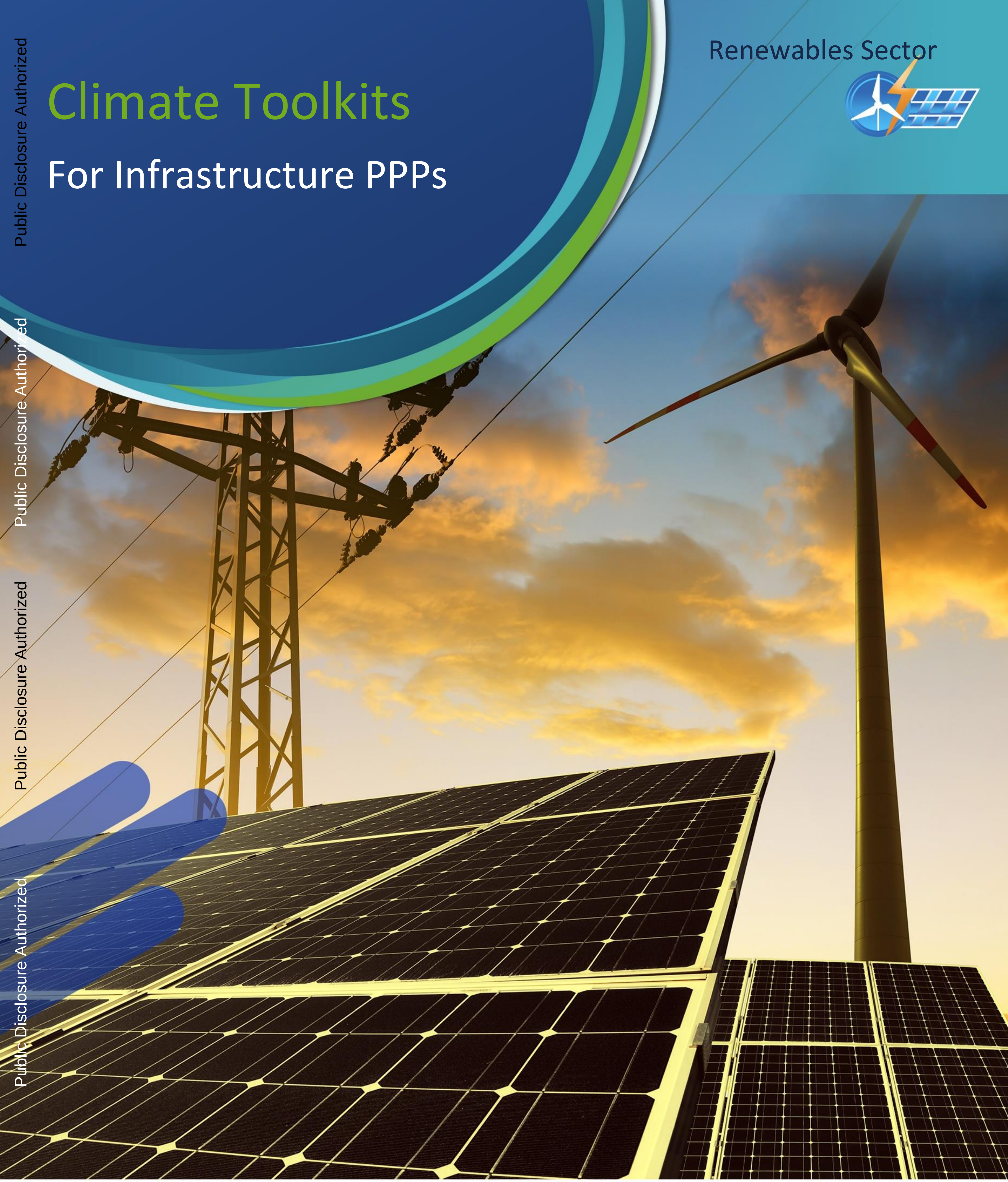
Renewables Sector

Climate Toolkits

For Infrastructure PPPs



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PPIAF Enabling Infrastructure Investment

Global Infrastructure Facility A G20 INITIATIVE

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About PPIAF

PPIAF helps developing-country governments strengthen policy, regulations, and institutions that enable sustainable infrastructure with private-sector participation. As part of these efforts, PPIAF promotes knowledge transfer by capturing lessons while funding research and tools; builds capacity to scale infrastructure delivery; and assists sub-national entities in accessing financing without sovereign guarantees. Donor-supported and housed within the World Bank, PPIAF's work helps generate hundreds of millions of dollars in infrastructure investment. While many initiatives focus on structuring and financing infrastructure projects with private participation, PPIAF sets the stage to make this possible.

About the GIF

The Global Infrastructure Facility, a G20 initiative, has the overarching goals of increasing private investment in sustainable infrastructure across emerging markets and developing economies, and improving services that contribute to poverty reduction and equitable growth aligned with the Sustainable Development Goals (SDGs). The GIF provides funding and hands-on technical support to client governments and multilateral development bank partners to build pipelines of bankable sustainable infrastructure. The GIF enables collective action among a wide range of partners—including donors, development finance institutions, and country governments, together with inputs of private sector investors and financiers—to leverage both resources and knowledge to find solutions to sustainable infrastructure financing challenges.

About CTA

IFC's PPP Transaction Advisory (CTA) advises governments on designing and implementing public-private partnership (PPP) projects that provide or expand much needed access to and/or improved delivery of high-quality infrastructure services—such as power, transportation, health, water and sanitation—to people while being affordable for governments. In doing so, CTA assists on the technical, financial, contractual, and procurement aspects of PPP transactions. To date, CTA has signed over 400 projects in 87 countries, mobilizing over $30 billion of private investment in infrastructure, and demonstrating that well-structured PPPs can produce significant development gains even in challenging environments.

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List of Abbreviations and Acronyms

ADB	Asian Development Bank
AHP	analytical hierarchy process
BE	baseline emissions
BII	Biodiversity Intactness Index
CBA	cost-benefit analysis
CCKP	Climate Change Knowledge Portal
CO_2	carbon dioxide
CO_2-eq	carbon dioxide equivalent
CRA	climate risk and adaptation
CSP	concentrated solar power
CMIP	Coupled Model Intercomparison Project
CTIP3	Climate Toolkits for Infrastructure PPPs
DEA	data envelopment analysis
EIRR	economic internal rate of return
EMDE	emerging market and developing economy
ER	emission reduction
EU	European Union
GFDRR	Global Facility for Disaster Reduction and Recovery
GHG	greenhouse gas
GIS	geographic information system
G-MCDM	grey-based multi-criteria decision-making
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IFC	International Finance Corporation
IPCC	International Panel on Climate Change
IPCC WGI	Intergovernmental Panel on Climate Change Working Group I
IRENA	International Renewable Energy Agency
KPIs	key performance indicators
kWh	kilowatt-hour
kWp	kilowatt-peak
LCA	life-cycle assessment
LCOE	levelized cost of electricity
LULC	land use/land cover
MCDM	multi-criteria decision-making
MIGA	Multilateral Investment Guarantee Agency
MJ	megajoule
MW	megawatt
NBS	nature-based solutions
NPV	net present value

O&M	operation and maintenance
OSM	OpenStreetMap
PE	project emissions
PPA	power purchase agreement
PPP	public-private partnership
PV	photovoltaic
QA/QC	quality assurance/quality control
RCP	Representative Concentration Pathway
RE	renewable energy
RMI	Rocky Mountain Institute
SMART	specific, measurable, achievable, relevant, and time-bound
SSPs	Shared Socioeconomic Pathways
T&D	transmission and distribution
TNC	The Nature Conservancy
UN	United Nations
UNEP/GRID-Geneva	United Nations Environment Programme/Global Resource Information Database Geneva
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
USGS	United States Geological Survey
VfM	Value for Money
WB	World Bank
WBG	World Bank Group
WESR	World Environment Situation Room

Foreword

The time for action to build a better future and green recovery has never been stronger as we navigate the uncertainty of a world dealing with multiple crisis on top of climate change. As governments across the globe face fiscal constraints, it has become imperative to crowd in private sector solutions, innovation, and finance to create new solutions and pathways to meet Paris Agreement goals on climate change and UN Sustainable Development Goal (SDG) commitments.

Participation of the private sector in Paris-Aligned infrastructure investments is critical and public-private partnerships (PPPs) are among the key solutions. PPPs are critical in supporting governments to bridge the infrastructure gap not only for the additional capital they bring but sector expertise and innovation as well. However, the PPP model is not without challenges, climate change creates uncertainty that can be difficult to account for in the framework of PPPs, which require a certain degree of predictability to attract investment and finance.

This sector-specific toolkit on the renewables sector (with a focus on wind and solar) aims to address this challenge by embedding a climate approach into upstream PPP structuring. If structured correctly, PPPs in wind and solar can increase climate resilience offering market-based solutions to address both mitigation and adaptation challenges. PPPs are able to provide well-informed and well-balanced risk allocation between partners- offering long-term visibility and stability for the duration of a contract (typically 20 to 30 years)- compensating climate change uncertainty through contractual predictability.

The toolkit attempts to address questions like:

- In what ways does climate change affect renewable energy projects, and what measures can be taken to alleviate these impacts through a PPP structure? How do you introduce adaptation and resilience to address the impacts?
- How can we innovate to allow for optimal risk allocation and contractual predictability in an environment marked by uncertainty and the need for resilience to unpredictable scenarios?

The Global Infrastructure Facility (GIF), The Public Private Infrastructure Advisory Facility (PPIAF) and International Finance Corporation, Transaction Advisory, Public-Private Partnership and Corporate Finance Advisory Services in collaboration with sector specialists across the World Bank Group (WBG)-have joined forces to build upon best practice on a topic at the cross-roads of climate change, infrastructure, and private sector participation. It is a field in evolution where there will be a great deal of innovation ahead of us.

Currently an insufficient focus is given to considering climate change in the framework of PPPs. For instance, the PPP tender selection criteria are currently ultimately based on the least cost approach, which may promote assets not resilient enough to withstand climate impacts. This may in turn result in total asset loss with devastating effects on the economy and society. This toolkit is indeed about providing solutions to public officials and their advisors on how to better align interests and incentives towards climate-smart investments and tap into private sector financing capacity.

The renewables sector toolkit as part of the Climate Toolkits for Infrastructure PPPs (CTIP3) suite is ultimately a call for action for decision makers, to push for bold initiatives so that infrastructure investments become a critical and steady pathway to achieve Paris Agreement and SDG commitments.

Emmanuel B. Nyirinkindi Vice President, Cross-Cutting Solutions, International Finance Corporation

Imad Najib Ayed Fakhoury Global Director, Infrastructure Finance, PPPs and Guarantees Global Practice, World Bank

INTRODUCTION

Global transition to a renewable energy economy

The world is increasingly taking action in all sectors of the economy, focusing more and more on decarbonization pathways to achieve Paris Agreement goals and to create a more sustainable and inclusive future. The energy sector—a significant source of pollutants—is rapidly transitioning to renewables that rely on energy generation from wind or the sun. This energy transition is key to realizing climate change goals globally.

Managing climate risks in renewable energy projects

Additional investment in wind and solar energy technology can accelerate the transition, harnessing power sources that already exist in most parts of the world and that do not produce greenhouse gases (GHGs). At the same time, the COVID-19 pandemic and global geopolitical stresses have increased financial risks, especially in countries where the macroeconomic outlook remains unclear, or where economic growth is expected to slow down. In addition, climate-related risks are becoming particularly acute as investments expand geographically in sites experiencing climate-induced threats of considerable intensity, and as the hazards (both the frequency and severity of events) are further exacerbated due to the warming effect caused when GHGs accumulate in the earth's atmosphere. In such a landscape, the risk management resources pertinent to the renewable energy sector—including industry expertise to conduct feasibility studies, green financing, and specialized risk transfer products—are in even greater demand.

The energy sector produces approximately 75 percent of global GHG emissions, representing about 800 million people living without electricity. Because about 3 billion people—primarily women and children—still rely on biomass fuels for cooking and heating, with significant implications for health and time poverty,[1] the importance of gender-smart and inclusive interventions should not be ignored within the design or implementation of renewable energy projects. The renewable energy sector offers opportunities to increase women's employment and entrepreneurship in renewable energy, and hence, by addressing these possibilities, one can ensure that large-scale renewable energy transition programs do not continue to widen gender gaps.

Quantifying benefits and ensuring public approval

The Paris Agreement and the various climate-related national and international commitments have set specific, ambitious goals for the reduction of GHG emissions for timelines that range from 2030 to beyond 2050. Renewables will be a key contributor toward meeting global net zero ambitions. Despite the environmental and socioeconomic benefits of renewables, high upfront capital expenditures (CAPEX) and lack of public acceptability are often constraints on the exploitation of renewable energy. A dearth of broad-based support may slow down the planning and permitting processes, thus impacting the market appetite for investments. In this regard, properly estimating, acknowledging, and communicating the benefits of GHG reductions and their associated co-benefits will help maximize support and consensus among key stakeholders for renewable energy projects from the early planning stages.

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[1] World Bank Group. 2021. World Bank Group Climate Change Action Plan 2021-2025: Supporting Green, Resilient, and Inclusive Development. Washington, DC: World Bank. https://openknowledge.worldbank.org/handle/10986/35799.

Climate considerations will influence the project economics

By nature, renewable energy depends primarily on climatic factors, which greatly affect not only their reliability (e.g., consistency of solar irradiance is key to determining solar panels' efficiency), but also their operability (e.g., availability of water to remove dust from solar panels' surfaces). Hence, climate-related parameters will, to a large extent, define the geographic location and typology of infrastructure, which will, in turn, directly influence the project's economics.

A public-private partnership (PPP) could, in some cases, add benefits (e.g., potentially more effective use of new materials; new technologies to optimize efficiency; and innovation in the design of adaptation measures) compared to traditional procurement. On the other hand, climate-change-induced risks could diminish the availability of private financing, especially when risk transfer options such as insurance are limited. Therefore, the implications of climate considerations for the costs and benefits as well as the value for money (VfM) of a renewable energy project as a PPP should be assessed at the earlier stages of project selection in order to identify and address the impact on the viability of the project and risk mitigation opportunities.

Well-defined, measurable indicators are essential

Climate change may introduce challenges in the delivery of new renewable energy projects. Meeting climate mitigation and adaptation goals will involve such considerations as proper design and construction, adequate monitoring, sustainable operations, and efficient maintenance. To ensure that climate considerations are fully embedded in such processes, it is recommended that governments and advisors provide specifications and output requirements in the form of specific, measurable, achievable, relevant, and time-bound (SMART) indicators. It is also critical that these indicators be aligned with market-based and global standards that will also enable such projects to tap into a growing market of climate and sustainable finance.

The renewable energy sector toolkit and its intended users

This document is intended for use by government agencies in emerging markets and developing economies (EMDEs), in order to assist them in incorporating climate-related risks and opportunities in the preliminary preparation stages of renewable energy (solar and wind) infrastructure projects procured through PPPs. It complements the World Bank Group's Climate Toolkits for Infrastructure PPPs (CTIP3)[2] (the "Umbrella Toolkit") by providing step-by-step instructions on how to apply its provisions to renewable energy-specific PPPs. It is intended to familiarize public-sector non-expert users[3] with the potential effects of climate change on renewable energy projects—and the resulting considerations for climate mitigation, adaptation and resilience—so they can be adequately appraised as early as possible when pursuing such projects. As such, this toolkit aims to help users understand how climate change could affect—or be affected by—their renewable energy project, the potential consequences, and what measures can be taken to alleviate impacts. Note that this toolkit is not intended for the design to structuring and tendering phases, but should be consulted as a complementary tool to the Umbrella Toolkit.

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[2] World Bank, IFC (International Finance Corporation), and MIGA (Multilateral Investment Guarantee Agency). 2022. Climate Toolkits for Infrastructure PPPs. World Bank, Washington, DC.

[3] It is expected that the toolkit may also be useful for experienced government officials and their advisors; however the tools proposed herein are rather simplified and qualitative, although they rely on preliminary data so that non-experts are able to utilize them without necessarily requiring external support. Hence the toolkit's outcome may be used during the considerations of the first phase of the PPP cycle but should be updated during subsequent phases backed by quantitative analyses, as prescribed in the Umbrella Toolkit.

Types of Renewable Energy (RE) Projects covered by this guide

Solar Energy

Solar energy harnesses the power of the sun to generate electricity either directly through photovoltaic (PV) cells or indirectly using concentrated solar power (CSP). CSP generally requires large areas to be effective, whereas solar PV panels may be distributed and mounted on any surface exposed to the sun, making them ideal for integration into the urban environment or man-made structures. below.

TABLE 0.1. A comparison of PV and CSP technologies

	PV	CSP
Levelized cost of electricity ($/kilowatt-hour[kWh])[4]	0.048	0.107
Technology	PV systems directly convert sunlight to electricity	CSP systems concentrate sun energy in a reflector. The concentrated energy is then used to drive a heat engine, which is connected to an electric generator.
Energy dispatch	(Generally) non-dispatchable	Dispatchable
Key components	PV arrays, inverters, transformers, PV feeder, plant controller	Mirrors or reflectors, linear receiver or heat collection element, pump system for the heat transfer liquid, collector balance of the system, thermal energy storage system, power block (steam generator to produce electricity).

Wind Energy

Wind energy is created using wind turbines (WTs) that capture the kinetic energy of the earth's natural air flows to generate electricity. WTs turn moving air to power an electric generator that supplies an electric current. The wind turns the blades and the blades spin a shaft that is connected to the generator, which creates electricity. Wind turbines may be installed onshore (i.e., inland) or offshore, in the sea. In the latter case, the turbines are able to harness the increased wind potential away from the shore and avoid the land use-related limitations of onshore farms, but also have different requirements for energy transmission and grid connectivity.

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[4] The levelized cost of electricity (LCOE) represents the average revenue per unit of electricity generated that would be required to recover the costs of building and operating a generating plant over a specified cost recovery period. Reported values are according to the global weighted average LCOE reported in: IRENA (International Renewable Energy Agency). 2022. *Renewable Power Generation Costs in 2021*. IRENA, Abu Dhabi. Values fluctuate following the trends of the electricity market.

	Onshore Wind	Offshore Wind
Levelized cost of electricity ($/kWh)	0.033	0.075
Technology	Horizontal-axis turbines with three blades. The blades, shaft, and generator are on top of a tall tower, with the blades facing into the wind and the shaft horizontal to the ground. Typical WT sizes: 1-5 megawatts (MW)	Same as in onshore settings, but come in larger sizes. The larger the size, the greater the efficiency and the capacity to generate more power. Typical WT sizes: 2-10 MW
Energy dispatch	Non-dispatchable	Non-dispatchable
Power plant architecture (key components)	Wind turbines, array power cables, transformer, transmission and distribution lines	Wind turbines, array power cables, substation/converter platform (offshore), export power cable, substation/converter station (onshore), control station, transmission and distribution lines

Renewable Energy Storage and Supply to the Grid

Renewable energy is intermittent in nature (production depends on weather conditions), and production cannot be increased or decreased on demand based on the grid's requirements. Thus, in order to accelerate the green energy transition without risking the grid's stability and reliability, the industry is seeking ways for excess production to be stored and used when needed. Among the various solutions currently available, the battery energy storage systems (BESS) are gaining ground as an efficient means of temporarily storing energy that can be used to support grid stability, regulate frequency of produced electric power, and provide energy back-up when needed. The location and configuration of BESS may vary depending on climate considerations. For instance, a hybrid BESS may be favored for remote and/or smaller facilities, whereas larger plants may be better off relying on standalone storage systems located in areas less prone to climate risk. Such considerations may also affect the way overall power generation planning is done at the regional level.

Storage systems are often coupled with solar PV installations—and indeed serve as core components of intermittent renewable energy development. However, for the purposes of keeping the toolkit more concise and targeted—and following the results of stakeholder consultation—it is focused on the core components of solar and wind energy infrastructure and not on storage systems.

EXECUTIVE SUMMARY

This toolkit contains four modules covering the major climate entry points in the preliminary stages of renewable energy project preparation. Their inputs comprise fundamental project data as well as readily available climate-related resources and tools produced by the World Bank Group (WBG) and international organizations. The outcome should be a project-specific collection of considerations that will need to be further evaluated and quantified during the subsequent phases of implementation of the Umbrella Toolkit as well as an improved understanding of the potential needs for advisory services.

Module 1 provides practical guidance to governments and advisors on planning how climate-change-induced risks could affect their renewable energy project, and applicable adaptation measures to alleviate them and enhance the project's resilience. The module also supports users in pre-selecting a project location as well as other important options using a multi-criteria assessment methodology emphasizing the impact of climate change on the various factors (e.g., technical, social, economic) affecting project decisions.

Module 2 provides a simplified methodology for the life-cycle assessment (LCA) of the project's GHG emissions at a preliminary stage based on the project's typology and publicly available data.

Module 3 provides tools to qualitatively estimate the impacts of climate considerations on the costs, benefits, and VfM of a renewable energy infrastructure project.

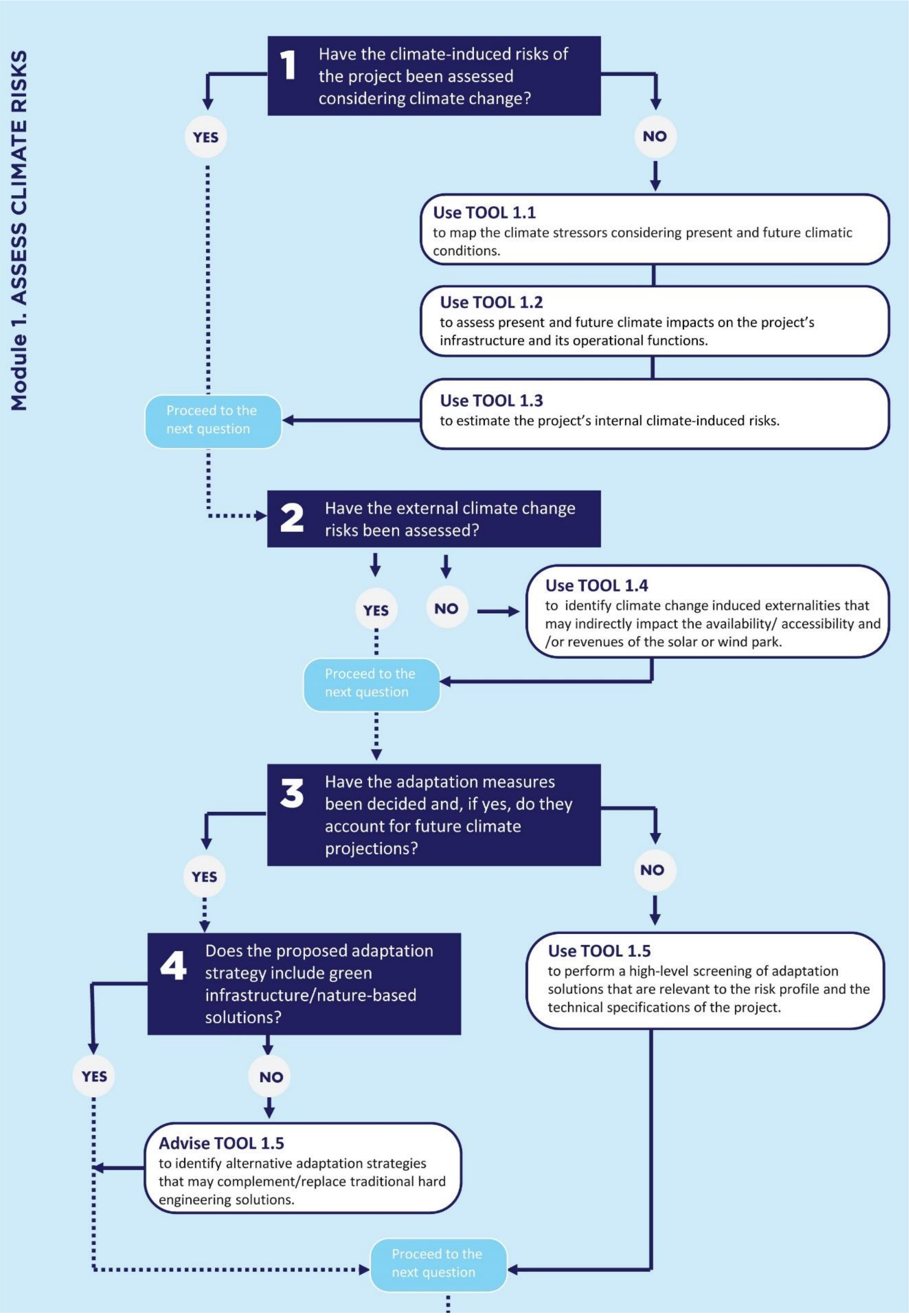
Module 4 presents a set of indicative key performance indicators (KPIs) for all of the above processes that are specific to wind and solar energy projects.

The interconnections between the modules and the tools contained within each module are explained schematically in the **Toolkit Navigator** on the next page.

Toolkit Navigator

The toolkit supports users in exploring alternative power-plant configurations that cover projected energy demands in order to decide on a preferred option (or options) that can be better delivered under a PPP. Alternative plant configurations may differ in location, power generation capacity, typology, and power-plant architecture. As such, projects may have different (installation, operational) costs, reliability in exploiting resources, levels of exposure to climate threats, maximizing benefits in GHG reduction, and resilience to the anticipated changes of climatic conditions.

In this regard, the choice of the preferred option cannot be agnostic of climate change and its impacts on the renewable energy project. The flowchart below describes a modular process to assist users with understanding the climate risks and opportunities associated with the different alternatives and deciding to proceed with the ones that have the highest cost/benefit ratio (after factoring in climate-induced costs and benefits).



Module 1. ASSESS CLIMATE RISKS

1 Have the climate-induced risks of the project been assessed considering climate change?

Use TOOL 1.1 to map the climate stressors considering present and future climatic conditions.

Use TOOL 1.2 to assess present and future climate impacts on the project's infrastructure and its operational functions.

Use TOOL 1.3 to estimate the project's internal climate-induced risks.

Proceed to the next question

2 Have the external climate change risks been assessed?

Use TOOL 1.4 to identify climate change induced externalities that may indirectly impact the availability/ accessibility and /or revenues of the solar or wind park.

Proceed to the next question

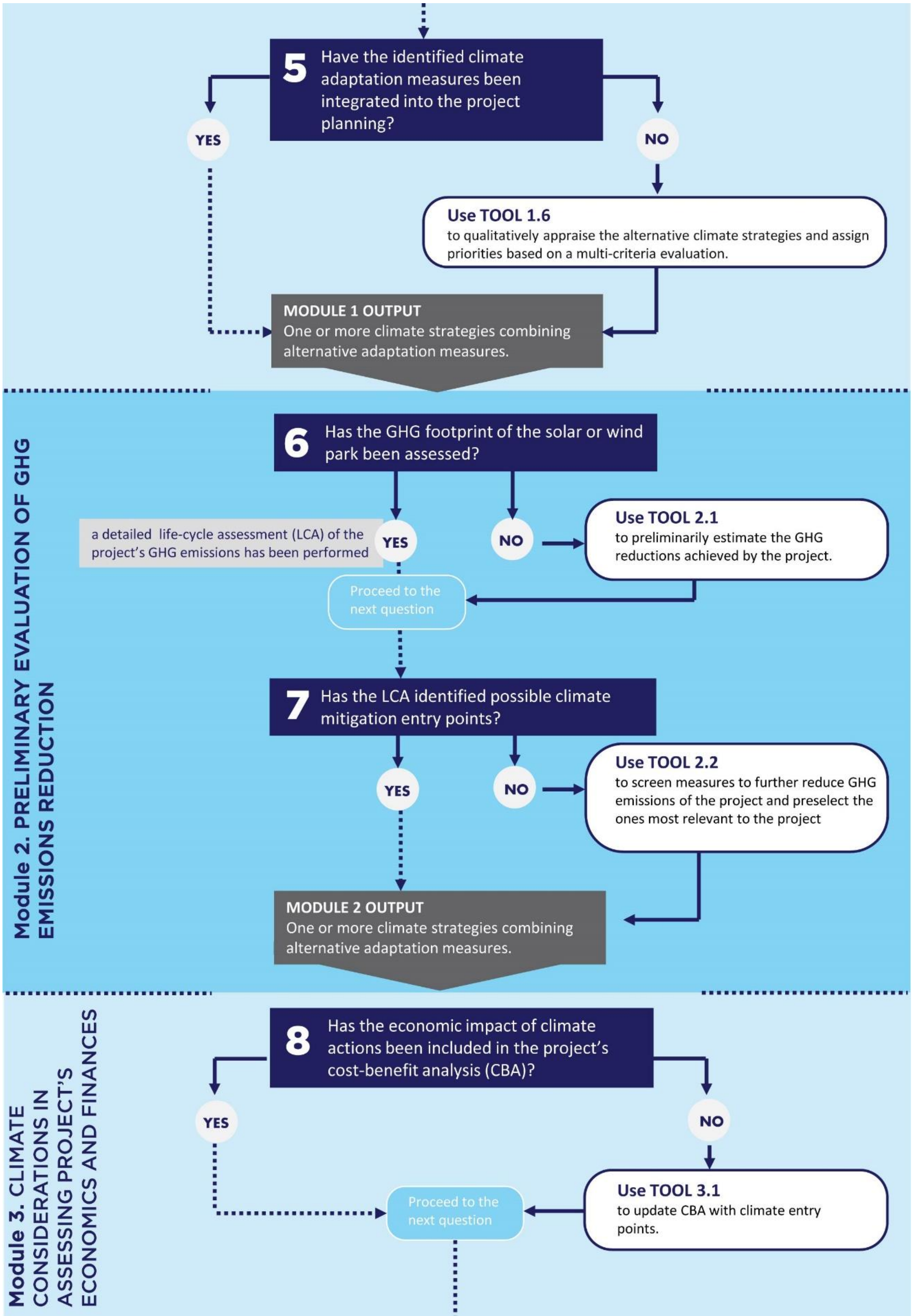
3 Have the adaptation measures been decided and, if yes, do they account for future climate projections?

4 Does the proposed adaptation strategy include green infrastructure/nature-based solutions?

Use TOOL 1.5 to perform a high-level screening of adaptation solutions that are relevant to the risk profile and the technical specifications of the project.

Advise TOOL 1.5 to identify alternative adaptation strategies that may complement/replace traditional hard engineering solutions.

Proceed to the next question



Module 2. PRELIMINARY EVALUATION OF GHG EMISSIONS REDUCTION

Module 3. CLIMATE CONSIDERATIONS IN ASSESSING PROJECT'S ECONOMICS AND FINANCES

5 Have the identified climate adaptation measures been integrated into the project planning?

Use TOOL 1.6
to qualitatively appraise the alternative climate strategies and assign priorities based on a multi-criteria evaluation.

MODULE 1 OUTPUT
One or more climate strategies combining alternative adaptation measures.

6 Has the GHG footprint of the solar or wind park been assessed?

a detailed life-cycle assessment (LCA) of the project's GHG emissions has been performed

Use TOOL 2.1
to preliminarily estimate the GHG reductions achieved by the project.

Proceed to the next question

7 Has the LCA identified possible climate mitigation entry points?

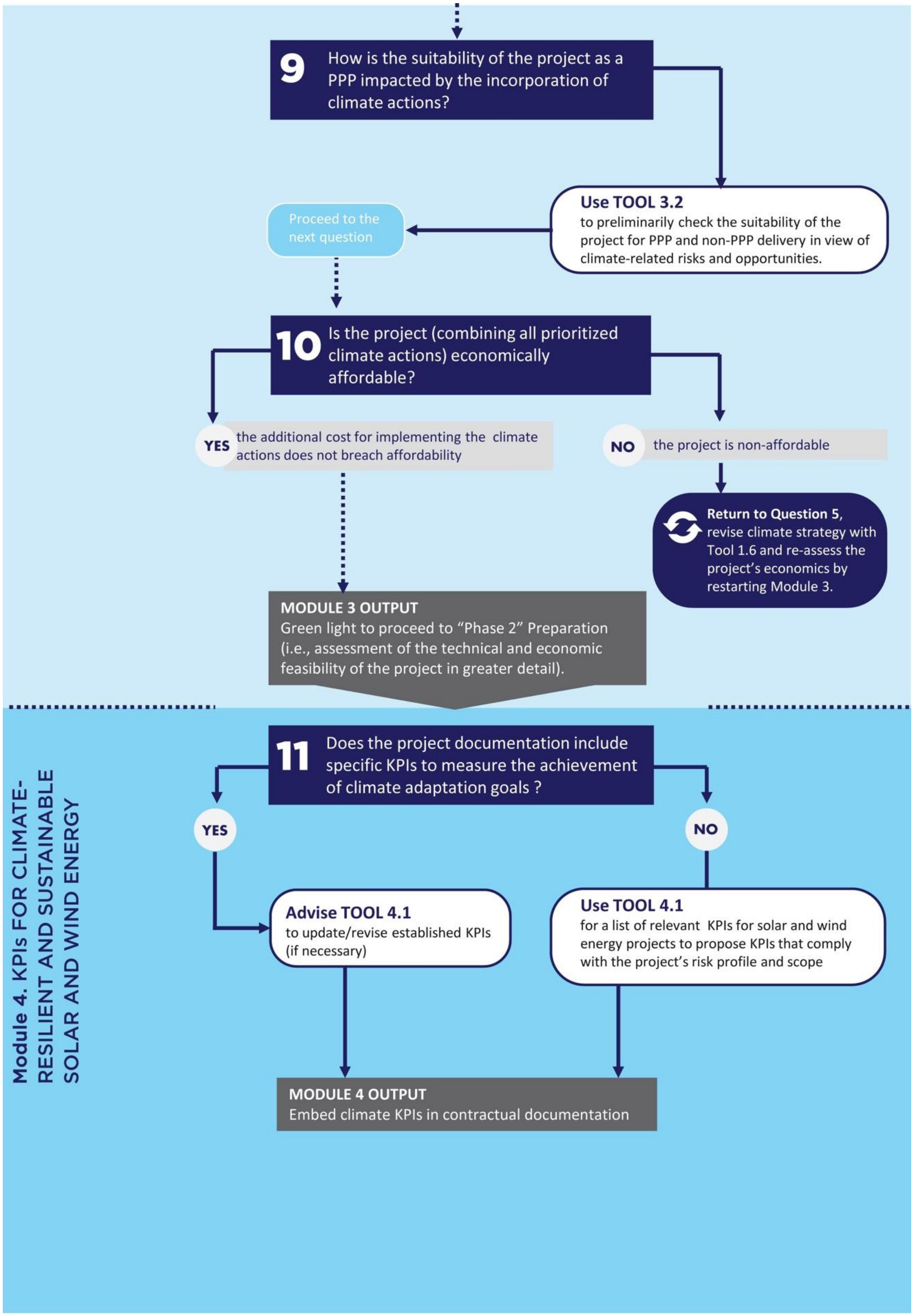
Use TOOL 2.2
to screen measures to further reduce GHG emissions of the project and preselect the ones most relevant to the project

MODULE 2 OUTPUT
One or more climate strategies combining alternative adaptation measures.

8 Has the economic impact of climate actions been included in the project's cost-benefit analysis (CBA)?

Use TOOL 3.1
to update CBA with climate entry points.

Proceed to the next question



9 How is the suitability of the project as a PPP impacted by the incorporation of climate actions?

Use TOOL 3.2
to preliminarily check the suitability of the project for PPP and non-PPP delivery in view of climate-related risks and opportunities.

Proceed to the next question

10 Is the project (combining all prioritized climate actions) economically affordable?

YES the additional cost for implementing the climate actions does not breach affordability

NO the project is non-affordable

Return to Question 5, revise climate strategy with Tool 1.6 and re-assess the project's economics by restarting Module 3.

MODULE 3 OUTPUT
Green light to proceed to "Phase 2" Preparation (i.e., assessment of the technical and economic feasibility of the project in greater detail).

Module 4. KPIs FOR CLIMATE-RESILIENT AND SUSTAINABLE SOLAR AND WIND ENERGY

11 Does the project documentation include specific KPIs to measure the achievement of climate adaptation goals ?

YES

Advise TOOL 4.1
to update/revise established KPIs (if necessary)

NO

Use TOOL 4.1
for a list of relevant KPIs for solar and wind energy projects to propose KPIs that comply with the project's risk profile and scope

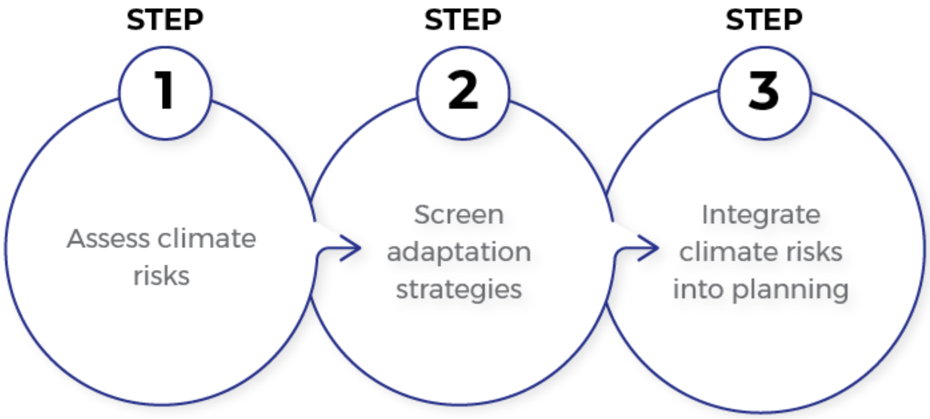
MODULE 4 OUTPUT
Embed climate KPIs in contractual documentation

MODULE

1

Module 1

ASSESS CLIMATE RISKS AND PLAN ADAPTATION STRATEGIES



The module is divided into three steps:

Step 1 - Assess climate risks: First, users should assess the various ways a renewable energy project (or any alternatives) can be negatively impacted by changing climatic conditions. These may constitute risks that are either "internal" to the project (i.e., potential loss due to failures within the project boundaries) or "external" (i.e., potential loss due to failures of the interconnected or interdependent systems and networks beyond the boundaries of the project).

Step 2 - Screen possible adaptation strategies to reduce climate risks: Next, users are guided to identify ways to alleviate these impacts and understand the cost implications of the various adaptation options to build resilience.

Step 3 - Integrate climate risks into the planning of solar or wind parks: The aforementioned climate considerations are later introduced into a multi-criteria decision-making (MCDM) framework that aims to assist users in excluding risky or technically unfeasible projects, instead prioritizing those that receive the maximum consensus among stakeholders and that are less susceptible to changing climatic conditions.

Step 1

Assess Climate Risks

SCOPE

To identify and qualitatively assess (high, medium, low) the climate risks that may potentially affect the energy production, revenues, and operations of a solar or wind project due to potential damage or failures of the renewable project or of its interconnected infrastructure and interdependent systems.

PROCESS

The methodology for assessing climate risks is described in detail in the Umbrella Toolkit (Modules 1.2 and 2.1). The underlying assumption is that the risk depends on the intensity of the hazard, the likelihood of having a hazard of such intensity affecting the project, and the severity of the impact, according to the equation:

RISK = [HAZARD x LIKELIHOOD] x IMPACT

The process initiates with the identification of climate threats potentially affecting the project. Then threats are characterized as high, medium, or low (taking into account their intensity and likelihood of occurrence). This is performed for different climatic futures (representing different climate projections). Next, the impacts of each hazard are assessed and combined with the (HAZARD X LIKELIHOOD) product to derive the climate-risk matrix of the renewable energy project. The process is assisted by four tools as outlined below:

TOOLS

TOOL 1.1 Mapping climate threats considering future projections
TOOL 1.2 Assessment of climate impacts
TOOL 1.3 Assessment of climate risks
TOOL 1.4 Evaluation of climate-induced externalities and impacts

OUTPUT	▪ A qualitative risk matrix of the renewable energy project. ▪ A prioritization/ranking of the most significant risks that will be passed onto **Step 2** to plan for adaptation measures.

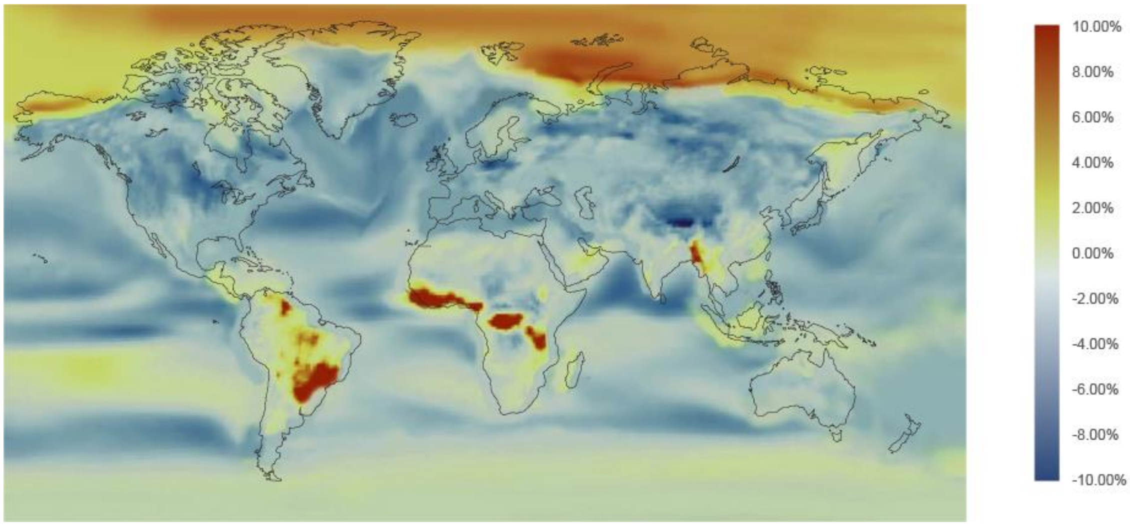


FIGURE 1.1a Global distribution of median trends: change (%) of surface wind speed in the period (2040-2060) relative to (1981-2010) *Source*: Intergovernmental Panel on Climate Change Working Group I (IPCC WGI) Interactive Atlas.

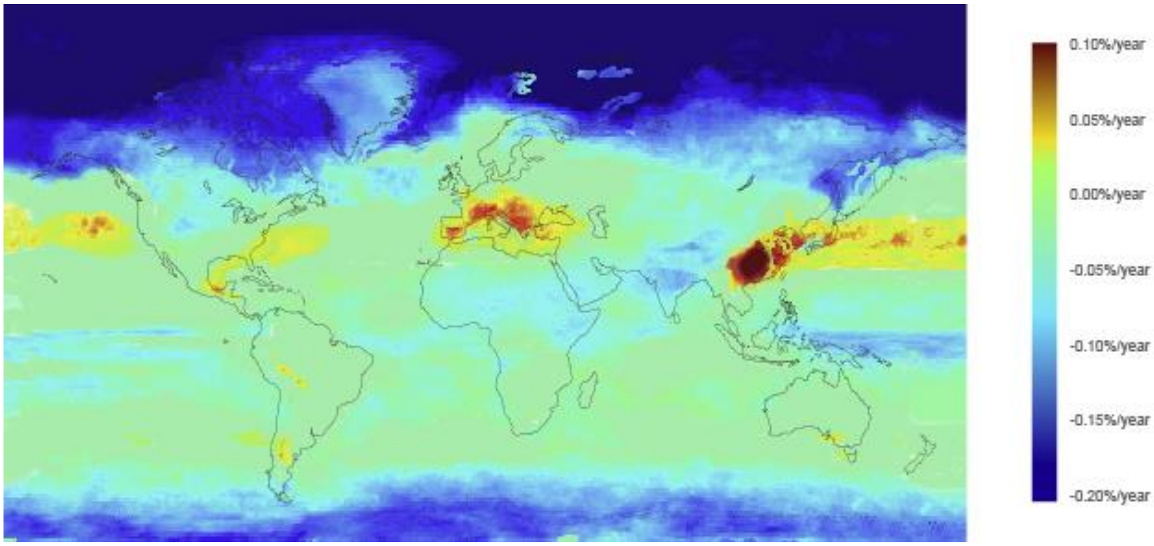
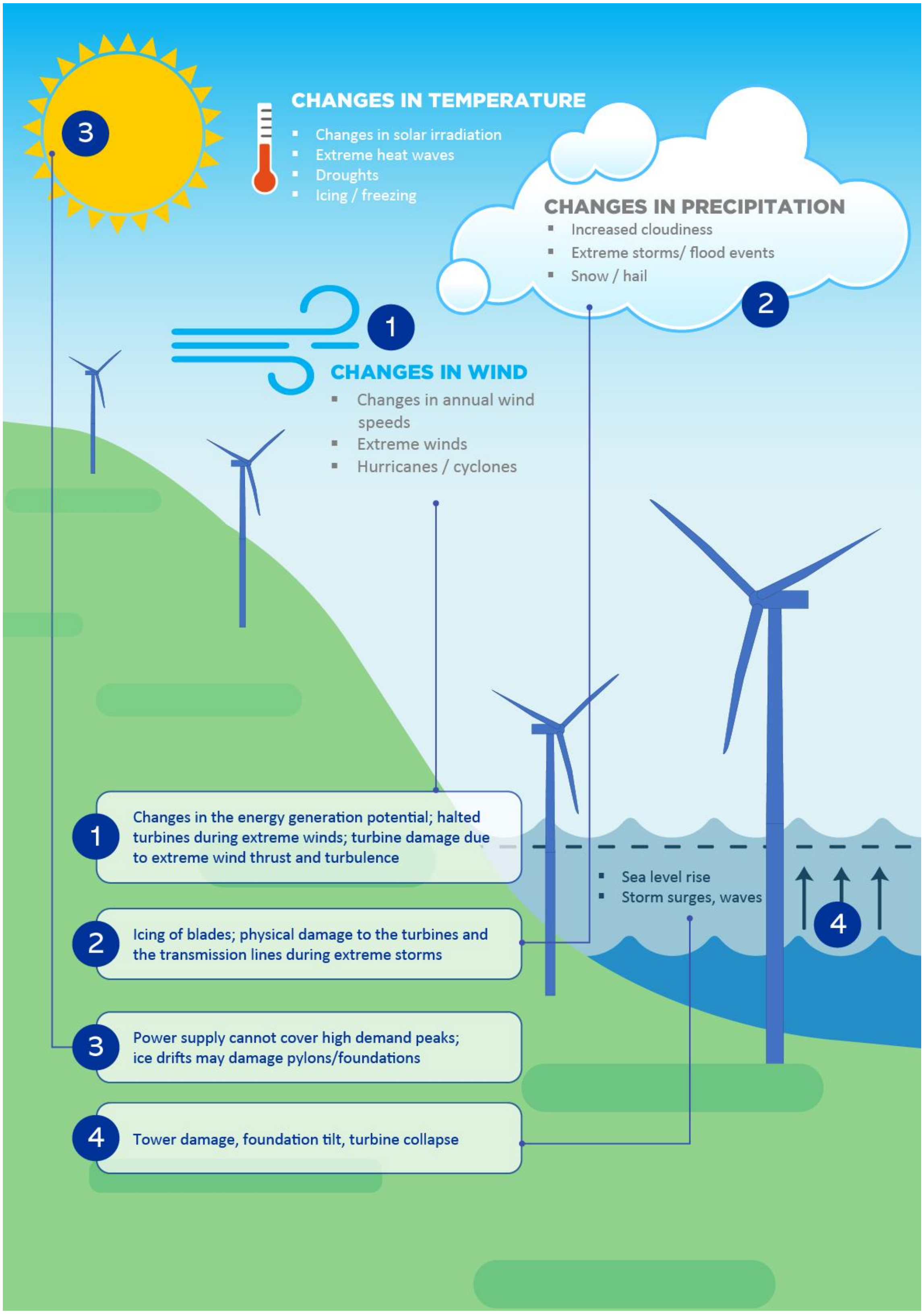


FIGURE 1.1b Annual change (%) in PV power output of the year 2050 relative to the year 2006 *Source*: Wild, M., D. Folini, F. Henschel, N. Fischer, and B. Müller. 2015. “Projections of long-term changes in solar radiation based on CMIP5 climate models and their influence on energy yields of photovoltaic systems.” *Solar Energy* 116 (June 2015): 12-24. https://doi.org/10.1016/j.solener.2015.03.039.

TABLE 1.2 List of resources that can be used for preliminary identification of climate hazards at the project location

Resource	Description	Climate Scenarios
Climate Change Knowledge Portal (CCKP) developed by the World Bank Group	The CCKP contains climate, disaster risk, and socioeconomic datasets, as well as synthesis products, such as the Climate Risk Country Profiles, that include climate-related natural hazards and climate change impacts. Temperature-related variables (e.g., number of hot/frost days, cold spell duration index) and precipitation-related variables (e.g., average largest five-day cumulative rainfall) are available historically and for future projections based on different climatic models.	**Yes**
ThinkHazard! developed by the World Bank Group	ThinkHazard! provides a general view of the hazards (river flood, earthquake, drought, cyclone, coastal flood, tsunami, volcano, and landslide) for a given location. The tool highlights the likelihood of different natural hazards affecting project areas (very low, low, medium, and high), provides guidance on how to reduce the impact of these hazards, and where to find more information. A brief statement is made to describe the potential impact of climate change on the hazard.	**Yes**
ClimateLinks developed by the United States Agency for International Development (USAID)	ClimateLinks is a global knowledge portal that includes climate-related information and tools. Regional and country risk profiles are available, providing key climate stressors and risks for different regions or countries. Climate projections include temperature, precipitation variability, extreme weather events, sea level rise.	**Yes**
Intergovernmental Panel on Climate Change Working Group I (IPCC WGI) Interactive Atlas developed by the IPCC	The Interactive Atlas regional information supports the assessment done in the Sixth Assessment Report of Working Group I (AR6-WGI) chapters, the Technical Summary (TS) and the Summary for Policymakers (SPM), allowing for flexible temporal and spatial analyses of trends and changes in key atmospheric and oceanic variables, extreme indexes and climatic impact drivers related to temperature, sea level rise, sea ice concentration, drought, wind and storm, snow/ice and more.	**Yes**
WorldClim developed by WorldClim	WorldClim contains historical climate data (temperature, precipitation, solar radiation, wind speed, water vapor pressure) and a spectrum of future weather maps (temperature and precipitation) with a 30-second spatial resolution.	**Yes**

Resource	Description	Climate Scenarios
The World Bank Maps developed by the World Bank Group	The World Bank Maps offer a broad set of datasets, including relevant information for renewable energy projects, electricity networks, power generation, and infrastructure, as well as climate change risk for temperature and precipitation changes.	**Yes**
WESR (World Environment Situation Room): Risk developed by the UNEP/GRID-Geneva	The WESR: Risk platform provides access to global datasets regarding hazards (floods, droughts, forest fires, tropical cyclones, earthquakes, tsunamis, landslides, volcanoes), exposure (economic or population), as well as the risk of losses (mortality and economic risk).	**No**
Global Solar Atlas developed by the World Bank Group	The Global Solar Atlas provides quick and easy access to solar resource and photovoltaic power potential data globally, regionally, and at a country scale. Available data include long-term yearly averages of daily totals of the PV Electricity Output, Global Horizontal Irradiation, Diffuse Horizontal Irradiation, Direct Normal Irradiation, and Air Temperature at a height of two meters.	**No**
Global Wind Atlas developed by the World Bank Group	The Global Wind Atlas facilitates online queries and provides downloadable datasets and high-resolution maps of the wind resource potential and its variability by year, month, and hour, for use in geographic information system (GIS) tools, at the global, country, and first administrative unit (state/province) level. Available datasets include mean wind speed and mean wind power density maps, topography, orography, land use roughness length, bathymetry.	**No**
Offshore Wind Technical Potential | Analysis and Maps developed by the World Bank	The offshore wind technical potential is an estimate of the amount of generation capacity that could be technically feasible, considering only wind speed and water depth. Offshore wind technical potential maps are available for 56 countries and regions.	**No**
EarthExplorer developed by the United States Geological Survey (USGS)	EarthExplorer provides a comprehensive collection of land remote-sensing data that spans more than 50 years of coverage for the world, and provides digitized global maps of various data collections, including aerial photography, satellite imagery, elevation data, and land cover products.	**No**



CHANGES IN TEMPERATURE

- Changes in solar irradiation
- Extreme heat waves
- Droughts
- Icing / freezing

CHANGES IN PRECIPITATION

- Increased cloudiness
- Extreme storms/ flood events
- Snow / hail

CHANGES IN WIND

- Changes in annual wind speeds
- Extreme winds
- Hurricanes / cyclones

- Sea level rise
- Storm surges, waves

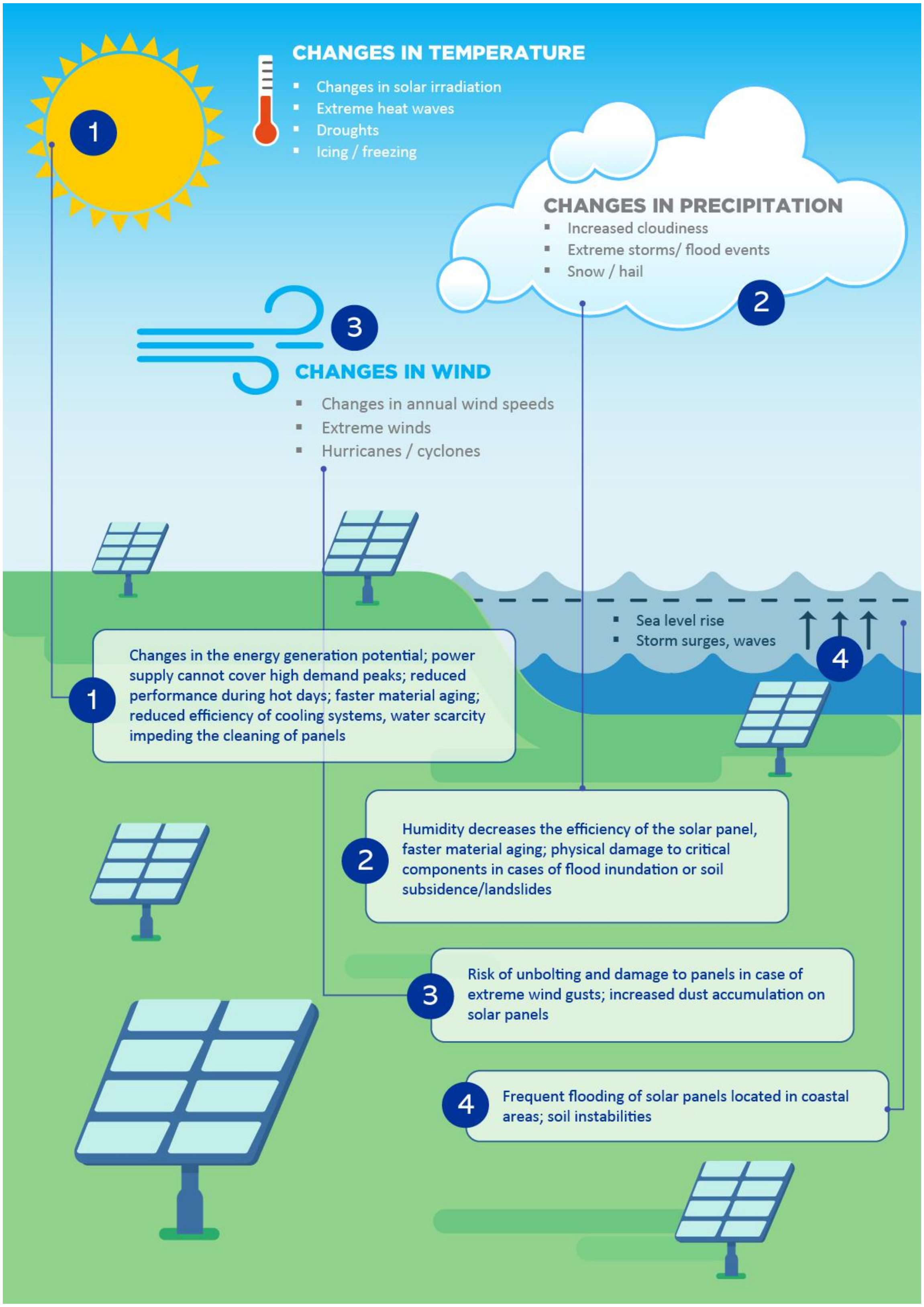
1 Changes in the energy generation potential; halted turbines during extreme winds; turbine damage due to extreme wind thrust and turbulence

2 Icing of blades; physical damage to the turbines and the transmission lines during extreme storms

3 Power supply cannot cover high demand peaks; ice drifts may damage pylons/foundations

4 Tower damage, foundation tilt, turbine collapse

FIGURE 1.2 Examples of climate-induced impacts to wind parks



1 Changes in the energy generation potential; power supply cannot cover high demand peaks; reduced performance during hot days; faster material aging; reduced efficiency of cooling systems, water scarcity impeding the cleaning of panels

2 Humidity decreases the efficiency of the solar panel, faster material aging; physical damage to critical components in cases of flood inundation or soil subsidence/landslides

3 Risk of unbolting and damage to panels in case of extreme wind gusts; increased dust accumulation on solar panels

4 Frequent flooding of solar panels located in coastal areas; soil instabilities

FIGURE 1.3 Examples of climate-induced impacts to solar parks

TOOL 1.1

MAPPING POTENTIAL CLIMATE THREATS CONSIDERING FUTURE PROJECTIONS

In the context of this toolkit, a threat is defined as any circumstance, action, or event that might exploit the potential vulnerabilities of the system (i.e., the susceptibility or inability of the system or the system's components to cope with climate variability and climate extremes), with the potential of adversely impacting the revenues/safety/availability of the infrastructure. The threat can be:

- A single hazard that may potentially damage or reduce the functionality of the infrastructure asset (or component of the asset). For example, a cyclone damaging PV panels or a severe storm damaging the pylons of wind turbines.
- A change in a climate stressor impacting the energy production of the plant. For example, an increase in annual cloudiness or a decrease in average wind speeds negatively impacting the electricity generation of solar and wind parks, respectively.
- A multiplier of a climate stressor to an already recognized external risk of the system (e.g., climate-induced impacts on interconnected infrastructure or changing demographics associated with climate change projections). This type of threat is separately covered in **Tool 1.4**.

INPUT

The tool assists users in identifying and mapping the climate threats to which the solar or wind facility may be exposed throughout its lifetime. The tool provides guidance on how to screen threats and qualitatively assess their severity and likelihood of occurrence.

1 **Decide on the timeframe of the assessment**

The minimum timeframe for assessing climate hazards will be the PPP life cycle. However, the government may wish to extend the timeframe of the study given that the life cycle of the infrastructure may be longer than the duration of the PPP contract (e.g., infrastructure design life).

2 **Screen climate hazards/stressors** that may adversely impact the renewable energy project.

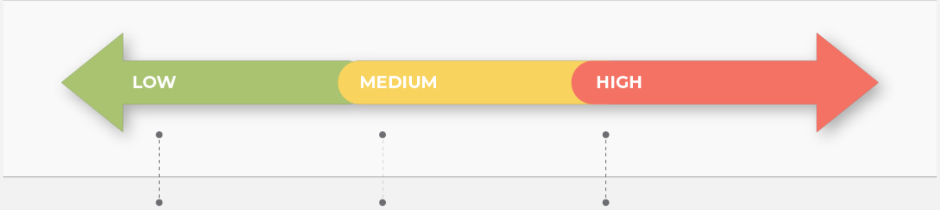
To retrieve country- or region-specific hazards, the users may refer to the resources in **Table 1.2**.

A generic list of hazards/climate stressors affecting solar and wind projects (applicable to a wide range of locations) is provided in **Table 1.3**. All hazards/stressors are classified according to four variables (temperature, precipitation, sea-level rise, and wind) that can be directly retrieved from climate models. Due to climate change, these climate variables change at a global and regional scale, affecting chronic and acute weather patterns. For example, an increase in the average air temperature will increase the number of very hot days and heatwaves; this will in turn impact freeze-thaw cycles and may increase incidences of wildfires.

3 Leverage local knowledge and experience to confirm/revise findings

This may include already available regional impact maps and previous hazard studies. Past experience in the area can also provide a foundation for identifying the most frequently encountered weather events or characterizing high-risk regions (e.g., flood plains, landslide/subsidence zones). Advice on regional risks may also be sought from local contractors or district engineers.

4 **Use the scoring system** provided below to estimate the current hazard level as a function of the **intensity** of the hazard and its **likelihood** of occurrence (or frequency of the event).



LOW
The hazard is not likely to occur during the timeframe of the assessment, and if it occurs its intensity will be low.

MEDIUM
A hazard of moderate intensity is expected to occur at least once during the timeframe of the assessment.

HIGH
Hazards may occur several times during the timeframe of the assessment, and their intensity is expected to be relatively high.

5 Determine the climate change trend (i.e., increasing, decreasing, or stable) for the identified climate hazards

Observe the global and (if available, the regional) future projections of the corresponding controlling variable (second columns of **Tables 1.3 & 1.4** and make reasonable estimates about the future trend of the hazard under consideration. For example, if the project region is showing an increasing trend in average precipitation (and if no other data are available), it is reasonable to anticipate an increase in extreme rainfall and flood events. It is generally considered good practice to use different climatic projections representing different Representative Concentration Pathways (RCP) scenarios (see also the note on the next page).

6 Assess the future hazard level by combining current hazard intensity and future trend

For example, for a “medium” current hazard level with an “increasing” trend, the future hazard level will be set to “high.”

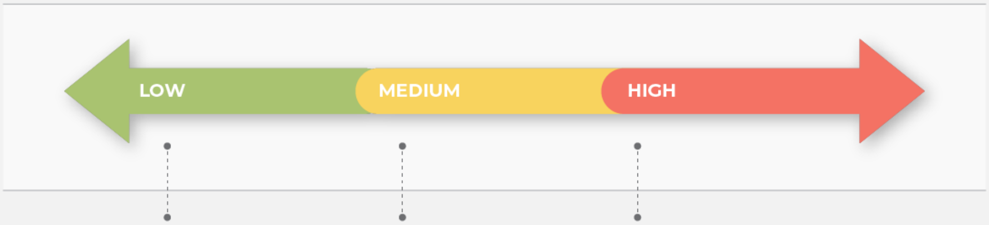
7 Screen climate predictions and determine how much climate stressors will change in the future

- Users are advised to focus on primary climate stressors and de-prioritize stressors that have subordinate impacts on the renewable energy project’s performance.

For wind energy, the primary stressor is the **wind speed**, and for solar energy, the **solar irradiation**.

- An overview of the predominant global trends is displayed in **Figure 1.1,** whereas comprehensive country-specific information can be found in Solaun and Cerda (2019).[5]
- Where applicable, update country-level data with regional predictions using any of the online resources in **Table 1.2**.

8 **Use the scoring system provided below to assess climate stressor variability based on the rate of anticipated change of the primary stressor.**



LOW	MEDIUM	HIGH
No significant change (with respect to today's values within the timeframe of the assessment.	Notable change over a period exceeding the timeframe of the assessment (e.g., more than 50 years).	A significant change is expected within the timeframe of the assessment (i.e., in the case of a rapidly evolving phenomenon).

OUTPUT

A preliminary characterization of the climate hazards/stressors potentially affecting the project for current and future climate conditions.

IMPORTANT NOTE

Future Climate Projections: Representative Concentration Pathways (RCPs) and Shared Socioeconomic Pathways (SSPs)

It is common practice to project future climate conditions based on the RCPs, to represent different trajectories of radiative forcing levels over time. Out of the four RCP scenarios, RCP 8.5 represents the highest emissions scenario, whereas RCP 2.6 represents the lowest emissions scenario. RCP 2.6 should be generally avoided when making projections because it is overly optimistic compared to recent emissions trends.

In 2016, the Shared Socioeconomic Pathways (SSPs) were introduced as an update and a substantial expansion over the RCPs. The SSP framework contains a total of eight different climate trajectories based on alternative/plausible scenarios of future emissions and land-use changes, according to which society and ecosystems will evolve in the 21st century. Global scale predictions of climate parameters for different SSPs are available in the WorldClim database.

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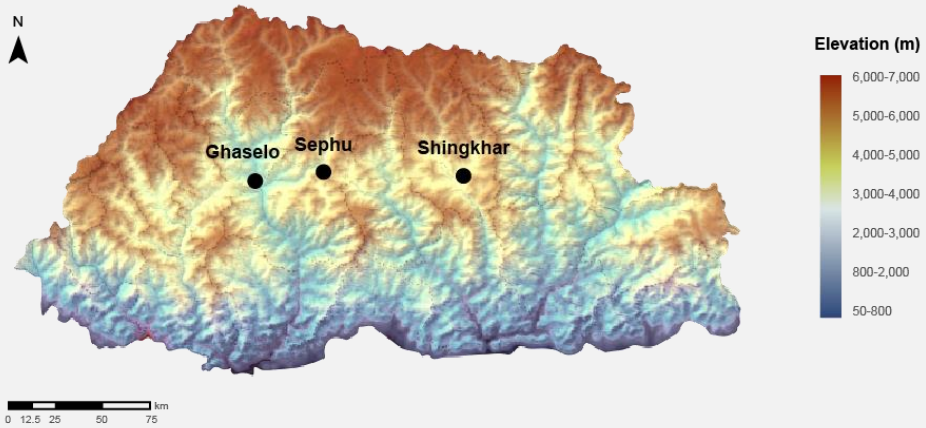
[5] Solaun, K. , and E. Cerda. 2019. "Climate change impacts on renewable energy generation. A review of quantitative projections." *Renewable and Sustainable Energy Reviews* 116 (December 2019).

BOX 1.1 CHARACTERIZATION OF CLIMATE-CHANGE-INDUCED HAZARDS FOR SOLAR AND WIND PLANTS: AN EXAMPLE CASE FROM BHUTAN

Bhutan is a country that is highly dependent on hydropower for its own power consumption and revenue (power export to India is an important revenue source). Given that hydropower is a climate-sensitive sector, Bhutan aims to diversify its power generation portfolio by developing other renewable projects. In this context, the Asian Development Bank (ADB) performed a Climate Risk and Adaptation (CRA) assessment for developing two solar PV plants (48 MW) and one wind power plant (23 MW) in the country—in Shingkhar and Sephu (solar) and Gaselo (wind) (**Figure B1.1.1**).

FIGURE B1.1.1 Elevation map of Bhutan and locations of the project areas: Gaselo (wind power), Sephu and Shingkhar (solar power) *Source*: Nolet and Lutz 2021.



The first part of the CRA focused on the characterization of current and future climatic conditions at the site-specific setting of the projects. The solar energy production estimates (using downscaled data from the CMIP5 model) demonstrated a slight decrease in total incident solar radiation for RCP 8.5, whereas for RCP 4.5 the decrease was projected until approximately 2050, after which the solar radiation would start to increase again. The results were in line with other studies in India and adjacent regions. On the other hand, the wind energy production assessments showed that wind speed changes are minor, and mainly point toward slight increases.

In addition, three climate hazards have been prioritized as most critical for the project under consideration: (i) extreme precipitation related to extreme runoff and flooding events, and landslide and erosion risks; (ii) drought; and (iii) heatwaves. For their characterization, the current and future trends for the following set of indicators were analyzed: (i) the annual maximum one-day precipitation was considered representative of future trends in extreme precipitation and therefore was linked to flooding, slope instability, erosion and extreme snowfall (for the mountainous sites); (ii) the consecutive dry days were linked to droughts; and (iii) the annual maximum/minimum of daily maximum/minimum temperatures were linked to extreme heat events.

The CRA highlighted the main risks for the infrastructure, which stemmed from extreme weather and hence supported the identification of the proper adaptation measures; these measures included drainage works, vegetation as a means to reduce erosion rates, and strong foundations.

Source: Nolet, C., and A.F. Lutz. 2021. “Renewable Energy for Climate Resilience in Bhutan – Climate Risk and Adaptation Assessment.”

TOOL 1.2

ASSESSMENT OF CLIMATE IMPACTS

In solar and wind projects, impacts can materialize as:

- **Physical damage** that may include the partial or total loss of the asset, increased maintenance costs, and business disruption.
- **Operational disruptions** (e.g., due to dust on solar panels or icing on wind turbines).
- **Reduced energy production** (due to the unavailability of natural resources) or missed opportunities for higher energy production (in case of an abundance of natural resources).

Whatever their specifics, impacts introduce losses reflected in increased expenditures or revenue losses. The higher the expected loss, the higher the severity of the impact. Schematic illustrations of the potential climate impacts on wind/solar parks are displayed in **Figures 1.2** and **1.3**.

INPUT

The tool assists users in qualitatively assessing the impact[6] of the climatic stressors identified above (input from **Tool 1.1**) on the wind or solar project (and the project components).

1 **Define climate-induced vulnerabilities of the renewable energy project under consideration**

Table 1.3 contains a list of potential impacts (typical of most solar and wind parks). Each impact is associated with a particular hazard/stressor. Shortlist the most relevant impacts (to your regional setting) by eliminating hazards/stressors that do not correspond to regional climate conditions/projections.

2 **Assess the potential loss** associated with negative impacts. Assessments should include:

- Number of days per year that the facility is out of service, or is underperforming (e.g., due to damage to critical asset components or operational disruption).
- Expected reduction in power generation (e.g., an x% reduction of annual solar irradiation will result in a y% reduction in power generation capacity).
- Indicative cost of repairs or rebuilding in extreme cases (e.g., increased cost of cleaning solar panels from soil and dust in case of increased drought).

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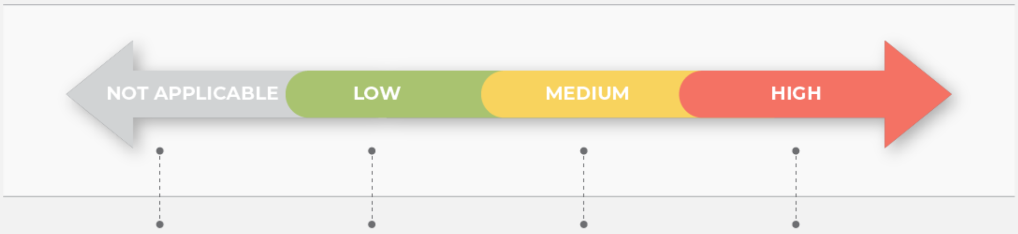
[6] The present tool focuses on potential negative impacts for which adaptation measures should be planned. However, it is sometimes the case that climate stressors can positively impact the facility (i.e., increased precipitation may reduce the operational costs associated with the cleaning of panels). For the purposes of this preliminary assessment, positive impacts have been tacitly excluded from consideration.

3 **Score impact severity**: Use the scoring system provided below to characterize the criticality of each potential impact on the operability and generation capacity of the wind or solar park.



NOT APPLICABLE	LOW	MEDIUM	HIGH
The project is not impacted by the climate threat.	▪ Components of the facility may be slightly damaged. ▪ Damaged components can be restored quickly and at low cost. ▪ The facility may operate at reduced capacity for a few hours.	▪ Substantial parts of the facility may be moderately damaged. ▪ Damage/service restoration can be costly. ▪ Operational disruptions may last for a few days.	▪ The majority of the facility has been severely damaged, requiring extensive restoration or replacement activities. ▪ The facility may remain out of service (or operate at reduced capacity) for an undetermined period. ▪ Unreliable service and social distrust.

4 **Repeat the assessment** for all the alternative project options and locations under investigation.

OUTPUT

A comprehensive list of potential climate impacts on the project and the project's components, highlighting key system vulnerabilities.

BOX 1.2. GROUND-MOUNT PV SYSTEMS AND HURRICANES

Field observations and expert structural engineering analysis were combined in a 2018 Rocky Mountain Institute paper to investigate the reasons some ground-mount PV systems failed while others survived during the 2017 hurricane season in the Caribbean. By analyzing the similarities of the survived and failed systems, the study determined the key indicators of structural vulnerabilities (common in all failed systems) and proposed design recommendations for enhancing resilience to hurricanes (common to the majority of the survived systems).

Vulnerability indicators	Hurricane resilience indicators
▪ Undersized rack or rack not designed for wind loads ▪ Undersized bolts ▪ Lack of vibration-resistant connections ▪ Use of self-tapping screws instead of through bolting	▪ Dual post piers ▪ Through bolting of solar modules ▪ Lateral racking supports ▪ Vibration-resistant module bolted connections such as nylon-insert lock nuts ▪ Quality assurance/quality control (QA/QC) in construction

Source: Burgess, C., and J. Goodman. 2018. *Solar Under Storm: Select Best Practices for Resilient Ground-Mount PV Systems with Hurricane Exposure*. RMI (Rocky Mountain Institute).

TABLE 1.3 Climate change threats and their potential impacts on solar parks

Climate Threats	Controlling Variable	Impacts on Solar Parks
CLIMATE STRESSORS (affected by climate change)		
Changes in cloudiness	Precipitation	• Prolonged cloudiness results in decreased solar power output, especially for concentrated solar power systems because they cannot use diffused light.
Changes in mean temperature	Temperature	• The performance of the photovoltaic panels decreases by about 0.5 percent for every 1°C increase in temperature. The exact impact depends on the used materials (e.g., PV panels with crystalline silicon are more vulnerable to temperature increases than amorphous silicon). • Increased demands for cooling of the solar equipment (e.g., increased usage of water for cooling the concentrating solar power systems) may further increase the operational costs. • Long-term exposure to higher temperatures causes faster material aging.
Changes in precipitation	Precipitation	• Increased mean precipitation may be favorable for cleaning purposes, but frequent rain clouds hinder energy production. Decreased mean precipitation hinders cleaning methods that are based on natural rain.
Changes in icing/freezing conditions	Temperature/ precipitation	• Colder temperatures increase the power output. However, accumulated water on solar panels can freeze in very low temperatures, resulting in ice formation that may reduce performance or potentially cause cracks (especially when shifting from hot to cold temperatures).
Soiling and accumulation of dust, dirt, snow, or increased air pollution	Precipitation/ temperature/ wind	• Soiling increase worsens the performance of the solar panels or mirrors, and increases operation and maintenance costs because more frequent cleaning is necessary (especially in regions where rainfall is expected to decrease significantly and/or the intensity and frequency of dust storms are expected to increase).
Relative humidity	Precipitation/ temperature	• An increase in humidity decreases the energy generation output (due to the reflection or refraction of the sunlight caused by the water droplets on the panels or mirrors). • It also results in faster deterioration of the panels or other components of the solar park over time.

CLIMATE HAZARDS (affected by climate change)		
Wind speeds	Wind	• Wind works favorably by cooling down the solar panels. A decrease in the mean average wind speed (in combination with increased temperatures) will increase cooling demands.
Sea level rise	Global sea level	• Facilities in coastal areas may be threatened by inundation or by the additional loading caused by the sea level increase and the corresponding influence of the groundwater pore pressures.
Extreme winds, rain, snow, hail, cyclones, and more frequent lightning	Wind/precipitation	• Extreme weather events may cause physical damage to the project components (including the inverter, the panels, the mirrors, as well as the transmission and distribution lines and the access roads), adversely affecting the functionality of the park.
Extreme heat	Temperature	• Extreme heat introduces extreme energy demands on very hot days. The solar park's power output may not be able to cover the daily load demand during that period. • Extreme heat usually has a detrimental effect on vegetation in the vicinity of solar parks which, in turn, reduces the cooling benefits that such vegetation could offer.
Droughts (increase in the number of dry days) and increase in water unavailability	Temperature/ precipitation	• Increased water demand and water usage conflicts. • Cooling systems that use water (especially for the CSPS that utilizes water in a fundamental way) cannot work without water. Cleaning methods that use water may have to be replaced by non-water cleaning techniques
Landslides (a cascading hazard caused by extreme rain that saturates soil and decreases stability)	Precipitation	• Facilities (including the transmission lines and access roads) located in landslide-prone areas may experience increased (or unprecedented) risk when significant changes in precipitation extremes occur during the lifetime of the project.
Floods	Precipitation	• Physical damages to the solar facility as well as the transmission lines, the substations, and the interdependent roads or other interdependent infrastructure.
Fires	Temperature[7]	• Physical damage to the power facilities and the transmission and distribution equipment hinders access to the facility

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[7] Although there is no direct relation between fires and climate change, there is evidence that as climate conditions have become hotter and drier, wildfires have grown more intense and destructive.

TABLE 1.4 Climate change threats and their potential impacts on wind parks

Climate Threat	Controlling Variable	Impacts on Wind Parks
CLIMATE STRESSORS (affected by climate change)		
Changes in wind potential (intensity)	Wind	• Unfavorable changes in the mean wind characteristics (decreased mean wind speed or different wind directions) will have a long-term negative impact on the overall performance of the wind park. • Decreased power output during prolonged periods of low wind (i.e., below the operational threshold). Favorable changes in the mean wind characteristics may result in regret when the sizing of the park does not capture the full wind energy potential.
Changes in icing/freezing conditions	Temperature/ precipitation	• The formation of ice on the blades results in reduced performance. • Increased deterioration of various components of the structure. • Electrical or mechanical (e.g., rubber seals may become brittle at low temperatures) failures. • Measurement and control errors. • Challenges to the installation and operation processes.
Sea level rise and salinity	Global sea level	• Facilities in coastal areas may be threatened by: inundation or permanent settlements and foundation instabilities as a result of sea level and ground water level increase' • Foundation instabilities/failures of offshore wind turbines caused by harsher wave/current conditions. • Salinity causes increased corrosion in the structure’s steel components.
Increase in the mean temperature	Temperature	• Increased temperatures reduce the air density, resulting in decreased power production. • The increase of the global mean temperature results in ice melting and drifting sea ice which may cause additional static and dynamic loading on an offshore turbine structure in polar areas, exceeding its structural or geotechnical capacity.

CLIMATE HAZARDS (affected by climate change)		
Extreme wind speeds and increased turbulence intensity	Wind	▪ Extreme winds and high turbulence impose high stressing on the blades/pylon/foundation of the turbine and vibrations of the structure and machinery. When the structural capacity of the design is exceeded, physical damage to the various components should be expected. ▪ Decreased power output during extreme winds when the wind turbines are halted for safety reasons (to avoid major stresses and potential damages to the structure).
Extreme storms, waves, cyclones, hurricanes, storm surges, and more frequent lightning	Precipitation/wind	▪ Extreme weather events may cause physical damage to the project components (including the tower, the foundation, the rotor, as well as the transmission and distribution lines and the access roads or port facilities), adversely affecting the functionality of the park.
Extreme heat and heatwaves	Temperature	▪ Extreme heat introduces extreme energy demands on very hot days. The wind park's power output may not be able to cover the daily load demand during specific time periods.
Landslides (a cascading hazard caused by extreme rain that saturates soil and decreases stability)	Precipitation	▪ Facilities (including the transmission lines and access roads) located in landslide-prone areas may experience increased (or unprecedented) landslide risk when significant changes in precipitation extremes occur during the lifetime of the project.
Floods	Precipitation	▪ Physical damages to the wind facility as well as the transmission lines, the substations, and the interdependent roads or other interdependent infrastructure.
Fires	Temperature	▪ Physical damages to the power facilities and the transmission/distribution equipment. ▪ Even when not directly impacting the facility, (uncontrolled) wildfires may temporarily obstruct access to the facility.

TOOL 1.3

ASSESSMENT OF CLIMATE RISKS

Following the definitions provided in the Umbrella Toolkit (Modules 1.2 and 2.1), internal climate risks originate from hazards/stressors that are posed directly on the project, describing the **likelihood of a project to experience an impact of a given severity**. In preliminary climate assessments, the term "likelihood" is schematically used to encapsulate two factors:

- The *frequency of the climate event* (i.e., how often the facility experiences such impacts), which is primarily a function of the intensity of the event. The stronger the event, the lower its frequency.
- The *uncertainty of the evolution of climatic factors*. In that respect, climate projections following an RCP 8.5 pathway (very pessimistic scenario) may be considered less likely to materialize.

INPUT

The tool may be used for a qualitative assessment of *internal* climate-induced risks for solar or wind projects. **Tool 1.3** should be used in combination with **Tool 1.4** (intended to gauge external risks originating from hazards affecting not the project per se but its broader socioeconomic system) to estimate the total (internal and external) climate risk of the solar or wind project. The present tool is aligned with the World Bank's Climate and Disaster Risk Screening Tool. Advanced users who are familiar with this tool may consult it in parallel.

1 **Assign likelihoods to hazards/stressors** potentially affecting the renewable energy project.
  - For hazards: As a rule of thumb, set the likelihood to "low" for events that take place once or twice during the life cycle of the project (e.g., an extreme flood that has inundated the entire facility), or "high" for events that have a recurrence period (one to five years).
  - For climatic stressors: For conservative estimates, consider the likelihood to be "high" for all climate projections. Alternatively, set the likelihood to "low-medium" for climate projections made using RCP 8.5, and set the likelihood to "high" for RCP 4.5 and 6.0.

2 **Calculate the climate risk level of each hazard/stressor** according to the equation [HAZARD x LIKELIHOOD] x IMPACT using the two-dimensional color matrix provided below.
First, combine HAZARD/STRESSOR with LIKELIHOOD to estimate the THREAT severity. Then combine the THREAT severity with the IMPACT severity to calculate RISK level (i.e.,

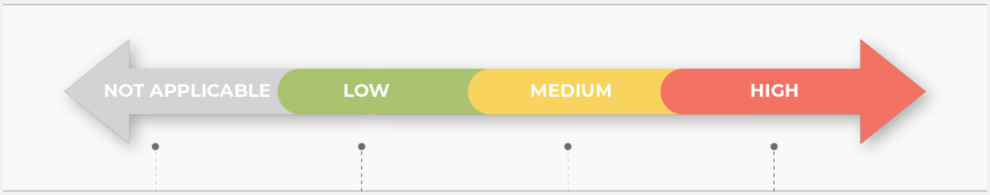
read the HAZARD severity in the first column and combine it with the IMPACT score displayed on the first row).

Example calculation: [Low x Medium] x High = Low x High = Medium

	Low	Medium	High
Low	LOW	LOW	MEDIUM
Medium	LOW	MEDIUM	HIGH
High	MEDIUM	HIGH	HIGH

3. **Build the risk matrix of the project** combining risks stemming from all potential threats. If available, repeat the process for alternative renewable energy locations/configurations.

4. **Describe consequences and, where possible, provide cost estimates for the level of operational disruption**. As displayed in the graphic below, low climate risks are associated with minimum disruptions to the facility and the broader community, whereas high climate risks may cause service unavailability for prolonged periods and significant revenue loss (that can be catastrophic for the investment), and in extreme cases, social unrest and distrust.



NOT APPLICABLE

Minor operations disruptions are very rare.

LOW

- The facility may experience (e.g., once per year) minor operational disruptions.
- Major operational disruptions are very rare.
- The increase in maintenance cost is relatively low.
- The energy production of the facility will remain constant (even for the RCP 8.5 projections).

MEDIUM

- Significant operational disruptions may happen on an annual basis or less frequently.
- A moderate increase in the maintenance cost should be expected.
- A slight decrease of energy production for RCP 6.0 or 4.5 projections (and a moderate decrease for the RCP 8.5 projections).

HIGH

- Major operational disruptions may take place frequently.
- Maintenance cost may substantially increase.
- A considerable decrease in energy production is projected in all RCP scenarios.

OUTPUT

A systematic description of all potential climate risks affecting the renewable energy generation project and associated rough cost estimates.

TOOL 1.4

EVALUATION OF CLIMATE-CHANGE-INDUCED EXTERNALITIES AND IMPACTS

External risks originate from hazards or stressors affecting either the interlinked infrastructure of the renewable energy project or its broader socioeconomic system, thus indirectly impacting the project's operations and power generation capacity. Because external risks are beyond the control of the project, it is important to identify them early in the project selection process, estimate the severity of their impacts, and plan contingencies where possible. It may even be advisable to abandon or restructure projects that experience high external risks that cannot be mitigated.

INPUT

This tool may be used to perform a preliminary screening of the broader socioeconomic impacts of climate change and their interactions with the project underway.

1. **Identify external risks that are pertinent to the regional setting of the renewable energy project under consideration.**

   A list of commonly encountered external risks in solar and wind projects is provided in **Table 1.5**. The list is indicative, describing conditions that may introduce positive or negative externalities to the project due to climate change. The users are requested to customize the list as appropriate to make it relevant to the project specifics.

2. **Score the "external risk level"** as "low," "medium," or "high" (specifying risk sources that are particular to the project under consideration) and add results to the climate risk matrix of the project (output of **Tool 1.3**).

3. **For each externality, estimate potential losses (or gains) and determine strategies to remediate their negative consequences.** The majority of external risks cannot be mitigated by means of design,[8] but they should be revisited and re-evaluated when assessing the bankability of the project and when the risk allocation matrix is structured (Phases 2 and 3 of the PPP project cycle). The users are hence advised to carefully evaluate them and document the results in detail.

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[8] External risks (e.g., failure of interconnected infrastructure) cannot be mitigated by redesigning the project because these fall outside the project boundaries. Hence, users are encouraged to identify such risks now, so that they can be considered when devising the appropriate risk-sharing mechanisms and assessing the project's bankability in Phases 2 and 3.

TABLE 1.5 External climate-induced risks and consequences for renewable projects

External Factors that Can Be Impacted by Climate Change	Example Consequences for Renewable Projects
Demographic changes in the characteristics of human population and population segments. These may refer to population distribution, age, marital status, occupation, income, education level, and other statistical measures that may influence the project.	Demographic changes may affect the project through changes in energy demand and prices. Population reduction or increase will be reflected in the needs for energy, either by households or by industries that will be developed to serve the respective communities.
Associated infrastructure (transmission lines, storage systems and access roads): Climate change induced hazards (e.g., permafrost thawing, landslides, mudflows, erosion, and scour) may disrupt the operation of associated infrastructure systems.	The risk of failure of the interconnected transmission lines poses a significant external risk to the renewable energy project. Storage systems applicable to renewable energy projects have not yet been developed at full utility scale but battery energy storage systems (BESS) currently constitute an integral part of renewable energy storage solutions. BESS are particularly vulnerable to extreme heat that increases the risk of thermal runaway[9] and which may result in explosions and/or fire. Overground transmission lines are significantly more vulnerable to climate-related hazards compared to underground lines. For example, extreme storms may cause failures of transmission lines leading to long disruptions of their operation. Thawing of permafrost ground (due to warming environmental conditions) or extreme storms can cause large-scale settlement and severe damage along roads that connect the site to the surrounding communities and external resources. Damages to the control buildings can be dangerous for the safety of the staff and the operability of the project. Particular attention must be paid to enhancing the safety and sustainability of the facility and the surrounding environment.
Social acceptance of wind and solar farms: evolution of regional and national regulations and guidelines for enhancing the involvement of the community.	Lawsuits from local groups could slow down projects, making permission issuing more complex and resulting in discouraging developers. It may be the case that the time required for such complaints or legal implications to be resolved is so extensive that the technology could become outdated. This risk is more applicable to larger-scale projects that usually have a greater environmental impact and therefore trigger greater opposition. Users seeking

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[9] Thermal runaway is defined as the phenomenon of energy leakage in the form of heat from a damaged battery. The process is exacerbated by extreme heat; if not mitigated in time, such heat release could lead to explosions.

External Factors that Can Be Impacted by Climate Change	Example Consequences for Renewable Projects
	further guidance may consult the International Finance Corporation's (IFC's) Performance Standards.[10]
Geomorphological and environmental changes: Climate-related hazards may affect the surrounding environment, morphology, and/or surrounding infrastructure, and consequently affect the operation and even the exposure and vulnerability of the project.	Wildfires pose a significant threat to renewable energy projects' operations due to their dependency on powerlines. Increased precipitation may trigger landslides in precarious zones, increasing the risk of structural failures.
Land use/land cover (LULC) changes, whereby a specific area of land is converted from one use to another.	Significant LULC changes in the surrounding environment of the project can have negative impacts on the project. For example, LULC changes may result in streamflow changes which can have an important effect on the flood risk of the area. Conversely, the development of the project in an unsuitable area (far from existing transmission infrastructure, close to protected areas, away from existing roads, interfering with animal migration routes) may have severe environmental and societal impacts. Considerable changes in land use, especially shifts toward water-depleting modes of agriculture, can increase competition for water resources, resulting in policy-enforced limitations that can affect solar projects. This is most prevalent in concentrated power systems (where water is a fundamental operational element).
Technological changes: The invention and practice of new technologies and innovative fields that may be impactful for the development and operation of renewable projects.	Technological advancements may provide opportunities for the project to adopt innovative techniques, which may enhance the project's resilience and its potential to operate as a means for adaptation to climate change impacts. For example, monitoring weather conditions and transmitting data to the control system of a wind park prevent the risk of catastrophic failure.
Policy and regulation changes: Evolution of national and worldwide guidelines and regulations on sustainability and climate change.	Changes in: (i) government policy, (ii) national or regional action protecting the use of water (for solar), (iii)acceptable noise thresholds (for wind turbines), or (iv) land usage and biodiversity issues can have major implications for the project's viability.

OUTPUT

A ranked list of climate externalities for the project, including a description of consequences and possible remediation measures

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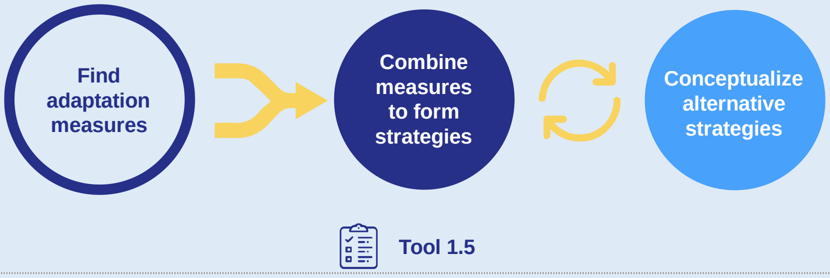
[10] IFC (International Finance Corporation). "Performance Standards." https://www.ifc.org/wps/wcm/connect/Topics_Ext_Content/IFC_External_Corporate_Site/Sustainability-At-IFC/Policies-Standards/Performance-Standards.

Step 2

Screen Possible Adaptation Strategies To Reduce Climate Risks

SCOPE	To identify adaptation measures and compose alternative strategies that build climate resilience into the renewable project by reducing the project-specific climate risks, while maximizing the positive socio-environmental impact of the project.
PROCESS	The process starts with a detailed mapping of possible adaptation solutions addressing the project's climate risks (derived from **Tool 1.3**). Users are then asked to build alternative adaptation strategies combining different adaptation measures. The alternative strategies may differ in terms of capital costs and may offer different protections within the multi-hazard environment of the project. Finally, a pre-selection of the preferred adaption strategy is performed in **Step 3** using a multi-criteria decision framework.
	
TOOLS	**TOOL 1.5** Planning of climate adaptation strategies
OUTPUT	A list of possible adaptation strategies for further consideration (during **Step 3**)

TOOL 1.5

PLANNING CLIMATE ADAPTATION STRATEGIES

The adaptation strategies for wind or solar energy parks can be classified into three major groups:

- **Changes in the planning of the project**, including changes in the location or changes in the installed capacity. For example, the agency may wish to consider expanding the intended capacity of the power park to benefit from the projected higher potential for power generation or to consider integrating a potential expansion in the planning process for the future.
- **Changes in the design through hard-engineering solutions** (i.e., structural interventions) aimed at increasing the robustness of the design against identified climate risks (e.g., increase in elevation of PV panels above the water surface elevation to minimize the risk of flooding, increase foundation dimensions of offshore wind turbines to increase stability in case of severe storms).
- **Green infrastructure solutions** that aim to protect the renewable energy project and safeguard its operational efficiency without building structural interventions and usually at a significantly lower cost. Such solutions will generate additional climate mitigation and biodiversity benefits. In this category, we may find nature-based solutions (NBS) that work with natural processes to reduce risks (e.g., use of vegetation for landslide protection and/or on-site soil stabilization, wild grasses and flowers to cool off panels and reduce dust, or eco-friendly scourings solutions for the protection of offshore foundations) or technological interventions (e.g., auto-calibration systems in solar panels to increase power-generation efficiency in cloudy conditions, and Internet of Things technologies to optimize maintenance and prevent damages in wind/solar parks).

INPUT

This tool will guide users through the process of structuring climate adaptation strategies that are appropriate for the level of anticipated climate risk.

1 **Select adaptation measures**. Identify threats that, based on the preceding analysis, introduce high risk to the renewable energy project. For each individual threat, look up **Table 1.6 & 1.7** and identify adaptation measures that can mitigate the respective climate impact. Users may also wish to refer to the International Atomic Energy Agency (IAEA) 2019 publication Adapting the Energy Sector to Climate Change, which provides examples of adaptation options for different power development systems, including renewable energy technologies.

2 **Build an adaptation strategy by combining different adaptation measures**. Define a comfortable level of risk and combine adaptation options that can reduce the risk below the maximum acceptable level.

3 **Conceptualize alternative adaptation strategies.** Review adaptation strategies and generate alternatives by replacing (where possible) hard-engineering solutions with soft-engineering solutions. It is generally considered good practice to come up with more than one strategy to be further evaluated in **Step 3**. Among such options, nature-based solutions are a cost effective way to build infrastructure resilient to a changing climate, while also delivering other societal benefits.

4 **Provide rough cost estimates for each adaptation strategy.** It is advisable to consult local contractors and—where available—cost estimators to obtain a preliminary appraisal of the costs associated with the preferred adaptation options.

5 **Repeat the process** for other climate hazards to come up with a complete strategy for the project (or the project alternatives).

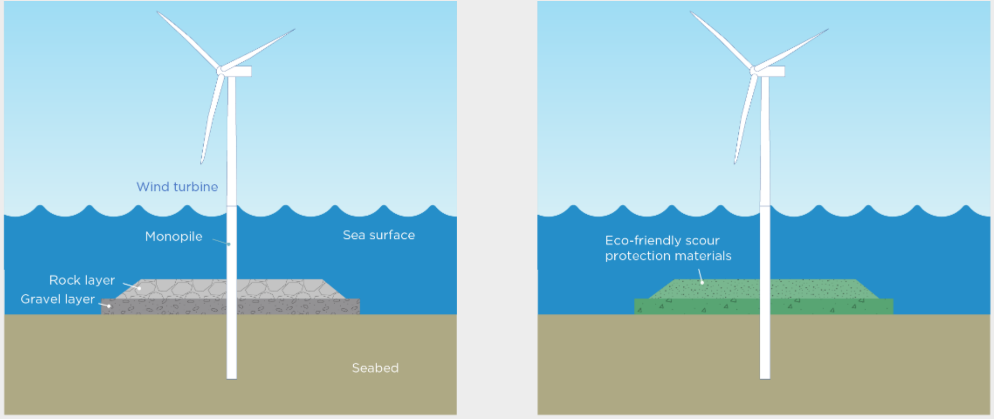
OUTPUT

A list of possible adaptation strategies for further consideration.

BOX 1.3. NATURE-BASED CONCEPTS INTEGRATED INTO THE DESIGN OF OFFSHORE WIND STRUCTURES

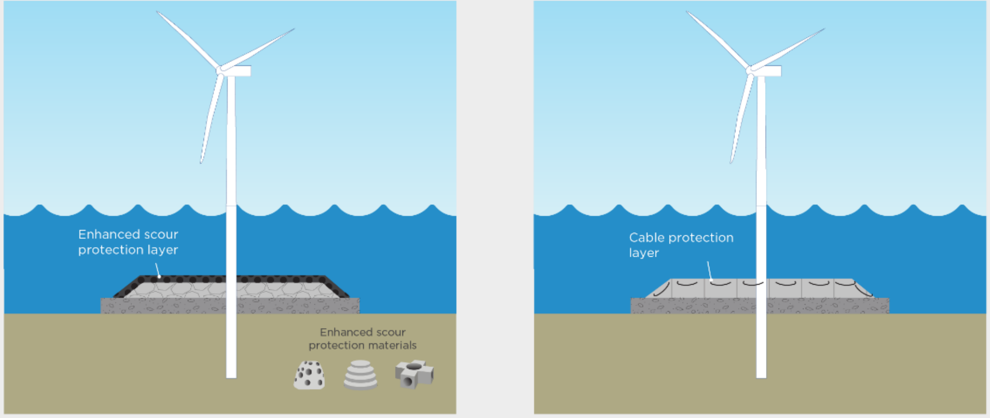
Scouring is the erosion of seabed sediment surrounding the foundation of a wind turbine. If extensive, scouring can lead to geotechnical failures resulting in very large displacements and tilting of the tower or even total collapse of the wind turbine. Placing rocks, stones, or gravel around the foundation is the most common strategy to prevent scouring. Using scour protection that respects marine life is an eco-friendly way to decrease the environmental impact of wind farms while keeping the turbines safe from strong waves/currents. The Nature Conservancy (TNC) and INSPIRE Environmental have created a catalogue of nature-based designs for augmenting offshore wind structures in the United States that include different ways to mimic the natural environment and enhance marine life (**Figure B1.3.1**): (i) eco-friendly scour protection materials in place of traditional scour methods, (ii) scour protection enhancements onto or adjacent to an existing turbine scour protection layer, and (iii) cable protection layers that would be used when inter-array and export cables cannot be adequately buried.

FIGURE 1.3.1 Examples of different scour protection configurations mimicking marine life environments (adapted from: The Nature Conservancy and INSPIRE Environmental 2021)



Traditional scour protection

1. Replacement with eco friendly scour protection materials (e.g., recycled concrete)



2. Addition of an enhanced scour protection layer

3. Cable protection layer

Source: The Nature Conservancy and INSPIRE Environmental. 2021. *Turbine Reefs: Nature-Based Designs for Augmenting Offshore Wind Structures in the United States*. https://www.nature.org/content/dam/tnc/nature/en/documents/TurbineReefs_Nature-BasedDesignsforOffshoreWind_FinalReport_Nov2021.pdf.

TABLE 1.6 List of potential climate adaptation measures for solar parks

Climate Threats	Impacts on Solar Parks	Adaptation Measures
Changes in solar irradiation	▪ Decrease in solar irradiation results in decreased solar power output, especially for concentrated solar power (CSP) systems because they cannot use diffused light	▪ In-depth solar irradiation analysis incorporating future projections during the sizing process.
Changes in cloudiness	▪ Prolonged cloudiness results in decreased solar power output, especially for CSP systems because they cannot use diffused light	▪ Installation of a thermal storage system for CSP systems (where part of the collected heat is stored) can make the power facility operational even during periods without direct sunshine. ▪ PV panels with rougher surfaces or textured glass and antireflective coatings perform better under cloudy weather conditions because they capture sunlight from multiple angles. ▪ Installation of bypass diodes wired in parallel to the solar cells provides energy production even in shading conditions. ▪ Monocrystalline solar panels provide higher efficiency in cloudy conditions. ▪ Installation of an advanced tracking and control system to rotate the panels based on weather conditions.
Changes in mean temperature	▪ Drop in the PV performance ▪ Increased demands for cooling the solar equipment may increase operational costs ▪ Faster material aging	▪ Use of temperature-resistant materials. ▪ Usage of air or waterless cooling systems to decrease temperatures and improve power output (e.g., passive airflow beneath mounting structures). ▪ Heat-resistant cells and robust materials for the other components.
Changes in precipitation	▪ Increased precipitation is favorable for cleaning purposes, but frequent rain clouds hinder energy production ▪ Decreased mean precipitation is a threat to cleaning methods that are based on natural rain	▪ Use of cleaning methods that are not dependent on rainfall.
Changes in icing/freezing conditions	▪ Ice formation on the panels may reduce performance or potentially cause cracks (especially when shifting from hot to cold temperatures)	▪ Use of hydrophobic coatings.

Climate Threats	Impacts on Solar Parks	Adaptation Measures
Soiling and accumulation of dust, dirt, snow, or increased air pollution	▪ Increased soiling hampers the performance of the solar panels or mirrors and increases operation and maintenance costs because more frequent cleaning is necessary (especially in regions where rainfall is expected to decrease significantly and/or the intensity and frequency of dust storms are expected to increase)	▪ Increased monitoring and inspection. ▪ Increased frequency of cleaning. ▪ Anti-soiling coatings. ▪ Calibrating the panels to allow snow to fall or selecting an appropriate tilt panel angle to clean dust.
Relative humidity	▪ An increase in humidity decreases the energy generation output It also results in faster deterioration of the panels or other components of the solar park over time	▪ Use of hydrophobic coatings. ▪ Specify cabling and other components that can withstand high moisture content and are corrosion resistant. ▪ Frequent cleaning schedule and maintenance program.
Wind speeds	▪ Wind works favorably by cooling down the solar panels. A decrease in the mean average wind (in combination with increased temperatures) will increase cooling demands.	▪ Use of a robust cooling system.
Sea level rise	▪ Facilities in coastal areas may be threatened by inundation or by the additional loading caused by the increase of the sea level and the corresponding influence of the groundwater pore pressures	▪ Consideration of future sea level rise during the design process. ▪ Increase elevation of the critical components. ▪ Avoid low-lying areas/coastal areas during the site selection process. ▪ Protection and restoration of natural flood barriers such as flood plains, salt marshes, fresh-salt water transitions.
Extreme winds, rain, snow, hail, cyclones, and more frequent lightning	▪ Extreme weather events may cause physical damage to the project components (including the inverter, the panels, and the mirrors, as well as the transmission and distribution lines, and the access roads), adversely affecting the functionality of the park.	▪ More robust mounting of structures to withstand extreme weather conditions (e.g., wind-proofing measures). ▪ Reinforce glass to withstand extreme weather. ▪ Increase lightning protection of the site and the panels (e.g., installation of lightning rods). ▪ Decentralize the power generation and improve grid stability (e.g., by installing distributed systems like micro-inverters to each panel).
Extreme heat	▪ Extreme heat introduces extreme energy demands on very hot days. The solar park's power output may not be able to cover the daily load demand at specific time periods.	▪ Use of temperature-resistant materials. ▪ Usage of air or waterless cooling systems to decrease temperatures and improve power output (e.g., passive airflow beneath mounting structures). ▪ Heat-resistant cells and robust materials for the other components.

Climate Threats	Impacts on Solar Parks	Adaptation Measures
Droughts (increase in the number of dry days) and increase in water unavailability	▪ Increased water demand and water usage conflicts ▪ Cooling systems that use water cannot work properly	▪ The usage of water (source, quantity, frequency) should be assessed thoroughly at an early stage to avoid adverse impacts on local populations and the operation of the project. ▪ Selection of a reliable water source (groundwater, stored water, access to a mobile tank, or natural rainfall) for the cleaning or other functional purposes of the project. ▪ Avoid using cooling that utilizes water. ▪ Favor cleaning methods that do not rely on water (e.g., dry scrubbing) or state-of-the-art waterless technologies (e.g., with electrostatic repulsion).
Landslides	▪ Facilities (including the transmission lines and access roads) located in landslide-prone areas may experience increased (or unprecedented) landslide risk when significant changes in precipitation extremes occur during the lifetime of the project.	▪ In-depth landslide risk analysis during site selection that incorporates future projections (because a site that seems safe now may become dangerous in the future). ▪ Re-evaluation of the site selection and avoidance of landslide-prone sites. ▪ Special consideration of landslide protection measures, e.g., retaining walls, vegetation, underwater drainage, reducing slopes.
Floods	▪ Physical damages to the solar facility as well as the transmission lines, the substations, and the interdependent roads or other interdependent infrastructure.	▪ In-depth flood risk analysis during the site selection that incorporates future projections (because a site that seems safe now may become dangerous in the future). ▪ Re-evaluation of the site selection and avoidance of flood-prone sites. ▪ Special consideration of flood protection measures, e.g., increased drainage capacity of the site's drainage system, the elevation of the critical equipment (e.g., the transformer, inverter, solar panels). ▪ Protection and restoration of natural flood barriers such as flood plains, salt marshes, fresh-salt water transitions.
Fires	▪ Physical damages to the power facilities and the equipment of transmission and distribution lines	▪ Fire zoning, fire prevention, and firefighting plans such as continuous monitoring and early warning systems for immediate actions in case of a fire trigger.

TABLE 1.7 List of potential climate adaptation measures for wind parks

Climate Threats	Impacts on Wind Parks	Adaptation Measures
Changes in wind potential (intensity)	▪ Unfavorable changes in the mean wind characteristics (decreased mean wind speed, or different wind directions) will have a long-term negative impact on the overall performance of the wind park ▪ Decreased power output during prolonged periods of low wind (i.e., below the operational threshold) ▪ Favorable changes in the mean wind characteristics may result in regret when the sizing of the park does not capture the full wind energy potential	▪ In-depth wind potential analysis incorporating future projections for sizing purposes. ▪ Utilization of computer control and tracking systems that monitor the wind speed and direction and calibrate the orientation of the wind turbines (usually applicable to larger-scale wind turbines) for optimum performance.
Changes in icing/freezing conditions	▪ Icing on the blades results in reduced performance ▪ Faster deterioration of structural components ▪ Electrical or mechanical failures (e.g., rubber seals may become brittle at low temperatures) Measurement and control errors	▪ Implementation of anti-icing techniques such as active heating of the blades or passive hydrophobic coating. ▪ Installation of ice sensors.
Sea level rise and salinity	▪ Increased wave/current loading in offshore wind turbines impacts the stability and safety of the turbine ▪ Salinity causes increased corrosion for the steel components of the structure	▪ Consideration of the projected sea level rise during the design process. ▪ Use of anti-corrosive materials and coatings.
Increase in the mean temperature	▪ Increased temperatures reduce the air density resulting in decreased power production ▪ The increase of the global mean temperature results in ice melting and drifting sea ice which may cause additional static and dynamic loading on an offshore turbine structure in polar areas, exceeding its structural or geotechnical capacity	▪ Design optimization of the geometry of the blade and the tip speed ratio based on the air density. ▪ Incorporate drifting sea ice loads in the design. ▪ Increase foundation size (e.g., monopile diameter)/change foundation type (e.g., from monopods to multi-pod configurations)/install foundation protection.
Extreme wind speeds and increased turbulence intensity	▪ Physical damage to structural elements and machinery of the turbine. ▪ Decreased power output during extreme winds as the wind turbines are halted for safety reasons	▪ Proper design of the wind turbines to safely withstand extreme wind loads. ▪ Installation of early warning systems such as forward pointing light detection and ranging (LIDAR) technologies to detect gusts before they reach the turbines.

Climate Threats	Impacts on Wind Parks	Adaptation Measures
Extreme storms, waves, cyclones, hurricanes, storm surges, and more frequent lightning	▪ Extreme weather events may cause physical damage to the project components (including the tower, the foundation, and the rotor, as well as the transmission and distribution lines and the access roads or port facilities), adversely affecting the functionality of the park	▪ Use of materials with greater fatigue life. ▪ Adjust design specifications beyond the code thresholds to increase stability/safety of the wind turbine. ▪ Enhanced lightning protection and grounding.
Landslides	▪ Facilities (including the transmission lines and access roads) located in landslide-prone areas may experience increased (or unprecedented) landslide risk when significant changes in precipitation extremes occur during the lifetime of the project.	▪ In-depth landslide risk analysis during the site selection that incorporates future projections (because a site that seems safe now may become dangerous in the future). ▪ Re-evaluation of the site selection and avoidance of landslide-prone sites. ▪ Special consideration of landslide protection measures, e.g., retaining walls, vegetation, underwater drainage, reducing slopes.
Floods	▪ Physical damages to the wind facility as well as the transmission lines, the substations, and the interdependent roads or other interdependent infrastructure.	▪ In-depth flood risk analysis during the site selection that incorporates future projections (because a site that seems safe now may become dangerous in the future). ▪ Re-evaluation of the site selection and avoidance of flood-prone sites. ▪ Special consideration of flood protection measures, e.g., increased drainage capacity of the site's drainage system, the elevation of the critical equipment, (e.g., the transformer, inverter, and the positioning of the wind turbines).
Fires	▪ Physical damages to the power facilities and the transmission/distribution equipment	▪ Fire zoning, fire prevention, and firefighting plans such as continuous monitoring and early warning systems for immediate actions in case of a fire trigger.

Step 3

Integrate Climate Risks Into The Planning Of Solar Or Wind Parks

SCOPE	To describe a multi-criteria analytical framework that will support users in incorporating climate decisions into the planning of new wind and solar parks.
PROCESS	Having completed the previous steps of this guide, users face a dizzying array of data/requirements that need to be mainstreamed into strategic decisions about the new renewable energy project. Comparing alternative installations with respect to their power generation potential, cost of energy, and efficiency is just one side of the coin. On the other side, there are climate-related risks, vulnerabilities, and opportunities than can also influence planning decisions. Balancing competing objectives requires a multi-criteria approach that can best work within a participatory decision-making environment. The methodological framework of such an approach—called a multi-criteria decision-making (MCDM) framework—is described in **Tool 1.6**. The process starts with the selection of important variables, the establishment of a stakeholder council, and the definition of objectives. Following a scoring and weighting procedure, the preferred strategy is derived, which will be subsequently forwarded for a preliminary economic analysis (conducted in **Module 3**).

TOOLS	**TOOL 1.6** Multi-criteria decision-making framework
OUTPUT	A climate-informed planning decision for a new solar or wind project.

TOOL 1.6

A MULTI-CRITERIA DECISION-MAKING (MCDM) METHOD

The multi-criteria decision-making (MCDM) method offers a scientifically sound decision framework, which can provide a comprehensive and transparent basis for any kind of assessment, including decisions on the planning of new RE installations. In the context of this guide, the MCDM method aims to assist users in planning for renewable energy projects that, in addition to other traditional objectives, are:

- Climate resilient (i.e., can sustain extreme climate hazards with minimal disruption)
- Climate insensitive (i.e., are less affected by the variability of climate stressors)

Users are referred to the Umbrella Toolkit (Module 2.1) for insights on how climate decisions may benefit from empirically based multi-criteria analysis (and other equivalent approaches).

It must be acknowledged that MCDM-based methods are based on empirical, linear correlations. They do not model the actual physical processes. Although they can be very efficient in analyzing complex problems, they are prone to erroneous judgment. Therefore, it is recommended to carry out a validation of the MCDM framework against a known problem (e.g., another renewable energy project in a similar environment, preferably in the same country).

INPUT

This tool describes the general framework for conducting an MCDM analysis to assist the preliminary planning decisions of a RE project. Depending on the input parameters and the specific objectives of the assessment, the MCDM can support any other type of decision, from risk assessments (where the objective is to minimize the climate-induced impacts) to operational decisions of power plants (see example in **Box 1.5**). Instances of MCDM may also vary in complexity, from purely qualitative formulations to mathematical formulations using fuzzy-logic theories for optimization.

1 **Define the objective of the decision-making** (assessed variable), considering identification of optimum project location and layout, panel or turbine type, climate risk minimization factors, among other areas.

2 **Engage a council of experts** (e.g., wind or solar experts, environmental scientists, geotechnical engineers, community engagement experts) that will provide elicitation regarding the effect of different parameters on the output of the decision-making process. In preliminary assessments, elicitation is based on empirical evidence and involves qualitative comparison among parameters of relative importance (described below).

3 **Collect input parameters (as traditionally done)**

Input variables should describe the general project set-up and reflect the dependence of the project's energy potential on local environmental factors and constraints. Users are referred to the International Finance Corporation's (IFC's) photovoltaic power plant guide[11] and to the Asian Development Bank's (ADB's) wind resource assessment guidelines.[12]

Examples for solar parks include:

- Solar energy indicators (e.g., solar irradiation, daily sunshine duration).
- Technical design parameters (e.g., design irradiation, collector tilt, freeze protection temperature, row spacing, stow angle).
- Topography/geomorphology data (e.g., elevation, sun angle, terrain information, and soil data).
- Water availability and water usage conflicts (for cleaning the solar panels).

Examples for wind parks include:

- Wind energy indicators (e.g., wind speed at the location site, turbulence intensity).
- Technical design parameters (e.g., wind turbine capacity, operational wind speed).
- Geomorphology and oceanographic data (e.g., terrain, foundation soil, sea depths, seabed conditions, ocean currents).

Other parameters (common to solar/wind installations):

- Energy demand parameters (e.g., electricity pricing, historical electricity consumption and future trends, cost of electricity, cost of land acquisition).
- Transmission grid accessibility.
- Site accessibility (proximity to transportation network).
- LULC and proximity to residential areas.
- Existence of a battery energy storage system of adequate capacity, either as a component of the existing grid or as part of the renewable energy project.

4 **Collect climate parameters** affecting the power generation capacity, operations, and safety of the renewable energy project. Information should be selected from Tools 1.2, 1.3, 1.4 and 1.5 and may involve:

- Climate risks (including loss estimates).
- Climate adaptation strategies (described by a capital cost).
- Benefits from undertaking a specific climate adaptation strategy (e.g., loss reduction, reduction of operational/maintenance cost, and broader socioeconomic benefits).

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[11] IFC (International Finance Corporation). 2022. Utility-Scale Solar Photovoltaic Power Plants: A Project Developer's Guide. https://www.ifc.org/wps/wcm/connect/topics_ext_content/ifc_external_corporate_site/sustainability-at-ifc/publications/publications_utility-scale+solar+photovoltaic+power+plants.

[12] ADB (Asian Development Bank). 2014. *Guidelines for Wind Resource Assessment: Best Practices for Countries Initiating Wind Development*. Mandaluyong City, Philippines: ADB. https://www.adb.org/sites/default/files/publication/42032/guidelines-wind-resource-assessment.pdf.

5 Ranking, classification, and rating of criteria

Ask the council of experts to rank the criteria based on their importance in influencing the assessed variable. Ranking (i.e., weighting) of the criteria can be achieved through a pair-wise comparison of relative importance. A number of approaches of varying sophistication can be employed at this step[15], however the analytical hierarchy process (AHP) is the most widely adopted and easiest to navigate. It relies upon the construction of a paired comparison matrix, where the relative importance of one parameter in comparison to another is evaluated on a scale of 1 to 5. Synthesis of experts' responses in one AHP matrix results in the identification of a weighting factor for each criterion.

6 Synthesis of criteria and aggregation of results

Perform a weighted combination of the criteria to produce a qualitative map of the assessed variable. Abandon strategies/options that do not contribute to high-ranked criteria and continue the process in an iterative manner until reaching a manageable list of alternative climate strategies or specific climate measures. Users should ensure that the do-nothing option is also included in the list of alternatives. Guidance on evaluation methods that are compatible with the MCDM framework is provided in the Umbrella Toolkit (Module 2.1).

Users may also wish to repeat the process by changing the objective of the assessment to acquire a more holistic overview of the pros and cons of the different solutions.

OUTPUT

A decision for a new solar/wind project that meets climate objectives and achieves stakeholders' consensus.

IMPORTANT NOTE

MCDM Assessments in a Global Information System-Enabled Environment: Data Requirements and Resources

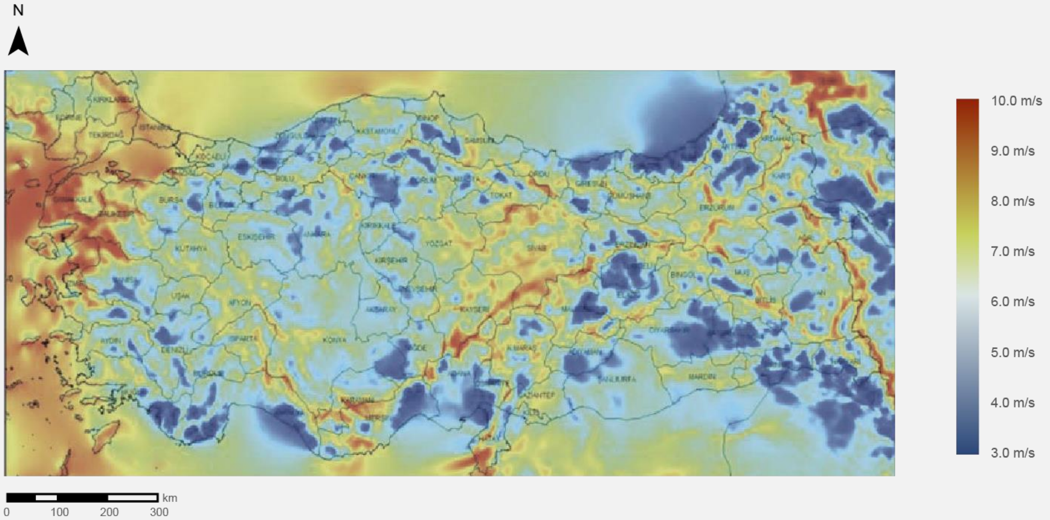
Site specificity is the most important parameter when deciding on a new solar/wind project. The geospatial distribution of the solar radiation, air temperature, wind speed, water depth, and other relevant variables determine the renewable power-density potential and therefore the suitability of a specific location. To this end, the analysis that supports any planning decision is performed in a geospatial and meteorological context, making use of GIS tools, geomorphological maps, and meteorological historic data and future climate projections. Typically, preliminary assessments use global scale models, whereas regional data or site-specific analyses (based on local measurements or modelling) may be employed for the more elaborate feasibility studies of the subsequent phases of the project cycle.

BOX 1.4. SITE SELECTION OF WIND POWER PLANTS: EXAMPLE APPLICATION IN TURKEY

For the installation of a potential onshore wind farm in Turkey, a multi-criteria decision-making (MCDM) process in combination with geographic information system (GIS) technologies were utilized to determine the most suitable location, with the aim of attracting investors and contributing to the implementation of the wind power plants for energy planners in Turkey's Develi area. Develi was selected due to its high wind potential (average wind speed greater than 7 meters per second (m/s)), the nonexistence of major fault lines in its underground, the fact that no wind farms had been previously installed there, and the increased interest in renewables presented by the Develi municipality.

First, the key factors that affect the site selection were determined (wind speed, forests, military regions, civil and military aviation, designated regions, agriculture, water sources, roads and ports, fault lines, bird migration paths, and energy transmission lines) and populated using different international and national database sources. Then a first filter on the site selection was applied by excluding regions with a wind speed of less than 3 m/s. Next, a spatial analysis was performed by defining buffer zones for nine restrictions: agricultural regions (outside), military regions (5 kilometers (km)), roads (0.1 km), designated regions (5 km), urban regions (3 km), fault lines (150 m), energy transmission lines (0-5 km), airports and aviation (3 km), and bird migration paths (3 km). These restrictions were used to evaluate the suitability of different sites based on environmental and social constraints applicable in Turkey. By combining the 12 map layers in GIS and using the principles of the MCDM process, two regions (Havadan and Kulpak) were identified for wind power plant installation (with a total wind energy potential of 17.1 MW) according to wind potential, technical, environmental, and social impacts.

FIGURE B1.4.1 Turkey wind potential atlas at 100 m elevation



Source: Genç, M.S. 2021. "Determination of the most appropriate site selection of wind power plants based Geographic Information System and Multi-Criteria Decision-Making approach in Develi, Turkey." *International Journal of Sustainable Energy Planning and Management* 30. https://doi.org/10.5278/ijsepm.6242.

BOX 1.5. A MCDM PROCESS FOR THE SELECTION OF A CLEANING METHOD FOR SOLAR PV PANELS

Different technologies and methods are available in practice for cleaning solar PV panels (e.g., robot water-based (sprinkler and brush), robot pressure-based (no use of water), manual cleaning (use of brushes and water), nano-coating cleaning technique). The suitability of the different cleaning alternatives may be assessed based on social, economic, environmental, political, or other influential factors. Almallahi et al. (2022) concluded on the optimal cleaning method of solar PV panels in the United Arab Emirates following a multi-criteria decision-making (MCDM) approach with the participation of solar energy experts with local knowledge and experience in Dubai. The criteria of the assessment were: the running cost, time required for cleaning, safety, energy required, water consumption, environmental impact (CO_2 emissions throughout the life cycle of the cleaning system), and economic impact (job creation). The optimal cleaning method was determined using different weighting methods (i.e., simple additive weighting and multiplicative exponential weighting) within the selected MCDM framework. The study concluded that the **water-based robot sprinkler and brush cleaning** method was the most effective option.

PHOTO B5.1.1 For efficient performance regular cleaning is required to remove dust accumulated on solar panels

Source: Almallahi, Maryam Nooman, Sameh Alshihabi, Reza Alayi, and Mamdouh El Haj Assad. 2022. “Multi-Criteria Decision-Making Approach for the Selection of Cleaning Method of Solar PV Panels in United Arab Emirates Based on Sustainability Perspective.” *International Journal of Low-Carbon Technologies* 17: 380-393. https://academic.oup.com/ijlct/article/doi/10.1093/ijlct/ctac010/6534487.

MODULE

2

Module 2

PRELIMINARY EVALUATION OF GHG EMISSIONS REDUCTION

It is widely accepted that energy produced by renewable sources generates negligible emissions. According to the United Nations (UN),[13] "Renewable energy sources—which are available in abundance all around us, provided by the sun, wind, water, waste, and heat from the Earth—are replenished by nature and emit little to no greenhouse gases or pollutants into the air." Therefore, renewable energy projects are aligned with climate goals set by international frameworks such as the Paris Agreement, and also investing in such projects helps achieve the climate-related commitments of the country.

In this context, understanding the benefits of investing in clean energy and properly quantifying them—in terms of avoided GHG emissions—is a critical step in the process of preparing a wind or solar energy PPP project and can help maximize gains.

To properly quantify such benefits, it is essential that sufficient project data are available, which may not be the case at the very early stages of the project (to which the present toolkit refers). Hence, the tools presented in the ensuing module aim at a preliminary, non-exhaustive evaluation of GHG emissions gains and potential ways of increasing them so that users are better positioned to define the requirements of the analyses that will be carried out by experts in the subsequent project phases.

The module includes a single step: estimate the GHG benefit of the project.

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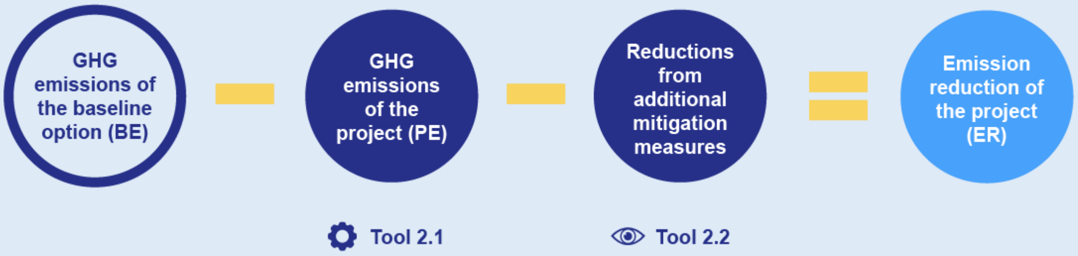
[13] United Nations. "Climate Action." https://www.un.org/en/climatechange/raising-ambition/renewable-energy.

Step 1

Estimate The GHG Benefit of The Project

SCOPE	This step will assist users in assessing the GHG reduction gain that is achieved by a specific solar or wind energy project versus a comparable (i.e., of similar capacity) CO_2-intensive energy production project. It will also inform the assessment of the project's carbon footprint and help identify potential additional climate benefits that could be produced as a result of the optimized design and operation of the project.
PROCESS	The process starts with identifying a plausible conventional (i.e., non-renewable) energy production project (the "baseline" option) and quantifying its corresponding baseline emissions (BE). It continues with the quantification of the emissions produced by the project (project emissions, or PE) and, thereby, the achieved emission reduction (ER). Finally, it is shown how the benefits may be increased by considering additional mitigation measures which are appropriate for the project.



TOOLS	**TOOL 2.1** A simplified procedure for the preliminary assessment of GHG emissions avoidance **TOOL 2.2** A checklist of potential measures to enhance the climate benefits of renewable energy projects
OUTPUT	GHG emissions calculations for the project and the project's alternatives

TOOL 2.1

A SIMPLIFIED PROCEDURE FOR THE ASSESSMENT OF AVOIDANCE OF GHG EMISSIONS

The tool may be used to calculate the reduction of emissions attributable to a renewable (solar or wind) energy project in order to obtain an understanding of the climate benefits of the project. **Table 2.1** summarizes the GHG emissions associated with various energy production projects, highlighting key benefits of shifting to renewable sources.

It should be noted that the calculations to be performed at this stage are based on preliminary data and generic assumptions and should not be perceived as final. In the subsequent phases of the project, this analysis will be repeated to include a life-cycle assessment (LCA) of GHG emissions as described in the Umbrella Toolkit, including the following stages: (i) manufacturing of the equipment; (ii) equipment transportation and installation at the project site; (iii) project operation (including supply, transmission, and distribution) and maintenance activities; and (iv) decommissioning and recycling of the equipment at the end of its lifetime or following a major overhaul. A comparative example for the assessment of GHG emissions of onshore and offshore wind farms is briefly described in **Box 6**.

The involvement of experts is recommended even at the early stages of the assessment in order to increase the accuracy of the estimation. The following process is based on the use of publicly available GHG emission calculators such as the Clean Energy Emission Reduction (CLEER) tool developed by USAID.[14] Because this is a rapidly evolving field, users are encouraged to search for updated calculation tools prior to performing their assessment.

INPUT

1 **Identify and collect necessary data** referring both to the baseline option as well as to the renewable project option, which are necessary to comparatively assess the emissions. Such data (USAID 2019) include:

- For the baseline option: Type and consumption of fossil fuel for a set quantity of annual electricity generation.
- For the renewable project (wind): Capacity and assumed operating hours annually.
- For the renewable project (solar): Rated capacity, location, and assumed operating hours annually.

2 **Review available tools/methodologies for the estimation of GHG emissions in renewable projects**. Tools and guidelines to be advised may include:

- USAID, 2019: Clean Energy Emission Reduction (CLEER)

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[14] Clean Energy Emission Reduction Tool. https://cleertool.org/Support/index.

- IEA, 2021: World Energy Model Documentation
- UNFCCC: Tools to calculate emission factors for an electricity system
- Guidelines for Estimating Greenhouse Gas Emissions of ADB Projects – Additional Guidance for Clean Energy Projects

3 **Use one of the online resources to estimate the GHG reduction of the project option with respect to the baseline option**
Different tools may include different assumptions and limitations that need to be noted and documented. Users are advised to ensure that the resources employed are indeed appropriate for the project's infrastructure typology and geographic location.

4 **Repeat the calculation** for alternative project options (e.g., different PV types, different wind turbine dimensions) in order to identify the ones that optimize the benefit (i.e., net reduction with respect to the baseline option) at the preliminary stage. It should be noted that in all cases renewable energy projects are associated with significantly lower GHG emissions and hence, the main driver for the selection of the preferred option may not be the marginal differences between them but rather other design options (e.g., cost, availability).

OUTPUT

A shortlist of project options documenting the benefits of each one and the corresponding assumptions made for the calculations. It is recommended to include in such documentation the output file of the resource used, which may assist the experts involved in the subsequent phases of the project.

TABLE 2.1 A comparison of GHG emissions from different power energy projects.

		Life-Cycle GHG emissions g CO_2-eq./kWh			Indicative Influencing Factors
		min	max	mean	
POWER SOURCE	**Onshore wind power**	5	40	**14**	Local conditions, lifetime, turbine size, capacity factor
	Offshore wind power	5	32	**18**	Local conditions, lifetime, turbine size, capacity factor, platform/foundation type and mass, distance to shore
	Photovoltaic power	13	126	**51**	Local conditions, lifetime, electricity generation capacity, cell material (monocrystalline, polycrystalline silicon or thin film cells)
POWER SO	**Concentrated solar power**	10	56	**28**	Local conditions, lifetime, receiver type (power tower, parabolic trough

		Life-Cycle GHG emissions g CO_2-eq./kWh			Indicative Influencing Factors
		min	max	mean	
					collectors), electricity generation capacity
	Hydropower (reservoir)	2	90	**21**	Lifetime, emissions from flooded land (e.g., the decomposition of flooded biomass), local conditions, electricity generation capacity
	Hydropower (run-of-river)	1	48	**19**	Lifetime, emissions from flooded land (e.g., the decomposition of flooded biomass), local conditions, electricity generation capacity
	Geothermal power	15	75	**38**	Electricity generation capacity, geothermal technology (flash steam, enhanced geothermal systems)
	Coal power	692	1250	**949**	Lifetime, electricity generation capacity, coal technology (subcritical pulverized coal combustion, integrated gasification combined cycle, fluidized bed, and supercritical pulverized coal combustion)
	Natural gas power	360	540	**446**	Lifetime, electricity generation capacity

Source: Ostfold Research. 2019. Life cycle GHG emissions of renewable and non-renewable electricity generation technologies. Part of the RE-Invest project.
Note: gCO2 eq/ kWh stands for grammars of CO2 equivalent per kilowatt-hour

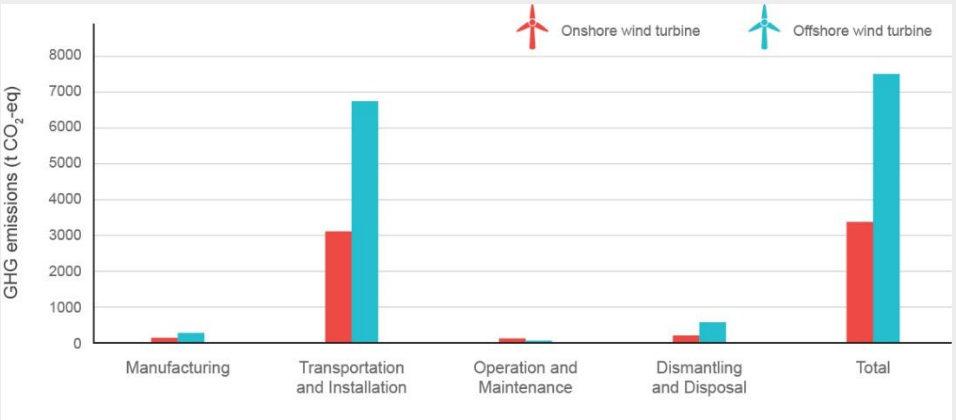
BOX 1.6. EXAMPLE ESTIMATION OF GHG EMISSIONS FOR ONSHORE AND OFFSHORE WIND FARM PROJECTS

An indicative LCA of GHG emissions by wind turbines with a nominal capacity of 2 MW may be found in the study by Wang et al. (2019), which also includes a comparison of GHG emissions between offshore and onshore environments. The study assumed a lifetime of 20 years and estimated the GHG emissions resulting from each stage of the life cycle, namely the manufacturing, the transportation and installation, the operation and maintenance, and the dismantling and disposal, as follows:

$$GHG = \sum (t_i \times G_i)$$

Where t_i is the amount of a GHG-emitting source i and G_i is the GHG coefficient associated with the specific source. Ignoring differences in the GHG emissions produced by energy transmission, Wang et al. estimate 0.082 kg CO_2-eq/MJ (Megajoules) for an onshore wind turbine as opposed to the quite higher value of 0.130 kg CO_2-eq/MJ for an offshore wind turbine. **Figure B1.6.1** presents the GHG emissions during the different life-cycle stages for an onshore and offshore wind turbine. The higher emissions for the offshore wind turbine appear to be due to the construction of the foundation system. Nevertheless, the study points out that both offshore and onshore wind turbines produce significantly lower GHG emissions in comparison to coal power plants.

FIGURE B1.6.1 GHG emissions during the different life-cycle stages for an onshore and offshore wind turbine (adapted from Wang, Wang, and Liu 2019).



Source: Wang, S., S. Wang, and J. Liu. 2019. "Life-cycle green-house gas emissions of onshore and offshore wind turbines." *Journal of Cleaner Production* 210: 804–810.

TOOL 2.2

A CHECKLIST OF POTENTIAL MEASURES TO ENHANCE THE CLIMATE BENEFITS OF RENEWABLE ENERGY PROJECTS

In principle, solar and wind parks are considered “green” projects because they produce considerably more carbon-free energy during their lifespan compared to their own carbon footprint. Yet, as evidenced by **Table 2.1**, the actual emissions within the same category of renewables may vary depending on a number of parameters, highlighting the potential for optimizing the benefit through proper project planning and design, construction, operation and maintenance, and recycling/reuse.

In fact, given that a renewable project is considered a clean energy project, the reduction of emissions may be achieved mainly by the appropriate screening of locations for the development of the solar or wind park (i.e., close to the existing infrastructure of transmission lines, substations, and roads to avoid constructing new infrastructure) but also through the adoption of eco-friendly construction methods, the use of low-carbon materials, and the implementation of circular economy concepts after the decommission (e.g., reuse of different parts of wind turbines and solar recycling). Moreover, operational elements (e.g., optimization of performance, low-carbon cleaning methods, and electric operational vehicles for inspections) may also further reduce GHG emissions. This tool assists in identifying methods for further enhancing climate benefits and qualitatively appraising their value for money.

INPUT

1 **Perform a thorough review of low-carbon methods** and processes applicable to wind and solar parks, including applications of the circular economy concepts (in order to consider a second life for the physical project components after decommissioning) and consult the **Figure 2.2** checklist to identify applicable mitigation measures.

2 **Identify potential co-benefits** and describe how they can positively impact the overall socioeconomic value of the investment. Examples include:

Public health protection. GHG reduction will reduce air and water pollution, resulting in cleaner air and human health benefits.

Economic growth through job creation and market development. Investing in energy efficiency, recycling, and reducing waste material can stimulate the local economy and spur development of energy efficiency service markets. Most of these jobs are performed locally by workers from relatively small local companies.

Gender-smart and inclusive growth. The new renewable energy era generates new job types where people with currently limited access to employment can have the opportunity to thrive and be empowered. Considering a gender-inclusive focus and/or a gender analysis in the design stages can support the optimization of the benefits of the project.[15]

Reduced project costs. Locating projects close to transmission lines or employing local contractors leads to savings in both the construction and the operations and maintenance phases of the project.

Public image improvement and responsible government stewardship of resources, which is important for enhancing the public acceptability of the PPP project.

Monetizing the above benefits is not straightforward and is beyond the scope of this toolkit to propose a fully quantified appraisal methodology in that respect. A preliminary qualitative description of the potential benefits is considered adequate for the purpose of this preliminary assessment.

3 **Consult** with local experts and general contractors to understand the additional costs associated with the methods above and make a preliminary decision on their cost over benefit ratio.

4 **Synthesize** as many as possible mitigation strategies from the different options identified in (1) above to achieve the maximum possible reduction in GHG emissions.

OUTPUT

Re-evaluated estimation of the project's emission and the cost effectiveness of the selected GHG emission reduction strategies.

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[15] For further guidance, users may consult: World Bank. 2021. "Green, Resilient and Inclusive Development (GRID)." https://thedocs.worldbank.org/en/doc/9385bfef1c330ed6ed972dd9e70d0fb7-0200022021/green-resilient-and-inclusive-development-grid.

Planning & Design

- ✓ Consider site location (to benefit from proximity with existing transmission lines, roads, substations)
- ✓ Use materials and technologies with low carbon footprint for the solar or wind park and the interdependent infrastructure (new roads, transmission and distribution lines)
- ✓ Favor primary and secondary suppliers of plant machinery/equipment that have sustainability sourcing/procurement/ management certification

Construction/ Manufacturing

- ✓ Rational management of diesel fuel and electricity consumption by the on-site equipment.
- ✓ Optimize the construction sequence and apply construction practices that produce lower emissions (e.g., promote automated welding procedures over traditional welding in the manufacturing of wind-turbine components)
- ✓ Consider reducing, recycling and reusing the waste material produced during construction (e.g., from demolitions and excavations)

Operation & Management

- ✓ Use automated control systems to optimize power output (thus maximizing the clean energy production of the facility)
- ✓ Use electric vehicles for inspections
- ✓ Apply vehicle sharing for the transportation of the staff on site

Decommissioning

- ✓ Apply the concepts of the circular economy (reusing, repairing, refurbishing, recycling existing project components and materials)
- ✓ Restore the environment and regenerate nature on site; this should also be included in the design and operation phases, for example when performing an infrastructure type service to help address resilience (e.g., erosion, flood prevention, cooling off panels, reducing dust)

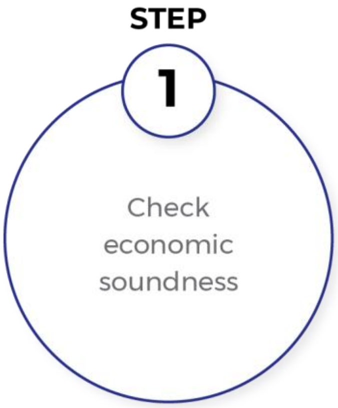
FIGURE 2.2 Checklist of climate mitigation strategies to reduce GHG emissions in solar and wind projects

MODULE

3

Module 3

CLIMATE CONSIDERATIONS IN ASSESSING PROJECT’S ECONOMICS AND FINANCES



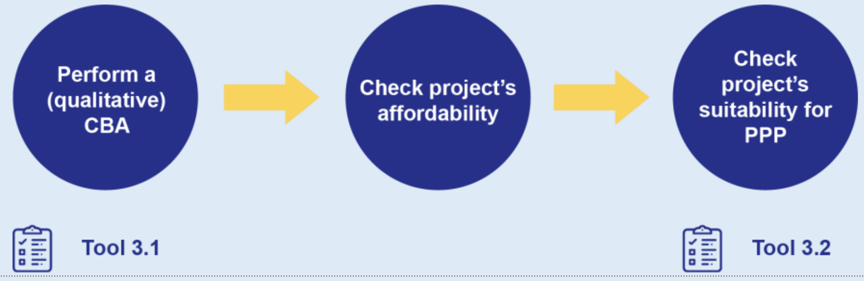
This module is meant to support the entities in charge of conducting their traditional economic assessments in Phase 1 in the PPP project cycle in view of the above climate considerations. In particular, the module includes a single step divided into two tools:

Tool 3.1 identifies all climate-related costs/benefits that should be integrated with an enhanced cost-benefit analysis (CBA)

Tool 3.2 assists with performing a VfM assessment to determine whether the PPP should be preferred over traditional procurement after incorporation of climate considerations

Step 1

Check Economic Soundness Of Alternative Climate Strategies

SCOPE	To compare the climate strategies identified in the previous module in terms of cost effectiveness, affordability, and suitability for a PPP. The output will be a project that has been successfully screened from an economic perspective and can therefore be considered suitable for proceeding to a full technical and economic appraisal.
PROCESS	Following the screening process presented in the Umbrella Toolkit, the economic analysis is performed in stages, starting with a preliminary CBA (**Tool 3.1**) to identify the project that maximizes the benefit over cost ratio. For best results, all important climate-related costs (e.g., additional climate CAPEX, cost of disruption caused by extreme weather events) and benefits (e.g., risk reduction benefits, protection of natural environment and biodiversity) should be synthesized and compared after monetary evaluation. Once the project has been identified, the affordability of the project is tested in view of the budgetary limits, constraints, and other concurrent investment plans of the public authority, following the general considerations described in the Umbrella Toolkit. The final check is to assess how climate-induced risks, costs and opportunities may affect the suitability of a project for a PPP (**Tool 3.2**). The project that successfully passes all tests receives the green light to proceed to the appraisal phase.
	
TOOLS	**TOOL 3.1** Climate entry points for CBA (specific for solar and wind projects) **TOOL 3.2** Climate value drivers for value for money (VfM) analysis
OUTPUT	▪ A renewable project (solar or wind energy) option that can be moved forward for appraisal

TOOL 3.1

CLIMATE ENTRY POINTS FOR SOLAR- OR WIND-SPECIFIC CBA

The tool describes entry points for climate-related CBA considerations that are relevant to solar or wind energy projects. CBAs are customarily conducted for different scenarios, accounting for changes in the financing scheme, electric prices, and other variables. Prior to applying the tool, users are advised to review methodologies for estimating the monetary value of social-environmental benefits and the CBA Primer (2017)[16] and consult the Umbrella Toolkit (Modules 1.3 and 2.3), where climate-related considerations for CBA (applicable to all sectors) are described in greater detail.

INPUT

TABLE 2.2 Climate entry-points to be considered when performing the CBA of the project.

CBA process outline (per APMG PPP Certification Guide)	CBA sub-steps (per APMG PPP Certification Guide)	Climate Entry Point
Projecting financial data with conversion/ adjustment	Tax adjustment	• If applicable in the country, include tax incentives or expedited permitting that promotes climate mitigation and adaptation actions (e.g., use of the infrastructure for monitoring and protecting biodiversity, fire zoning, installation of early warning systems). • If applicable, include levies and environmental taxes into the "do nothing" option.
	Shadow prices and opportunity costs adjustment	Adjust costs and benefits as would otherwise be done following the 2017 World Bank Guidance Note on the shadow price of carbon.[17]
	Construction of the model	• Include the cost of implementing adaptation measures (e.g., cost of enhanced lightning protection, cost of increasing the design load thresholds, cost of anti-erosion measures). • Consider the cost of sustainable construction (e.g., cost of recycling demolition materials, investment in electrical construction machinery).
	Operational and maintenance Cost	• Consider the increase in the cost of operation (e.g., due to possible need to install additional energy storage systems for operation during seasonally reduced solar or wind resources, need to reserve additional water resources for cleaning, cost of possibly necessary repairs after intense storms and flood events).

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[16] Guzman, A., and F. Estrázulas. 2012. "Full Speed Ahead: Economic Cost-Benefit Analyses Pave the Way for Decision-Making." *Handshake* (IFC quarterly journal of public-private partnership) 7 (October).

[17] World Bank. 2017. "Shadow Price of Carbon in Economic Analysis." Guidance Note, November 12, 2017. https://thedocs.worldbank.org/en/doc/911381516303509498-0020022018/original/2017ShadowPriceofCarbonGuidanceNoteFINALCLEARED.pdf.

CBA process outline (per APMG PPP Certification Guide)	CBA sub-steps (per APMG PPP Certification Guide)	Climate Entry Point
		• Consider increase in maintenance costs (e.g., more frequent cleaning of solar panels or anti-icing of the wind turbine blades, maintenance of vegetated slopes, fire-smart landscaping actions, cost of monitoring). • Include provisions for increased costs for decommissioning of the equipment and restoration of the landscape after completion of the project's productive life. Consider the possibility of stricter restoration requirements in the future, resulting in increased expenses towards the end of the project's life.
	Term and residual value	Residual value estimates should be adjusted to include climate change impacts, for example: - Reductions related to frequent weather-related damages. - Reductions caused by reduced power generation.
Adding externalities	List of externalities	The cost of externalities may include: • Cost of indirect damage caused by power generation loss due to damage of transmission lines, broken supply chains due to damage in the road (or port) network leading to limited accessibility to the park, increased travel times. • Cost of emergency services (e.g., use of aerial means to extinguish fire or evacuate on-site personnel). • Permanent or temporary changes in LULC (See **Table 1.3**). • Disruption during construction (introduced by unfavorable weather conditions, e.g., extreme heat, frequent and intense rainfalls, cyclones, extreme waves). • External benefits arise from the installation of monitoring systems and weather stations at the energy park, useful for early warning and protection of the surrounding environment and nearby communities.[18]
Adding (other) socioeconomic benefits	Monetizing/inferring value for relevant benefits	• Include an increase in private investment confidence (business, entrepreneurship, property). • Include the effect of encouraging investments in renewables in the region.
	Considering/ qualifying other unvalued benefits	• Include resilience benefits such as: - Avoided loss to the network adjusted over the probability of the event. - Monitoring of the broader ecosystem (e.g., stormwater management at ground-mounted solar sites, slope stability monitoring). - Providing a reliable source of power to nearby businesses. • Environmental benefits of nature-based or eco-friendly solutions (e.g., vegetated slopes, habitat corridors). • Alignment with strategic climate objectives.
Relative price adjustments and bias/risks adjustments	Market imperfection	• Apply as would otherwise have been done.
	Other opportunity cost adjustments	• Consider alternative uses of the land and space that needs to be covered due to climate change-related works, if any, and apply such costs.

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[18] Floating solar can reduce water evaporation, which could help mitigate some impacts of climate change. Agrisolar can also provide benefits in terms of land use and improved agricultural yields.

CBA process outline (per APMG PPP Certification Guide)	CBA sub-steps (per APMG PPP Certification Guide)	Climate Entry Point
	Taxes	• Same as above, apply only to the extent that tax advantages are applicable when a project exceeds its purpose in social benefits; and/or • Consider the tax income gained from steady uninterrupted operations.
Defining base case, defining and calculating economic internal rate of return (EIRR)	Discount rate definition and calculation of net present value (NPV) and EIRR	• Consider adjusting discount rate for valuation depending on levels of certainty of cash flows (applies to projects that include climate adaptation measures) and uncertainty of cash flows (applies to alternatives with no adaptation measures). This needs to be aligned with the probabilistic analysis of events occurring to avoid "hurting" a project with uncertainty twice (once with a high probability of costs occurring, and a second time with a high discount rate because of the uncertainty of cash flows).
Incorporating uncertainty: sensitivities	Test the strength of the proposed business plan and present the effect of variations	• As would otherwise be conducted.

OUTPUT

The results of the analysis of climate entry points in the project's CBA may be summarized in a screening report highlighting which climate mitigation and adaptation aspects have been considered and ensuring these have been adequately evaluated.

IMPORTANT NOTE

Choosing Discount Rate

The discount rate used in the economic analysis is particularly important when evaluating and comparing adaptation options because the associated benefits (or avoided costs) are likely not to realize for many decades. There is no consensus on the appropriate discount rate to use for resilience strategies. As a good practice, study teams may choose to explore the sensitivity of economic analysis findings to different discount rates or the possibility of applying a non-constant discount rate over the horizon of the assessment.

TOOL 3.2

CLIMATE VALUE DRIVERS FOR VFM ANALYSIS

A VfM analysis is performed to identify whether (and to what extent) climate-related risks, opportunities, and uncertainties may affect the suitability of a project for PPP and non-PPP delivery. The tool describes entry points for climate-related considerations for VfM analysis that are relevant to solar or wind projects. It explains the rationale of these considerations; identifies conditions of positive, negative, or conditional performance; and, where applicable, provides specific references and examples.

INPUT

TABLE 2.3 Climate-entry points to be considered when appraising the VfM of the Project.

VfM Driver	Guiding Questions	Climate Considerations Impacting VfM	Impact on PPP Suitability
Project size	Is the project too big for the market? Or is the project too complex to be delivered as a PPP?	Increased climate risks, requiring the use of larger, more efficient equipment. This will lead to the introduction of untested technologies and infrastructure assets of high unit cost, which hinder the market's appetite or the project's financing.	**Negative**
		Existence of a thorough risk assessment, which helps the public party better understand the part of the project it may realistically outsource to the private sector, while bearing the extra cost induced by upfront climate resilience measures (such as the elevation of a PV farm site to be less prone to flooding for instance).	**Positive**
Market appetite	Would there be private investor appetite?	Identification of previously unknown climate risks (e.g., the potentially increasing effect of droughts that could result in increased water competition) will hamper an investor's appetite to invest in solar.	**Negative**
		Completion of a thorough CBA, accounting for climate adaptation/mitigation risks and risk allocation, provides visibility and will play a significant role in increasing private sector appetite.	**Positive**
		Engagement with local communities and other stakeholders and the establishment of an inclusive, participatory method for decision-making regarding land and water use will enhance confidence in the appropriateness of the development.	**Positive**
Precedent projects	Are precedent transactions already developed as PPPs for this type of project in the country/	Existence of a legacy of renewable energy development in the country will help increase understanding of climate risks (involved stakeholders are better informed, and the local	**Positive**

VfM Driver	Guiding Questions	Climate Considerations Impacting VfM	Impact on PPP Suitability
	region/similar countries?	communities are familiar with the services and benefits provided).	
Risk allocation	Are there any significant climate risks within the project that are not manageable by a private partner?	Consideration of how gradual changes in weather patterns or extreme climate events may, under certain circumstances, cause extended losses to solar or wind projects.	**Negative**
		Consideration of how high costs for adaptation works or unavailability of insurance may render risk less manageable by the private partner (e.g., risk of panel or turbine failures due to extreme loading or stress during storms implies high restoration/replacement costs).	**Negative**
		Understanding of how uncertainty in estimating climate risks (i.e., CAPEX and/or O&M costs) will potentially impact the PPP suitability of wind or solar projects.	**Mostly negative** (unless specific measures to increase certainty are taken)
	Are there circumstances where climate risks can be better assumed by the private party?	Consideration of how higher efficiency in disaster preparedness, response, and recovery are impacted by the private sector's capital and innovation. Additional evaluation of how other private sector interventions, such as insurance coverage, may increase the capability of the private party to assume a certain level of climate risk.	**Positive**
	Is there a risk of non-availability of the land/right of way and land acquisition cost overrun?	Assessment of how geophysical hazards (e.g., landslide, subsidence, flooding, icing conditions) will be intensified by climate change; hence solar or wind projects interfering with landslide-prone areas, thawing permafrost zones, areas impacted by coastal erosion will experience higher risks.	**Mostly negative** (unless recognized and proper measures are structured)
Certainty of offtake/ supply	Is it possible that the project will experience a change in demand due to climate change?	Evaluation of how the interdependencies between climate, land use, population, water usage, or innovative technologies for power generation render renewable energy development vulnerable to external factors that may not be under the control of the PPP and will have a negative impact on the demand for electricity and, as a result, energy prices, thus compromising investment certainty.	**Mostly negative** (unless climate uncertainty and interdependencies have been properly addressed during planning)
		Understanding of how increased growth of a region (partially affected by milder climate conditions) will positively impact the energy demand.	**Mostly positive**
Project quality	Will the project quality increase if the project is developed through a PPP scheme?	Consideration that, in several cases, the private party brings innovation and high standards. Examples of such innovation applicable to solar or wind parks indicatively include contractors with experience in the development of integrated monitoring systems for adaptive management of solar or wind power generation, flood risk management, and early warning.	**Mostly positive** (provided that the methods used are tested)

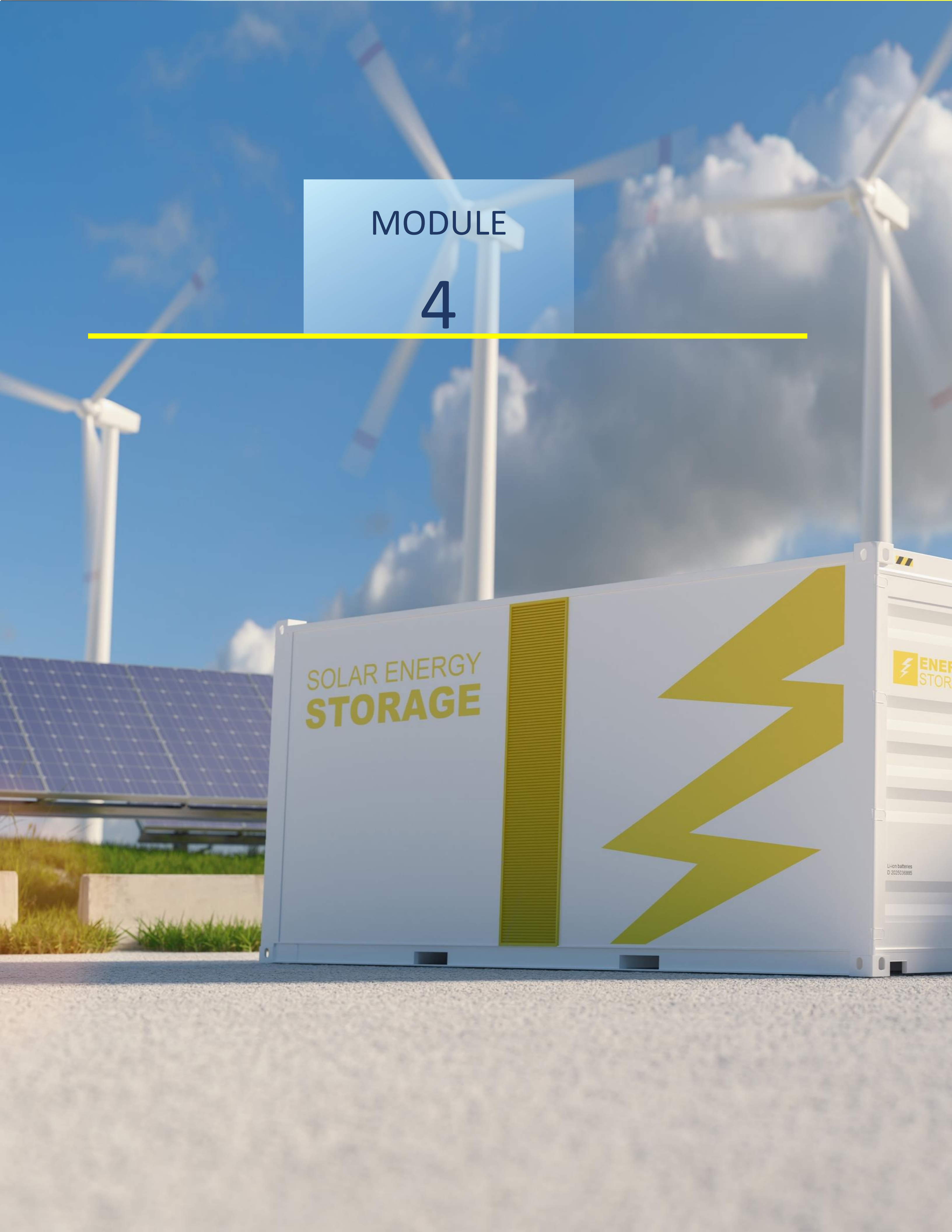
VfM Driver	Guiding Questions	Climate Considerations Impacting VfM	Impact on PPP Suitability
		Consideration that, as commercial lenders become more informed on the climate change risk, they will demand higher climate-resilience standards to ensure repayment/returns.	**Positive**
Output-based contracting	Is it possible to define clear output requirements for the plant's performance with respect to weather events?	Existence of a power purchase agreement (PPA) linked with financial incentives or penalties to encourage faster and better response to climate-related disruptions.	**Mostly positive**
Finance availability	Are there any significant climate risks that may harm the availability of financing?	Evaluation of how unmitigated risks (such as permanent or temporary changes in solar or wind resources, water demand changes, geomorphological changes) will test the willingness of financiers to participate or could prompt requests for higher guarantees.	**Negative** (unless recognized and proper adaptation measures are structured)
Legal or regulatory framework	Has the country adopted national legislation on climate change?	Prior existence of a national framework promoting green investments (defining subsidies and incentives for private sector participation) definitely boosts a project. For example, subsidies to invest in renewables and tax incentives will positively impact the development of renewables.	**Mostly positive**

OUTPUT

The results of the VfM may be summarized in a screening report highlighting which climate mitigation and resilience aspects have been considered and how they are impacting the suitability of the project as a PPP.

MODULE

4



Module 4

KPIs FOR CLIMATE-RESILIENT AND SUSTAINABLE SOLAR AND WIND ENERGY

Key performance indicators (KPIs) are customarily used in PPP solar and wind power projects to assess and evaluate the project's performance during design, construction, and operation. KPIs are developed around specific government objectives, and the private partner will either be entitled to additional payments for good performance or reduced payments for poor performance. Expanding this general notion to PPPs containing climate actions, the relevant KPIs can be used to measure the solar or wind project's resilience to climate change, i.e., the ability to prepare, respond to and quickly recover from climatic hazards and the project's ability to contribute to climate change adaptation (resilience through the project).

The tool presented in the next pages provides indicative high-level examples of climate KPIs soliciting forward-looking information to be included in performance-based contracts.

Based on the understanding that there is no one-size-fits-all for KPIs, the tool describes climate indicators that may be applicable to a broad range of solar or wind power projects. It is then the obligation of the entity in charge, with the assistance of experienced consultants, to derive project-specific KPIs that best describe the technical/operational challenges of the project and take advantage of the expertise and innovation skills of the private sector.

TOOL 4.1

KPIs MEASURING CLIMATE RESILIENCE OBJECTIVES

This tool is designed to assist the public authorities and their advisors when structuring and preparing performance-based contracts for solar and wind energy projects. The relevant KPIs included in this section have a dual purpose: (i) to facilitate assessments of a project's resilience to climate change, and (ii) to track the effectiveness of the project in contributing to the sustainability and socio-environmental objectives of the country/region.

KPIs are typically described by a performance objective, a measurement indicator, and a threshold to measure compliance with the objective. It should be noted that the tool does not provide threshold values for the suggested KPIs. This is country- and project-specific information that the public authority should provide based on good-practice examples, applicable norms/rules, and in consultation with the technical advisor in due consideration of the project's risk profile, the frequency of the event, and the importance of the project for the management of climate-induced risks. Overall, it is considered good practice to define two levels of achievement: a *conserving level* as having no negative impacts (i.e., a "do no harm" level of impact) and an *improved level* that will overall benefit the project's performance. Performance below the conserving level signifies the application of penalties, whereas performance above the improved level may be tied to specific rewards/incentives for the private partner.

INPUT

Tables 4.1 and **4.2** provide a non-exhaustive list of climate KPIs that can be widely adaptable to solar and wind projects and have been recommended by international literature and frameworks.[19] The KPIs describe the project's performance to resilience and sustainability goals covering the entire life cycle of the project, from design and construction to operation and maintenance. Users are advised to revise/complete the list of KPIs to better reflect the project-specific goals.

TABLE 4.1 Indicative climate KPIs measuring the climate resilience of the project

Project Phase	Example Indicators
DESIGN/ CONSTRUCTION	Existence of climate risk assessments and climate adaptation studies
	Existence of an emergency response plan addressing climate events

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[19] SERENDI-PV Consortium. 2021. *Key Performance Indicators (KPIs) on state of the art of PV reliability, performance, profitability and grid integration*. Ref. Ares(2021)3861898 - 13/06/2021. EU Horizon 2020 Grant Agreement No 953016.

Project Phase	Example Indicators
OPERATIONS/ MAINTENANCE	Climate-related energy-yield losses. For example, annual soiling losses measured in kWh/m2 or the soiling ratio[20] • *Temperature-induced losses measured in kWh/kWp* = how much energy (kWh) is produced for every kilowatt-peak (kWp) of module capacity over the course of a typical time period or actual year • Losses due to icing measured in number of affected turbines or kWh
	Number of climate-related incidents causing disruptions or requiring significant capital mobilization: (*number/year*) Annually mobilized capital due to climate-related damages and disruptions: local *currency*
	• Time to repair physical damages due to climatic stressors: *unit time* • Time to receive spare parts for damaged equipment: *unit time* • Time to restore operation (e.g., the time required to drain a flooded solar park or time required to de-ice wind blades): *unit time*
	Time to restore service continuity after a disastrous event: time as a function of x% restoration (e.g., 3 hours for 75% restoration; 1 day for 100% restoration)
	• Plant availability factor: *measured in unit forced outage rate*[21] • Amount of storage capacity (kWh-*hours*) or percentage (*%*) of energy stored for sustaining operation in hazardous weather conditions or during intermittency in energy systems
	Installation/operation of a robust/reliable monitoring system that includes weather forecasting modules. Example KPIs for the monitoring system: *number of installed sensors/ accuracy of sensors; data availability index (time that the monitoring system delivers data); and data quality index (existence of quality control system)*
	Frequency of benchmarking of emergency response plans against best practices
	Emergency response fleet (*number of vehicles and operators*) and emergency management drills (*number/year*)
	Ratio of maintenance work completed/maintenance work planned *(%)*
	Frequency of anti-icing, anti-soiling, anti-snow, anti-erosion (or other hazards) maintenance actions (*number/year*)

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[20] The soiling ratio is defined in the IEC 61724-1 as the “ratio of the actual power output of the PV array under given soiling conditions to the power that would be expected if the PV array were clean and free of soiling” and may be measured with the help of a reference PV module which is kept constantly clean by very frequent cleaning (e.g., daily) or other protective measures.

[21] The forced outage rate is an indicator of the unavailability of the unit and is measured as the ratio of failure hours due to unexpected breakdowns (i.e., the unit is out of service when required) to the total number of service hours.

TABLE 4.2 Indicative climate KPIs measuring social/environmental goals

Project Phase	Example Indicators
DESIGN/ CONSTRUCTION	Amount of energy produced by the park: number of households supplied directly (e.g., mini-grid projects) or indirectly (through the grid) by the park
	Existence of a life-cycle analysis demonstrating project's GHG emissions
	Existence of environmental impact assessment (considering biodiversity loss): *reduction of Biodiversity Intactness Index (BII) (%); reduction of terrestrial animal diversity or affected animal populations (e.g., number of dead birds)*
	• Number of new jobs created by the project. • Percentage (%) of new jobs that were covered by locals and/or women
	Use of suppliers that have sustainability sourcing/procurement/ management certification: *percentage* or *number.*
OPERATIONS/ MAINTENANCE	Time period to resolve environmental/social issues that have been created by the project: *time unit*
	Amount of materials being reused or recycled after decommissioning: *% of the total amount*
	Existence of environmental and social impact assessment (e.g., impact of wind farms on birds, restrained access to fishing zone due to large offshore wind farm projects, visual and noise impact and associated social issues)
	Social acceptance of the project: *number of lawsuits and complaints for the project development*

OUTPUT

Project-specific climate KPIs for consideration in the project documentation/contract

Summary and Conclusions

CLIMATE ENTRY POINTS IN THE EARLY STAGES OF A SOLAR OR WIND PROJECT'S PREPARATION

After completion of all the steps described in this toolkit, users are expected to have shaped a clear view of how to incorporate climate considerations in the early stages of a solar or wind PPP project's preparation, using a set of practical tools that allow:

- **Appraisal of the climate-related risks that the specific project is exposed to,** which are defined as the potential losses that could be either internal to the project (in the form of physical damage and loss of revenues due to a climate event immediately impacting the operability of the infrastructure) or external (in the form of economic losses due to an acute event or chronic hazard impacting the operation of the project's infrastructure, which may remain physically intact). To this end, a set of readily available online resources are provided that allow users to understand which hazards may affect the project given its location and components. Based on such data, the potential effects of each hazard on specific project assets may be assessed. Hence, users will be able to form a preliminary opinion as to the vulnerability of the project as a whole, the appropriateness for the project/region, and the associated needs for risk reduction measures.
- **Preliminary exploration of climate adaptation and resilience strategies** aimed at reducing the risks identified above and enhancing the project's bankability. Users are guided through the relevant tools enabling identification of adaptation measures for their solar or wind project while at the same time providing a high-level indication regarding the costs and benefits of each option through a multi-criteria decision-making framework, so that users are able to design different resilience strategies, each with distinct costs and benefits.
- **Preliminary evaluation of the GHG emissions reduction gain of the project** by performing a comparison of the GHG emissions associated with the construction and operation of the solar or wind project with a comparable (i.e., of similar capacity) CO_2-intensive energy production project. The relevant tools provide guidance on how to provide a preliminary LCA of the project's emissions supported by a list of international resources for assessing emissions associated with the various project components and stages (e.g., construction, operation).
- **Identification of applicable additional mitigation measures** that can be adopted in an optimized design and operation of the project and produce additional climate benefits. To this end, the toolkit provides guidance on screening measures that can reduce the project's own carbon footprint during the different stages of the project, including planning and design, construction/manufacturing, operation and maintenance/use, end-of-life and decommissioning.
- **Preliminary identification of climate entry points in the cost-benefit analysis of the project** using a step-by-step approach that supports users in understanding how climate risks, as well as adaptation and resilience plans, may be reflected in the project economics by presenting the tradeoffs between climate-related risks and investments.
- **Preliminary appraisal of the project's VfM and suitability as a PPP** using a set of tabulated instructions explaining the effects of the various potential climate actions identified above on parameters such as project bankability, investor appetite, and project risk profile. It is also shown how failure to act—or invest—may result in a negative impact on the project in case investor risks remain unmitigated, or if insufficient measures hamper the eligibility of the project to receive funding from multiple sources.

- **Preliminary identification of climate KPIs** that could be used to trigger climate-related clauses of the payment mechanism in PPP contracts. It is shown that climate considerations are meant to be present in all phases of the PPP project—from project selection, design, and construction throughout project implementation. To this end, a non-exhaustive set of essential climate-related KPIs is presented as part of the relevant tool that describes solar- and wind-specific actions and quantifiers to allow them to be monitored.

This toolkit, when used in conjunction with the WBG's Umbrella Toolkit, is meant to support PPP agencies operating in EMDE countries in incorporating climate risks and opportunities in solar or wind PPP projects by providing detailed guidance applicable to the early stages of such projects' preparation. Given the importance and complexity of incorporating climate change in PPP projects, all appraisals performed at the preliminary stages with the help of this toolkit will need to be reassessed in detail with the help of expert consultants on the basis of project-specific data that will become available in subsequent stages of the project.

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