declining groundwater levels), the economic situation (increasing tourist arrivals in recent years), and population growth, more desalinated water will be needed in this region to meet the increase in drinking water consumption and give respite to current water resources. Desalination in the Canary Islands is a fundamental water resource: more than 70% of the water for human consumption in the Canary Islands comes from over 300 desalination plants (de la Fuente, 2018). Gran Canaria currently has more than 120 plants (El Kori *et al.*, 2021), and on the islands of Fuerteventura and Lanzarote practically all the water consumed comes from desalination plants (Rosales-Asensio *et al.*, 2020). Water desalination consumes around 10% of the total electricity demand in Gran Canaria, but only 15.5% of this demand is supplied by renewable energy sources (El Kori *et al.*, 2021). The water-energy nexus in the Canary Islands is as important as it is complex to manage, and there is an increasing dependence on industrial water production (desalination).

In this case study, **the increase in energy demand due to increased desalination and pumping needs is identified as one central risk** (REIS, n.d.),[16] and a full impact chain analysis is carried out. **To develop the extent of risk alleviation to be addressed through renewable energy use**, the risk is expanded to **the risk of increased energy demand and greenhouse gas emissions due to increased desalination and pumping needs.**

STEP 2: Identify hazards, vulnerability and exposure

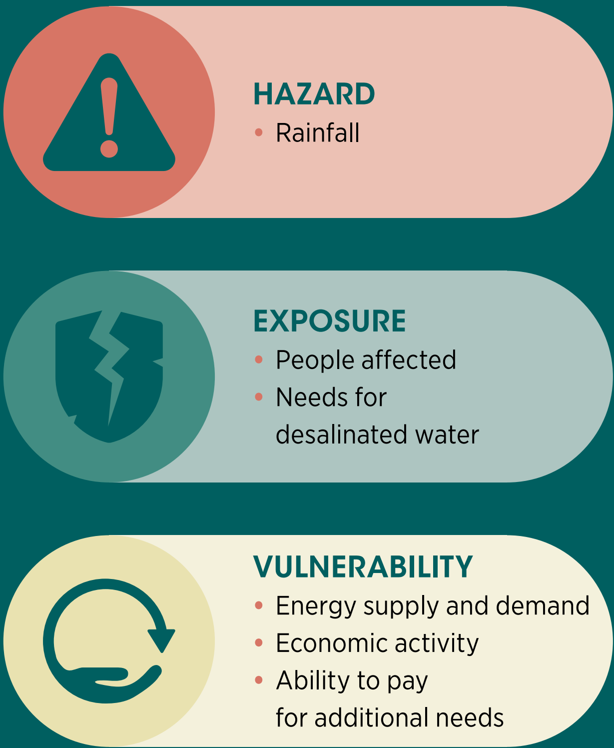
The hazards are the inevitable exogenous driver of the risk. The physical changes can be due to extreme events or can comprise gradual change, such as in temperature, precipitation pattern or amount of rainfall. Identifying vulnerability means identifying the attributes of the system (interrelated components such as economy, society, nature and so on) that contribute to the risk. It helps to think about vulnerability in terms of sensitivity (*i.e.* which aspects of the system make it sensitive to climate hazards) and adaptive capacity (*i.e.* how well the system can protect itself from the hazards). Here, as throughout the process, it is helpful to be as precise and explicit as possible.

Exposure refers to livelihoods at stake. Some common examples are the number of people living in an area where the hazard prevails, the number of buildings in a flood-prone area, and the share of smallholder farmers in a population. The degree of exposure will increase the risk (Box 4). **Vulnerability** is determined by factors of sensitivity, capturing the aspects of the system that make it vulnerable, such as the lack of water in natural reservoirs, the existing energy system and its supply and demand structure, and economic activities that may need water. One example of adaptive capacity is determined by the ability to pay for additional energy consumption.

[15] *The Canary Islands are composed of seven main islands, from the largest to the smallest: Tenerife, Fuerteventura, Gran Canaria, Lanzarote, La Palma, La Gomera and El Hierro.*

[16] *The Regional Exchange Information System (REIS) platform provides a huge opportunity for all EU islands to engage in in-depth discussions and establish a benchmark for climate change adaptation and Blue Growth initiatives (REIS, n.d.).*

Box 4 Identification of hazards, vulnerability and exposure – the water desalination in Canary Islands case study



Once the risk has been identified for the water desalination case study in the Canary Islands, the next step is listing associated hazards, vulnerability and exposure. The **hazard**, being the external driver from climate change, in this case would be the reduction in rainfall, leading to a depletion of the natural reservoirs and increased need for alternative water resources.

The **exposure** indicators would be the people affected and the water needs supplied by desalination plants. Both can differ by location and by fluctuations in the population, for instance due to seasonal changes in population.

Vulnerability in the case of the Canary Islands would be water availability and the energy supply and demand that are associated with water provision. Economic activity and the ability to pay for the additional needs for desalination and the increased energy demand also play a key role in the adaptive capacity of the islands.

Source: (SOCLIMPACT, 2020a).

STEP 3: Develop indicators

The selection of indicators for the different elements of the risk assessment dimensions is crucial for the entire exercise. Indicators[17] need to be meaningful, measurable and mutually exclusive and need to have intuitive thresholds (see discussion on scores and weights in Step 5). Indicators that can be operationalised with data from official sources, collected using a published methodology and regularly updated should be preferred. The latter helps to update the risk assessment when updates for the data become available. The indicators should be as locally measurable as possible (Box 5). For instance, production output in a subregion is a better measure of the subregion's economic capacity than gross domestic product (GDP) at the country level.

Box 5 Development of indicators – the water desalination in Canary Islands case study

The **hazard** consists of reduction in rainfall because of climate change, as groundwater reservoirs are not recharged by precipitation to the extent needed to cover demand. The Standardised Precipitation Evapotranspiration Index (SPEI) is an indicator widely used in climate sciences to describe critical levels of rainfall pattern changes. SPEI values between –1 and 1 are considered near normal for a given area. Values below –1 signify drought, and values above 1 signify unusually moist conditions (US EPA, 2023).

[17] *Indicators need to fit into a specific, measurable, achievable, realistic and timely (SMART) criterion (McCarthy et al., 2012; Seyisi et al., 2023).*

The Canary Islands are in a geographical zone highly vulnerable to climate change, with a noticeable shift to drier conditions expected under a low-emissions pathway. The risk is analysed under two different IPCC scenarios. The first scenario is Representative Concentration Pathway (RCP)2.6, which represents a low greenhouse gas emissions (stringent) scenario to limit global mean temperature increase to below 2°C by 2100 compared to the preindustrial period (*i.e.* 1850-1900). The other scenario is RCP8.5, which is a high greenhouse gas emissions pathway due to an absence of policies to combat climate change, with a global mean temperature increase likely reaching beyond 3°C by 2100 relative to 1850-1900 (IPCC, 2019).

Gran Canaria, Fuerteventura and parts of Tenerife are expected to face moderate to extreme dryness under RCP2.6. For the archipelago, "extreme dry" thresholds are projected to be surpassed by the mid-century under RCP8.5. This case study examines the SPEI as a key indicator of rising water demand for residents, tourists and agricultural activities on the islands under the RCPs. To calculate the extra energy required to meet this additional water demand, the use of energy-intensive desalination processes using seawater as the source is assumed.

HAZARD

- Rainfall

Quantifiable indicators →

- Standardised Precipitation Evapotranspiration Index (SPEI)

Exposure can be characterised by the number of people living on the island and by the pressure on desalination from the share of desalinated water versus fresh water. Moreover, since the Canary Islands are a highly frequented tourist spot, seasonality plays a role in determining exposure to the hazard. Hence, the sub-indicators are number of residents; number of tourists; and minimum, maximum and average tourist flows. Data on water demand from tourists and residents are often not available. Yet the hourly demand profile, the amounts and the seasonal distribution vary a lot. As a proxy, data on tourists' arrivals and stays can be obtained, as can typical water demand profiles in tourist accommodations, such as hotels or apartments. Data on resident populations are readily available via the Eurostat database; the water use profile for residents can be obtained from the local utility.

EXPOSURE

- People affected
- Needs for desalinated water

Quantifiable indicators →

- Resident population
- Numbers of tourists
- Tourism seasonality
- Percentage of desalinated water in total water demand

The **vulnerability** can be characterised by the difference in energy demand attributable to the hazard, given the exposure. In this case study, it can be characterised by the overall match between supply and demand in the energy system and the system's readiness to cope with demand surges, be it with backup capacity or a shift in energy use, for instance with a demand-side management system in place. Economic activity that depends on water and the economic capacity to pay for additional energy are both used as indicators for adaptive capacity.

VULNERABILITY

- Energy supply and demand
- Economic activity
- Ability to pay for additional needs

Quantifiable indicators →

- Energy intensity
- Per capita energy demand
- Purchasing power for increased consumption (available income)

STEP 4: Introduce thresholds and normalise the indicators

For the exposure and vulnerability dimensions, common practice is to calculate the respective indicators based on current data. Hence, the risk index should answer the question: How large will the risk be, if an increasing climate hazard meets today's society, infrastructure and economies? In the Canary Island case study, the exposure dimension can be based on several indicators:

- **Resident population:** Population is measured in terms of population density, because this measure facilitates comparison among regions.

- **Number of tourists:** Since the pressure on energy supply and water supply on the Canaries is highly correlated with tourist numbers, particularly in relation to resident population numbers, the tourism intensity indicator is used (Manera and Valle, 2018) (SOCLIMPACT, 2020a).

- **Tourism seasonality:** This indicator is a measure of monthly variability in the number of tourists compared to the monthly average over the year.

- **Percentage of desalinated water in total water demand:** This ratio has increased over previous years in the Canary Islands. For example, in Gran Canaria it increased from 20% in 1990 to over 50% in 2019; the total water consumed in Lanzarote and Fuerteventura is now desalinated (Rosales-Asensio *et al.*, 2020; SOCLIMPACT, 2020a). The average percentage of desalinated water in the total water supplied to all seven Canary Islands is around 40% according to the Canary Water Center Foundation database (Rosales-Asensio *et al.*, 2020).

There are several indicators that can be considered under vulnerability within the Canary Islands case study:

- The **energy intensity** indicator is quantified by taking the electricity consumption per unit of GDP as a measure of the economy's electricity efficiency. The minimum-maximum approach, using 10th and 90th percentiles among EU countries,[18] has been used to normalise this indicator.[19]

- Data for **per capita electricity demand** also come from the energy intensity sources and are normalised using the same approach. The calculation involved dividing the total electricity consumption by the population, with the score derived from the 2000-2018 average per capita electricity demand. To illustrate the effects of renewable energy in desalination, risk mitigation and adaptation, this indicator is replaced by the emissions of electricity generation, and a similar procedure is employed. The archipelago does not have a connected energy system; each island – except for Fuerteventura and Lanzarote – provides its own electricity generation.

- The **purchasing power for increased energy consumption** is the indicator for the capacity needed to fulfil consumption needs, calculated by dividing the GDP by the population.

To include multiple indicators of the different dimensions (hazard, vulnerability and exposure) in the risk index, they need to be normalised and weighted. To normalise the indicators, a threshold is often applied (Box 6). Normalisation is based on minimum-maximum considerations. All values are normalised to the maximum value in the data set.

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[18] *The approach compares EU values using the 10th and 90th percentiles among EU countries as reference points. Percentiles are chosen over direct minimum and maximum values to minimise the effect of outliers.*

[19] *Normalisation brings indicators onto a common scale, which renders the variables comparable (to avoid comparing apples to pears).*

Box 6 Introduction of thresholds and normalisation of the indicators – the water desalination in Canary Islands case study

All the indicators are measured using different units. To have a comparable assessment of risks under different scenarios, it is important to bring all indicators to a common unit. The risk index is measured as a dimensionless metric, with values between 0 and 1 indicating risk levels from very low to extremely high. Step 4 aims to introduce thresholds to each indicator and normalise them.

EXPOSURE

- **Resident population:** A score of 0 is the minimum threshold, corresponding to 0 persons per square kilometre (km^2) (no inhabitants in the island); since the Canaries are EU islands, the highest population density in the EU serves as upper threshold, which corresponds to a score of 1 for normalisation. The maximum density in the EU was Malta (around 1 372.76 persons/km^2 over 2007-2018). Based on Canary Statistical Institute data, the score for population density for the Canary Islands is estimated to be 0.39.

- **Number of tourists:** The maximum recorded ratio of tourists per resident across the EU in 2014 was 4.42. This value serves as the maximum threshold for normalisation, corresponding to a score of 1. The minimum threshold, corresponding to a score of 0, is set at a value of 0 tourists per resident. Based on annual numbers of tourists from local statistical sources, the score for tourism intensity is estimated at 0.95.

- **Tourism seasonality:** The indicator shows high values when the peak monthly count exceeds the average monthly number (upper threshold of 1).[20] It is 0 when the monthly maximum and the average monthly tourist numbers are equal, indicating no seasonality.

- **Percentage of desalinated water in total water demand:** The normalisation results in a score of 1 for 100% desalinated water; a score of 0 indicates 0% desalinated water.

VULNERABILITY

- **Energy intensity:** The approach is to scale the energy intensity based on EU values, using the 10th and 90th percentiles among EU countries as benchmarks. A score of 0 corresponds to the 10th percentile of energy intensity; a score of 1 relates to the 90th percentile of energy intensity.

- **Per capita electricity demand:** With the current production technologies, high average CO_2 emission coefficients of 0.777 kilogrammes of CO_2 per kilowatt-hour can still currently be assumed (Diaz Perez *et al.*, 2018). Member State-specific emission factors are employed to compare the Canaries' per capita emissions and to provide the upper and lower thresholds.

- **Purchasing power for increased energy consumption:** The minimum-maximum approach is applied to the 2000-2018 average of this value to even out financial crisis effects and other business cycle effects, again using the 10th and 90th percentiles among EU countries. Here, a higher per capita GDP indicates a greater capacity to cover consumption needs. Therefore, the best score (0) is assigned to the 90th percentile of per capita GDP, and the worst score (1) is assigned to the 10th percentile.

[20] *If the maximum monthly value exceeds more than twofold the monthly average, it is capped at 1.*

Table 1 shows the results for vulnerability and exposure. If all indicators are viewed with equal weighting, population (residents) carries the highest risk, which means people would stop living on the islands and tourism would falter. This would obviously impact the GDP (or the GDP per capita), which is the second highest risk factor. However, this is just for a one-dimensional analysis; for a holistic view, weighting and overall risk must be established (see Step 5).

Table 1 Normalised indicator scores by element of the impact chain for the exposure and vulnerability dimensions

EXPOSURE				VULNERABILITY		
Resident population	Number of tourists	Tourism seasonality	Percentage of desalinated water in total water demand	Energy intensity	Per capita electricity demand	Purchasing power for increased energy consumption
0.39	0.95	0.13	0.40	0.20	0.19	0.66

Source: (SOCLIMPACT, 2020a).

In the case of **hazards** only, maximum future values are typically used. These values can be obtained from climate change simulations. Databases for climate change indicators in high geographical resolution can be found, for instance the CORDEX database. In the Canary Island case study, the hazard dimension can refer to the **SPEI indicator**, which is a representative indicator for rising water demand among residents and economic activities on the islands under the RCPs. Accordingly, the increase in energy demand (gigawatt-hours (GWh) per year) due to the increase in water demand is estimated, and most of the islands are assumed to have to produce desalinated seawater to meet further increases in demand under the different RCPs (REIS, n.d.). Table 2 shows the estimated additional energy demand (GWh/year) needed for increased drinking water production, based on the energy needed for seawater desalination under RCP2.6 and RCP8.5. To scale the hazard dimension, the energy required for desalination is used, and this is expected to rise by 56% and 84% compared to the present time under RCP2.6 and RCP8.5, respectively, by 2046-2065. Thus, the score would be 0.56 and 0.84 under RCP2.6 and RCP8.5, respectively.

Table 2 Energy required to desalinate seawater under different climate scenarios

Scenario	Energy consumption required to desalinate seawater (GWh/year)
Present time	1 121.4
RCP2.6: 2046-2065 LOW-EMISSION SCENARIO	1 749.4
RCP8.5: 2046-2065 HIGH-EMISSION SCENARIO	2 063.4

Source: (SOCLIMPACT, 2020b, 2020c).

$$\text{score}_{\text{SPEI}}^{\text{RCPi}} = (\text{energy cons}_{\text{RCP}_i} / \text{energy cons}_{\text{present time}}) - 1$$

If future values of exposure and vulnerability will be used, they will need to be based on simulations and modelling results. For instance, population projections can be used, as can projections of tourist numbers. Such projections are often published by the respective statistical offices. However, they will often be projected over a shorter time span than recommended for climate change risk assessment. One solution would be to calculate the risk from a future hazard to a population development in the not-so-distant future and the risk today, to get an idea of how the risk will increase under increasing factors of exposure and vulnerability.

STEP 5: Present results

The last step is to determine weights and the risk score. The three elements of the risk index need to be given weights in the final indicator. The weights can be determined based on time series correlations between the risk and the elements of the risk indicator in the past. *The Vulnerability Sourcebook* suggests a number of methods for how to either calculate the weights from statistics or derive them from expert discussions (GIZ *et al.*, 2014).[21] For the latter, the Sourcebook suggests participatory methods.[22]

The Organisation for Economic Co-operation and Development has published a handbook on composite indicators, containing a number of suggestions on how to build, normalise and impute data to create meaningful weights and on other aspects of indicator building (OECD *et al.*, 2008). Factor analysis or data envelopment analysis are among the suggested statistical methods, while the budget allocation approach features among the expert and stakeholder knowledge-based approaches.

Step 4 brought all indicators to a dimensionless unit that falls between 0 and 1. The next step is to bring them together to create a final score, which would enable the level of risk to be assessed under a common framework. Several methods can be used to bring them together. One straightforward method is to average their scores. While this simplifies the process, not all indicators carry an equal amount of risk. Some indicators pose greater risk than others. Therefore, it is essential to assign different weights to each indicator and factor these into the final score calculation.

There are several ways of assigning weight to the indicators. Participatory approaches involve stakeholders directly, ensuring their preferences and values are reflected. Multicriteria decision analysis methods provide structured frameworks for evaluating and prioritising criteria based on their relative importance.

The Canary Islands case study adopts the methodology followed in the SOCLIMPACT studies (SOCLIMPACT, 2020a) to estimate how important different dimensions are. Dimensions include exposure (how much something is affected), vulnerability (how easily it can be harmed), and hazard (the danger it faces). Some of the steps are:

1. Calculating the linear correlation coefficients between the indicators and the risk: A relationship is identified between each explanatory variable (indicators from each dimension of the impact chain: hazard, exposure and vulnerability) and the objective variable (the response analysed, for example the energy demand of desalination) using a linear correlation method. Figure 5 shows the linear correlation coefficients obtained based on the time series data.

2. Weighting the risk dimensions: The weighting is obtained by averaging the absolute linear correlation coefficients of all indicators in each dimension. This gives an idea of how important each dimension is in contributing to the overall risk.

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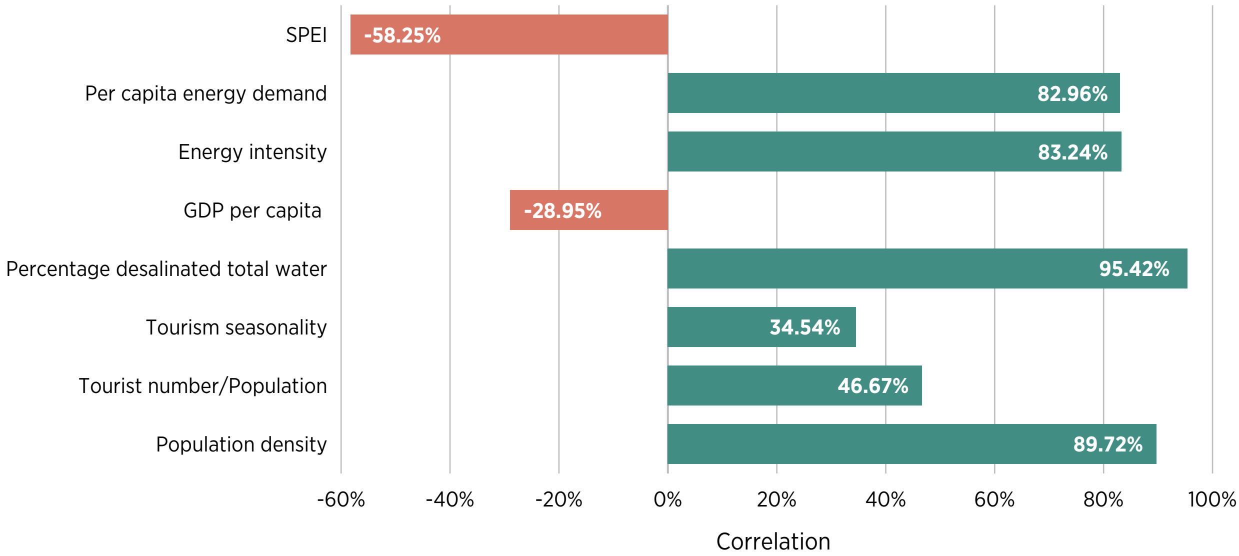
21 *Any experts should ideally have direct experience within the contexts and speak from lived experience, and communities should be actively involved in these participatory approaches.*

22 *One method for assigning different weights using a participatory approach is the budget allocation approach. Here, workshop participants are issued with a budget made up of a certain number of "coins". Each participant can spend their coins on those indicators the participant considers (more) important. This approach works best with a relatively small number of indicators (< 12) to ensure that participants are not overwhelmed with "budgeting" decisions, which can have a negative impact on results. If participants are uncomfortable with the idea of "play money", paper-based approaches can also be used to assign weighting. For instance, stakeholders can be asked to rank different indicators in a questionnaire (GIZ et al., 2014).*

Figure 5 Correlation between different indicators and energy demand of desalination.



Source: (SOCLIMPACT, 2020a).

Table 3 shows the implementation of the process and the computed weight. This method is objective because it relies on real data and uses a straightforward statistical process. However, the disadvantage of this method is that it can miss some risks, especially those related to climate change that were not noticeable ten years ago. This is reflected in the weight for the hazard (Column F).

Table 3 Calculation of weights

COLUMN A Objective	**COLUMN B** Element of the impact chain	**COLUMN C** Explanatory	**COLUMN D** Correlation	**COLUMN E** Average absolute values	**COLUMN F** Rescaled to 1: Final weight
THE RISK CHOSEN TO ESTABLISH THE RELATIONSHIP	**Different dimensions**	**Indicators within each dimension**	**Established from time series data with the risk**	**This step averages the values in column D**	**Values of Column E rescaled in such a way that the total is 1**
ENERGY DEMAND OF DESALINATION	**EXPOSURE**	Resident population	89.72%	0.67	0.35
		Number of tourists	46.67%		
		Tourism seasonality	34.54%		
		Percentage of desalinated water in total water demand	95.42%		
	VULNERABILITY	Purchasing power for increased energy consumption	−28.95%	0.65	0.34
		Energy intensity	83.24%		
		Per capita electricity demand	82.96%		
	HAZARD	SPEI	−58.25%	0.58	0.31

The risk score can be calculated based on the approach shown in Table 4 below. The risk index is measured as a dimensionless metric, with scaled values between 0 and 1 indicating risk levels from very low to extremely high. The risk is considered as very low from 0 to 0.2; it becomes low or medium when its value falls between 0.2 and 0.4 or between 0.4 and 0.6, respectively. The danger is regarded to be high above 0.6 (extremely high if over 0.8). As can be seen in Table 4, the hazard will change[23] due to climate change because of the direct relationship between climate and rainfall pattern. The higher the emission level and the greater the change in climate, the higher the hazard, and vice versa. The socio-economic indicators for exposure and vulnerability, however, will stay the same – this is because the data and estimates of risk are computed using the data available now. Other perspectives of this analysis, in particular, would be to estimate the long-term effects on those dimensions (exposure and vulnerability) using macro-econometric models, which could identify the evolutive socio-economic effects of adaptation measures.

Table 4 Risk index under different climate scenarios

	AVERAGE SCORE PER BLOCK (equal-weight average of all indicator scores in the block)	**RISK SCORE** (with weights from Table 3)
PRESENT CLIMATE		
HAZARD (SPEI)	0.00	0.29
EXPOSURE	0.48	
VULNERABILITY	0.35	
MID-CENTURY CLIMATE – RCP2.6		
HAZARD (SPEI)	0.56	0.46
EXPOSURE	0.48	
VULNERABILITY	0.35	
MID-CENTURY CLIMATE – RCP8.5		
HAZARD (SPEI)	0.84	0.55
EXPOSURE	0.48	
VULNERABILITY	0.35	

[23] *The development of the hazard is based on simulation results under the CORDEX framework of climate modelling.*

Table 4 provides a detailed assessment of risk scores for the Canary Islands under three different climate change scenarios: present climate and mid-century climate (2046-2065) under RCP2.6 and RCP8.5. The risk increases from low to intermediate. The risk score rises to 0.46 as more energy is needed for desalination and the hazard of arid conditions increases in a mid-century RCP2.6 scenario. The RCP8.5 scenario, with a worsened hazard, results in the highest risk score of 0.55. This analysis highlights the growing risks linked to higher emissions, as well as the importance of effective adaptation responses that align with such escalating impacts.

In the Canary Islands case study, desalination is used to demonstrate how the hazard, vulnerability and exposure framework can be applied to assess climate risk in relation to this crucial technology. This will give a concrete example of how IRENA may strengthen the resilience of renewable energy systems by using specific adaptation strategies and metrics.

The ultimate objective of the report is to demonstrate the role that renewables can play in climate adaptation and to assess if they can lower the risk level in a particular setting (Box 7). This sensitivity analysis aims to assess risk score when the energy demand is met by renewables. Energy in the Canary Islands is mostly produced by oil through thermoelectric power plants. The use of renewables will be integrated into the impact chain approach, thanks to the flexibility of the methodology allowing such integration.

Box 7 Mitigation of the risk through more renewables in desalination

Electricity for desalination on the Canaries is mainly taken from the grid, and electricity production on the Canaries is mainly based on diesel fuels. Less than 10% of electricity generation is based on renewable energy (Jaime Sadhwani and Sagaseta de Ilurdoz, 2019). Hence, increasing demand for desalinated water will increase not only energy demand but also greenhouse gas emissions. However, on Gran Canaria, research and pilot projects have proven the feasibility of generating fresh water through desalination using renewable energy sources. The Canary Islands Institute of Technology has developed and tested various prototypes which demonstrate that reverse osmosis desalination technologies can be powered by renewable energy (Sustainable Water & Energy Solutions Network, 2020). Additionally, intermittent energy supply can be backed up with hydropower storage. The Canary Islands Institute of Technology, a public enterprise established by the Government of the Canary Islands in 1992, has worked on off-grid small-scale and larger-scale renewable energy-driven desalination systems since 1996.

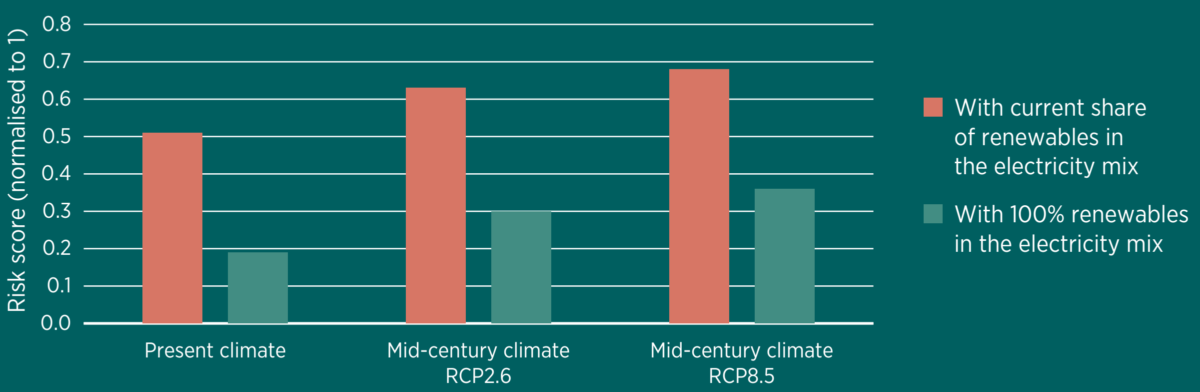
Hence, a new indicator is introduced in the risk assessment to incorporate the share of renewable energy in the electricity generation mix used for desalination. To achieve effective risk mitigation, the indicator should depict what percentage of non-renewable energy is being used in desalination. The more the energy mix becomes renewable, the less it will depend on non-renewable sources, lowering the risk of greenhouse gas emissions and avoiding maladaptive pathways. The weight of this indicator is 1 (before normalisation of weights), because it is 100% correlated with the greenhouse gas emissions from desalination. Around 5.6% of electricity production in the Canary Islands is produced by renewable energy sources (Leon *et al.*, 2021). Table 5 and Figure 6 show how the inclusion of the renewables in the electricity mix in the Canary Islands impact the risk index under different climate scenarios. The values of the risk index are between 0 and 1, indicating risk levels from very low to extremely high. The risk is considered very low from 0 to 0.2; it becomes low and medium when its value falls between 0.2 and 0.4 or between 0.4 and 0.6, respectively. The danger is regarded to be high above 0.6 (extremely high if over 0.8).

Table 5 Inclusion of the renewables' effects in the risk index under different climate scenarios

		AVERAGE SCORE PER BLOCK (equal-weight average of all indicator scores in the block)	**RISK SCORE** (incorporating the weight of current share of renewables in the electricity mix)*	**RISK SCORE** (incorporating the weight of 100% renewables in the electricity mix)
Present climate	**Hazard (SPEI)**	0.00	0.51	0.19
	Exposure	0.48		
	Vulnerability	0.35		
Mid-century climate – RCP2.6	**Hazard (SPEI)**	0.56	0.63	0.30
	Exposure	0.48		
	Vulnerability	0.35		
Mid-century climate – RCP8.5	**Hazard (SPEI)**	0.84	0.68	0.36
	Exposure	0.48		
	Vulnerability	0.35		

Note: * The current share of renewables in the electricity mix is 5.6% (Leon *et al.*, 2021).

Figure 6 Risk score incorporating the weights of the current share of renewables and 100% renewables in the electricity mix in the Canary Islands under different climate scenarios



This sensitivity analysis shows two key findings. First, including renewables in the energy mix lowers the risk in all cases. The risk of having more emissions from additional energy demand under the energy mix as of today (5.6% share of renewables (Leon *et al.*, 2021)) is higher, as is reflected in the higher values of the risk index than in Table 4. Second, carrying out desalination solely using renewable energy decreases the risk by around half to two-thirds, depending on the scenario.

The suggested risk assessment method can be easily adapted to reflect renewable energy benefits in adaptation. The method allows for the inclusion of quantitative methods, expert assessment and participatory methods to quantify the risk. One of the benefits in terms of process is the high level of stakeholder involvement.

3. CONCLUSIONS

The intersection of renewable energy and climate change adaptation presents a critical opportunity to address the dual challenges of mitigating climate impacts and supporting sustainable development. Promoting renewable energy as a strategy for adaptation requires increasing visibility of its benefits, including reduced greenhouse gas emissions, improved energy security, enhanced socio-economic outcomes, and greater resilience to climate impacts. Renewable energy-based adaptation solutions are crucial, as they have shown significant potential in addressing various climate-induced risks. For example, solar photovoltaic systems can support agricultural irrigation in drought-prone areas, enhancing water security and crop yields, among other factors such as access to seeds (drought-resistant type) and access to extension services. Wind energy can power desalination processes in water-scarce regions, providing fresh water without increasing greenhouse gas emissions.

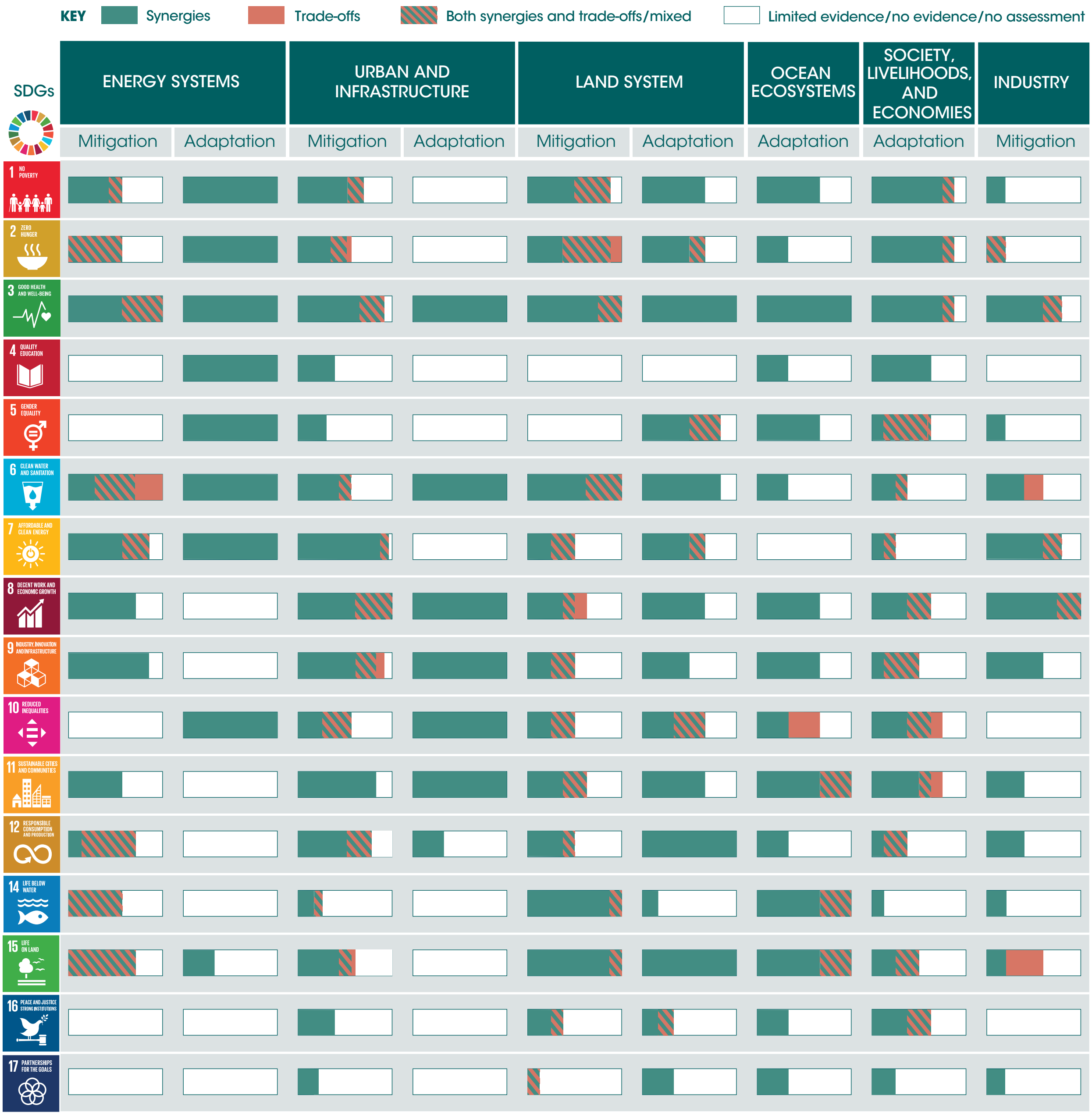
Developing adaptation measures involves three steps: identifying and quantifying the need for adaptation (phase 1), formulating relevant policies (phase 2), and implementing those policies (phase 3). This report focuses on phase 1, presenting a methodology for potential indicators and metrics to easily assess the benefits of renewable energy as a risk mitigator in adaptation. The previous sections introduced a risk index and demonstrated how renewable energy use in adaptation reduces risks. The methodology builds on existing works on risk (*e.g.* IPCC reports) and on impact chain analysis (*e.g. The Vulnerability Sourcebook*) and applies these frameworks to renewable energy. The proposed risk assessment method can be easily adapted to incorporate the benefits of renewable energy in adaptation. This method allows for the use of quantitative techniques, expert assessments and participatory approaches to quantify risk. One of the key advantages is the high level of stakeholder involvement throughout the process. As indicators are identified and methods for quantitative or qualitative risk measurement are developed, the adaptation gap and challenges become more clearly defined and communicable.

The scope of this report could be expanded by introducing a synergistic metric that would encompass the broader impacts of renewable energy on adaptation. This report acts as a foundation for more technical manuals, presenting measuring concepts in a step-by-step approach. Developing a synergistic metric that encompasses adaptation, mitigation and sustainable development benefits is a step forward in quantifying the comprehensive impacts of renewable energy-based adaptation initiatives. The Sixth Assessment Report also examined the potential synergies and trade-offs between various climate change mitigation and adaptation options and the Sustainable Development Goals (Figure 7) (Echeverri *et al.*, 2024). Such metrics could be essential for tracking progress, informing policy and securing funding from multilateral organisations. Demonstrating the tangible benefits of renewable energy-based adaptation measures strengthens and solidifies the case for increased investment and support.

The other challenge to the extensive use of renewable energy in the context of adaptation is, still, access to finance. Future studies should give priority to improving the methodologies and metrics to assess the effects of renewable energies on adaptation. It is essential to broaden the scope of pilot projects and case studies to encompass a wider range of geographical locations (*e.g.* Francophone African countries), sectors (*e.g.* agriculture), technologies (*e.g.* hydropower) and situations. This will provide useful information on the different ways in which renewable energies can be applied for adaptation purposes.

Integrating renewable energy into climate change adaptation represents a transformative approach to addressing climate risks. Robust risk assessments, innovative adaptation solutions and comprehensive synergistic metrics harness renewable energy’s potential to enhance resilience and achieve sustainable development. The insights and methodologies presented offer a roadmap for advancing climate adaptation efforts. Another approach could be to expand and deepen the methodology adopted in this report to examine how long-term impacts affect key risk dimensions, such as exposure and vulnerability, through macro-econometric models. Such models provide critical insights when considering the socio-economic impacts of adaptation measures taken over time. The model could cover the links between the economy, the energy sector and emissions and thus help in identifying sustainable policies. Such a comprehensive framework will also have great potential to foster inter-ministerial co-operation and discourse through the exchange of relevant policy issues, key assumptions and model results. In addition, embedding these projections in the regional or sector data would allow the models to show a much more detailed picture of the cumulative impacts on social and economic resilience and on the sustainability and equity of adaptation strategies.

Figure 7 Potential synergies and trade-offs between various climate change mitigation and adaptation options and the Sustainable Development Goals (SDGs)



Source: (Echeverri *et al.*, 2024).

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ANNEX 1: PROMOTION OF ADAPTATION AND ITS JOURNEY IN THE INTERNATIONAL SETTING

The journey of global climate adaptation frameworks began with the establishment of the United Nations Framework Convention on Climate Change (UNFCCC) at the Earth Summit in Rio de Janeiro in 1992, becoming effective in 1994 (UNFCCC, 2024c). This foundational moment was pivotal, formally recognising the need to adapt to the impacts of climate change. The Convention acknowledges the vulnerability of all countries to the effects of climate change and calls for special efforts to ease the consequences, especially in developing countries, which lack the resources to do so on their own. In the early years of the Convention, adaptation received less focus than mitigation, as Parties sought greater certainty regarding the impacts and vulnerabilities associated with climate change. When the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report was released, adaptation gained traction, and Parties agreed on a process to address adverse effects and to establish funding arrangements for adaptation (IPCC, 2001). Currently, work on adaptation takes place under different Convention bodies. The Adaptation Committee, which Parties agreed to set up under the Cancun Adaptation Framework as part of the Cancun Agreements, is a major step towards a cohesive, Convention-based approach to adaptation (UNFCCC, 2024a).

The Third Assessment Report of the IPCC in 2001 further underscored this necessity, highlighting how climate change was already affecting natural and human systems worldwide. This report catalysed the development of new planning and funding mechanisms, such as the Least Developed Countries Expert Group, established in 2001 to aid least developed countries in developing and implementing national adaptation programmes of action (NAPAs[24]). These programmes enabled least developed countries to identify urgent adaptation needs (via their NAPAs, providing a list of discrete projects) and secure funding through the Global Environment Facility's Least Developed Countries Fund.

In parallel, 1997 saw the adoption of the Kyoto Protocol (effective since 2005 (UNFCCC, 2024d)), and in 2010 the Adaptation Fund was introduced to support concrete adaptation projects in vulnerable developing countries (UNFCCC, 2024e). The Adaptation Fund became operational in the same year, accrediting its first implementing entities – the Centre de Suivi Ecologique in Senegal, the United Nations Development Programme, and the World Bank – and approving its first two projects for USD 14 million (Adaptation Fund, n.d.).

The year 2010 also marked the establishment of the Cancun Adaptation Framework, with the aim of enhancing international co-operation and support for adaptation in developing countries and establishing an Adaptation Committee to oversee it (UNFCCC, 2024a). Additionally, the Cancun Adaptation Framework initiated the national adaptation plans (NAPs), a more inclusive process than the NAPAs, allowing all developing countries to articulate long-term adaptation needs, not just least developed countries (McGray, 2014). UNFCCC came up with the concept of the NAP to catalyse adaptation measures and strategies and initiate action now to address the impacts of anticipated climate change. Hence, the objective of the NAP is to act today to reduce the potential adverse consequences of anticipated climate change. To develop meaningful NAPs, it is fundamental

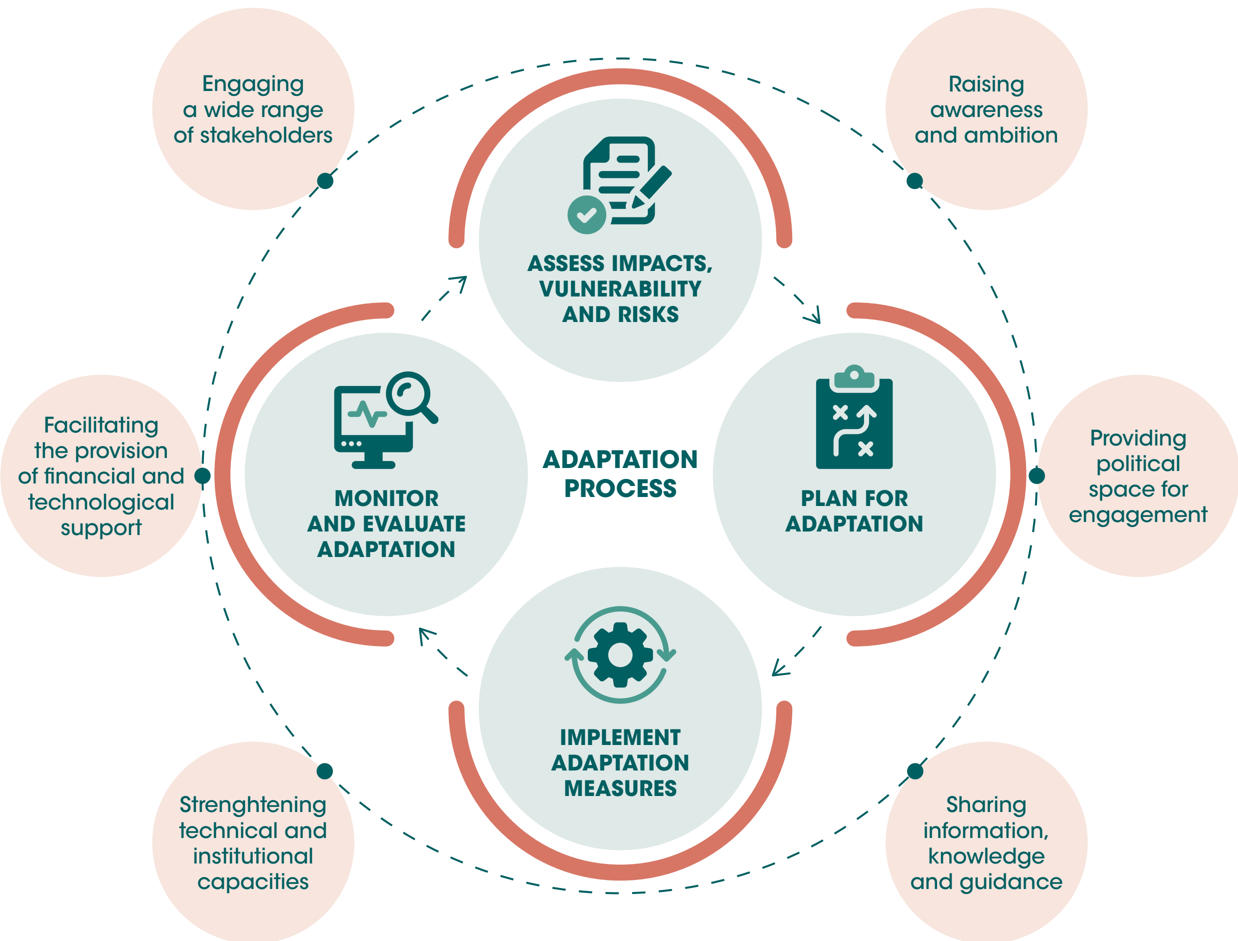
[24] *NAPAs are aiming to respond to current impacts of climate variabilities and changes. Examples would be building new water supply systems when drought occurs.*

to understand the anticipated climate and its impacts over medium- to long-term horizons. This is where risk assessment along all risk dimensions comes into play.

The landmark Paris Agreement on climate change in 2015 further solidified a global commitment to adaptation, introducing a global adaptation goal at COP21 (the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change) to improve adaptive capacities, build resilience and reduce vulnerability to climate change, aligning these efforts with the Sustainable Development Goals. This adaptation goal, supported by the Global Stocktake, aims to evaluate progress and drive continual improvement in adaptation efforts globally (UNFCCC, 2024f). Integral to this agreement are countries' nationally determined contributions (NDCs), which encapsulate self-reported adaptation strategies and targets that undergo periodic reviews to track progress and improve adaptation efforts. By early 2023, 81% of the Parties had included adaptation components in their NDCs, reflecting a trend towards more detailed and quantitative adaptation commitments (UNFCCC, 2023). For example, Uganda in its NDC aims to significantly increase sustainable land management practices and reduce the share of post-harvest losses by 2030, showcasing how these strategies are robustly integrated into national development agendas (Ministry of Water and Environment Republic of Uganda, 2022).

UNFCCC suggests use of the adaptation policy cycle, as depicted in Figure 8, starting with an assessment to raise awareness and ambition of climate adaptation measures, followed by the development of the NAP, which will be implemented, monitored and eventually reassessed. Stakeholder engagement is essential alongside this process, particularly because climate change damage, and hence climate adaptation, has a more regional or local nature than mitigation efforts and emissions reduction.

Figure 8 Adaptation policy cycle and support offered under the UNFCCC



Source: (UNFCCC, n.d.)

ANNEX 2: RENEWABLE ENERGY AT THE CORE OF THE CLIMATE CHANGE ADAPTATION STRATEGY

In 2021, IRENA laid out the relationship between renewable energy and climate adaptation, highlighting the ways in which renewable energy can provide dual adaptation pathways while also contributing to mitigation and enhancing efforts across other sectors (IRENA, 2021). Energy is central in allowing societies to build climate resilience and pursue inextricably linked climate adaptation measures. Higher temperatures lead to higher energy demand, in particular for cooling (Climate Central, 2023; Scoccimarro *et al.*, 2023) and other power-intensive adaptation operations like seawater desalination or irrigation. Based on International Energy Agency projections, a 1°C rise in global temperature from 2016 levels would increase cooling degree-days by around 25% (IEA, 2018).

Energy services can reduce vulnerability to climate hazards while increasing resilience for populations that already suffer the most from natural disasters as well providing the critical-level lighting, cooling and/or heating essential both for day-to-day living in developing countries and for supporting economic activities over time. This report focuses on energy-related impacts and gives examples to illustrate the potential of renewable energy in adaptation. The basic categories of the use of renewable energy in climate change adaptation are to address changes in energy demand and supply and to increase overall resilience by supporting livelihoods, energy access and productive uses (IRENA, 2021). On the demand side, renewable energy supports measures to deal with droughts, gradual temperature increase or heatwaves. On the supply side, the distributed nature of renewable energy increases resilience by providing backup, off-grid and individual solutions, which can be designed to standalone in case of damage or disaster affecting the main grid.

Paradoxically, some adaptation measures – such as air conditioning, desalination and the expanded use of irrigation systems – often have large emissions and can thus contribute to worsening climate change. But renewable energy provides a way forward, offering the ultimate sustainable win-win solution for combatting climate change while also aiding adaptation. Renewable energy technologies help reduce environmental effects and enhance resilience by integrating sustainable practices that address the long-term impacts of climate change. Sustainable hydropower approaches, for instance, lead to protection of the environment while also attracting economic development. The integrated nature of this approach not only supports adaptation but also creates novel investment opportunities through harnessing climate and carbon finance. This annex elaborates a few specific renewable energy-based adaptation solutions to face key climate hazards: high temperature, low precipitation, high precipitation, extreme wind, and sea-level rise.

With **higher temperatures**, energy demand for cooling and refrigeration systems at agricultural, industrial and household levels is expected to increase. Refrigeration and cooling are required for agricultural produce to minimise losses (*e.g.* in the fisheries sector). During heatwaves, air conditioning is a quick and effective solution to keeping indoor urban environments at optimal temperatures. Solar-assisted air conditioners (a promising technology) and renewable energy systems can support adaptation to rising temperature by providing clean and renewable electricity generation to operate cooling and refrigeration systems. Virtually any renewable technology for electricity generation can be used to power cooling systems, either by connecting the renewable energy system to the grid or by installing off-grid solutions like solar panels. Shading is also a very effective means to maintain thermal comfort in both outdoor and indoor environments (Lee *et al.*, 2018). For instance, the smart solar blinds currently in production can provide constant shading for cooling to decrease the need for indoor air conditioning, while at the same time tracking the sun movement to generate electricity (SolarGaps, 2018). Shading is a valid solution for cooling outdoor space as well. Infrastructural parts of renewable energy systems, such as solar photovoltaic panels, can strategically overhang from buildings to shade outdoor areas during the day, so that the produced electricity can be conveyed for other uses.

Lower precipitation levels are likely to translate to an increase in water scarcity due to prolonged droughts. One strategy for renewable energy-based climate change adaptation, in this case, involves the use of renewable electricity to power freshwater harvesting processes. Solar photovoltaic panels, for instance, can be coupled with groundwater pumping machines for irrigation in the agriculture sector (Frisvold and Marquez, 2013). Solar-powered desalination technologies are perceived to be promising to be developed in arid and sunny regions (Goosen *et al.*, 2003; Reif and Alhalabi, 2015). Other types of renewable energy technologies for water desalination, such as wind turbines and ocean-energy plants, can be deployed in coastal regions; Li *et al.*, 2018). The response to climate-induced water scarcity will need to also incorporate measures to reduce water consumption in energy production, thus eliminating the water trade-off between energy and agriculture. Wind and solar photovoltaic, for instance, are the two energy technologies with the lowest freshwater consumption per generated power-unit of all renewable and conventional sources and technologies (Closas & Rap, 2017; Spang *et al.*, 2014). These low water requirements for operation could justify the higher expenses for the installation of these technologies, as energy generation cost-benefit analyses should consider the increasing difficulties in producing electricity while consuming large amounts of fresh water.

With regard to **high precipitation**, renewable energy-based adaptation solutions in electricity focus on resilience-building against floods to mitigate their direct and indirect effects. Renewable energy technologies could be used to operate the power-requiring processes that allow for adaptation against floods. Renewable energy backup systems could be used to operate water pumps when flooding risk increases. Off-grid and mobile technologies, such as foldable solar panels, are particularly useful if conventional electricity provision is interrupted due to damage to transmission lines and generation plants or due to safety-related power cuts. The development and installation of dams and reservoirs in regions with high precipitation during rainy seasons is useful not only for the potential increase in electricity production and energy security but also for flood management where higher flood risk is predicted (Pircher, 1990). Hydropower dams might have an enabling role as a multipurpose reservoir, which could provide added resilience as short- to medium-term storage buffers. Renewable energy technologies other than hydropower can also support adaptation against climate change-induced flooding in ways that go beyond power provision for adaptation mechanisms (Simons, 2013).

Extreme winds often affect electricity generation. Recovery from extreme wind events requires an exceptional amount of energy for powering pumps for flooded homes and water treatment, re-establishing network connectivity, clearing roadways and rebuilding infrastructure. Such electricity could be provided by renewable technologies, especially off-grid and decentralised energy systems. Additionally, micro grids and mobile distributed energy systems are likely to provide a quicker re-establishment of power supply in affected areas, especially remote ones. Quick re-establishment of power supply is critical in the initial recovery stages, when clinics and emergency centres need to be quickly operable (NREL, 2016). At household level, foldable solar panels, for instance, could be retrieved and stored for safety if households are given notice before an extreme wind event, such as storms and hurricanes. Biogas digester bags for electricity generation can also be emptied and stored easily because of their structure. After the extreme event, such off-grid renewable energy systems could be quickly deployed again to provide fast energy restoration to facilitate the recovery efforts. Such systems, by nature, have the unique advantage of not being dependent on the conventional supply chain. As such, their advantages are not shared by portable energy systems based on conventional fuels, such as small diesel generators.

Renewable energy can also be applied to forecasting by powering off-grid meteorological and agricultural stations in rural areas outside the reach of the grid. These off-grid stations can collect data and create more reliable forecasting (Kai *et al.*, 2013). With more reliable forecasting, better preparation could be made. For example, the agricultural sector could better prepare crops against potential wind damage. A better prepared agricultural sector would mean a more robust food system and economy in the face of wind hazards (Kai *et al.*, 2013).

Sea-level rise also poses a major threat to people and economies in low-lying coastal regions, where even small water level increases can have major impacts. The Intergovernmental Panel on Climate Change expects an average global sea-level increase between 50 centimetres (cm) and around 100 cm by the year 2100, equivalent to two to five times the current increase relative to 1900 (IPCC, 2022). The impacts of sea-level rise and the corresponding adaptation needs differ by location, with island communities as well as coastal regions with low-lying topography, dense populations and significant economic activities (*e.g.* Southeast Asia), being particularly vulnerable. Rising sea levels increase the risk of flooding, land loss and population displacement. In Indonesia, 2.8 million people could potentially be displaced if sea levels rise by 1 metre. In Viet Nam's Mekong and Red River deltas, 11% of the inland river population could be exposed to such risks. Saltwater intrusion could disrupt freshwater reservoirs and cause agricultural losses. Renewable-based adaptation solutions, such as portable solar photovoltaic for displaced communities and integration of renewable energy with defensive structures like tidal barrages and sea walls, offer potential strategies for mitigating these impacts. However, both hard-engineering coastal protection measures and tidal and wave energy technologies are currently deemed too costly for widespread deployment. With further research, increased application, and economies of scale in the medium to long term, these costs may decrease, making the technologies more widely applicable.

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