Guidelines for Climate Proofing Investment in the Energy Sector

Asian Development Bank

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Foreword

Climate change is already a concern in Asia and the Pacific and its impacts are projected to intensify in the decades to come, threatening the development and security of the region. Countries in Asia and the Pacific are among the most vulnerable globally to the adverse impacts of climate change, with poor and marginalized communities likely to suffer the most heavily.

Energy production and distribution infrastructure can be highly vulnerable to the impacts of climate change. These impacts will have consequences for the design, construction, location, and operations of power infrastructure. Inadequate attention to these impacts can increase the long-term costs of energy sector investments and reduce the likelihood that these investments deliver intended benefits.

The long-term strategic framework of the Asian Development Bank (ADB), Strategy 2020, and its climate change strategy, *Addressing Climate Change in Asia and the Pacific: Priorities for Action*, confirm our commitment to help developing member countries (DMCs) in Asia and the Pacific to address the increasing challenges posed by climate change and to build a climate-resilient region. Adjusting to the need for climate-resilient development will mean integrating actions and responses to the physical, social, and economic impacts of climate change into all aspects of development planning and investment. Particularly, ADB is seeking to assist its DMCs to enhance the climate resilience of vulnerable sectors—such as transport, agriculture, energy, water, and health—by "climate proofing" investments in these sectors to ensure their intended outcomes are not compromised by climate change.

However, due to the complexity and uncertainty of the factors that define climate risks and vulnerability, particularly at a project scale and in specific socioeconomic contexts, climate proofing can be a challenging activity. There are gaps in the guidance materials and information resources currently available to facilitate the climate proofing of investment projects within the region. In response, ADB is developing a technical resource package to assist both its own operational staff and those of DMC partners to manage climate-related risks throughout the project cycle. This package will encompass preliminary risk-screening tools, climate projections, and guidance in their interpretation and use. It will also include technical notes for climate proofing vulnerable investments in critical development sectors. The package reflects the growing experience of ADB and its partners in pilot testing a wide range of climate-proofing approaches, methods, and tools on diverse projects in various settings.

This publication, which has been jointly produced by ADB's Regional and Sustainable Development Department and Southeast Asia Department, is the third in a series of technical notes covering various sectors.[1] It is a companion to an earlier report,*Climate Risk and Adaptation in the Electric Power Sector,* which highlights the climate change risks faced by the sector and the nature of possible adaptation options. This technical note aims to provide guidance to project teams as they integrate climate change adaptation and risk management into each step of project processing, design, and implementation. The technical note encompasses lessons learned and good practices identified through several completed and ongoing ADB energy projects. We hope that it improves—and simplifies—the work of development professionals in their efforts to enhance the climate resilience of energy sector projects. We welcome comments and feedback, which will improve subsequent versions of this note.

This report was prepared by Benoit Laplante (consultant) and Lorie Rufo (environment officer [climate adaptation], Regional and Sustainable Development Department) under the regional technical assistance project, Building Resilience to Disaster and Climate Change Impacts (RETA 7608), financed by ADB's Technical Assistance Special Fund. Charles Rodgers (senior environment specialist [climate change adaptation], Regional and Sustainable Development Department) and Pradeep Tharakan (climate change specialist, Southeast Asia Department) provided technical and overall guidance in the finalization of the report. Valuable comments and suggestions were also received from Xianfu Lu and the ADB Energy Community of Practice.

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[1] Guidelines for climate proofing investments in the transport sector (www.adb.org/documents/guidelines-climate-proofing-investment-transport-sector-road-infrastructure-projects) and in the agriculture, rural development, and food security sector (www.adb.org/documents/guidelines-climate-proofing-investment-agriculture-rural-development-and-food-security) are available.

Abbreviations

ADB	Asian Development Bank
DMC	developing member country
GCM	general circulation model
IPCC	Intergovernmental Panel on Climate Change
NPV	net present value
OECD	Organisation for Economic Co-operation and Development
PPTA	project preparation technical assistance
RCM	regional climate models
T&D	transmission and distribution
TGICA	Task Group on Data and Scenario Support for Impact and Climate Assessment
UNFCCC	United Nations Framework Convention on Climate Change

Glossary

Unless explicitly indicated otherwise, this glossary is a subset of the definitions presented in the glossaries of the Intergovernmental Panel on Climate Change 2007 report and the contributions of its various working groups, as well as from the United Nations Framework Convention on Climate Change.

Adaptation. Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. There may be various types of adaptation:

> *Anticipatory adaptation*. Adaptation that takes place before specific impacts of climate change are observed; occasionally referred as proactive adaptation.
>
> *Autonomous adaptation*. Adaptation that does not constitute a conscious response to climatic stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems.
>
> *Planned adaptation*. Adaptation that is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state.

Adaptation assessment. An adaptation assessment is the process of identifying options to adapt to climate change and of evaluating these options using criteria such as feasibility, gender equality, costs, and benefits.

Climate. Climate in a narrow sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. The relevant quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state, including a statistical description, of the climate system.

Climate change. Climate change refers to a change in climate over time, whether due to natural variability or as a result of human activity. The United Nations Framework Convention on Climate Change, in its Article 1, defines climate change as “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.”

Climate change impacts. The effects of climate change on natural and human systems. Depending on the state of adaptation, one can distinguish between potential impacts and residual impacts:

> *Potential impacts*. All impacts that may occur given a projected change in climate, without considering adaptation.
>
> *Residual impacts*. The impacts of climate change that would occur after adaptation has taken place.

Climate prediction. A climate prediction (or climate forecast) is the result of an attempt to estimate the actual evolution of the climate in the future at seasonal, interannual, or long-term time scales.

Climate projection. A climate projection is the simulated response of the climate system to a scenario of emissions or concentration of greenhouse gases, generally based upon numerical simulations by climate models. Climate projections critically depend on the emissions scenarios used and therefore on highly uncertain assumptions of future socioeconomic and technological development.

Climate variability. Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability) or to variations in natural or anthropogenic external forcing (external variability).

Downscaling. Downscaling is a method that derives local- to regional-scale information from larger-scale models or data analyses. Two main methods exist: dynamical downscaling and empirical/statistical downscaling. The dynamical method uses the output of regional climate models, global models with variable spatial resolution, or high-resolution global models. The empirical/statistical methods develop statistical relationships that link large-scale atmospheric variables with local and regional climate variables.

Extreme weather event. An event that is rare at a particular place and time of year. Definitions of “rare” vary, but an extreme weather event would normally be as rare or rarer than the 10th or 90th percentile of the observed probability density function estimated from observations.

General circulation model. A general circulation model (GCM) is a mathematical model of the general circulation of a planetary atmosphere or ocean. Equations of the model are the basis for complex computer programs commonly used for simulating the earth’s atmosphere or ocean. Atmosphere-ocean GCMs are key components of global climate models along with sea ice and land surface components. GCMs and global climate models are widely applied for projecting future climatic conditions.

Impact assessment. An impact assessment is the practice of identifying and evaluating, in monetary and/or nonmonetary terms, the effects of climate change on natural and human systems.

Maladaptation. Outcome of efforts to adapt which either result in increased vulnerability to climate change or undermine the ability to adapt in the future.

Resilience. The ability of a social or ecological system to absorb, accommodate, or recover from disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organization, and the capacity to adapt to stress and change.

Sensitivity. Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate variability or climate change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise).

Stationarity. Stationarity assumes that natural systems fluctuate within an unchanging envelope of variability. It implies that any variable (e.g., annual stream flow or annual flood peak) has a time-invariant (or 1-year–periodic) probability density function; the properties of this function (such as mean and variance) can be estimated from records. (Milly et al. 2008).

Uncertainty. An expression of the degree to which the exact value of a parameter is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable. Uncertainty can be represented by quantitative measures (for example, a probability density function) or by qualitative statements (for example, reflecting the judgment of a team of experts).

Vulnerability. Refers to the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed; its sensitivity; and its adaptive capacity.

Vulnerability assessment. A vulnerability assessment attempts to identify the root causes for a system's vulnerability to climate changes.

Executive Summary

Energy has been a key area of support provided by the Asian Development Bank (ADB) to its developing member countries (DMCs). Historically, electricity has dominated ADB's energy sector assistance. Over the period 1990–2006, loans to improve electric power production, distribution, efficiency, and security totaled $27.9 billion (ADB 2009a).In 2011 alone, loans from ordinary capital resources (OCR) and special funds reached $3.941 billion, representing 31.3% of all OCR and special funds lending outlays (ADB 2012a).

The energy sector is likely to remain an important sector of investment. Between 2005 and 2030, primary energy demand in the region is expected to grow at an annual rate of 2.4% (ADB 2009b). Electricity demand is projected to increase more rapidly, at an average annual rate of 3.4%, with DMCs accounting for 86.5% of the total increase. ADB projections indicate that electricity use in DMCs in 2030 will be approximately 2.3 times that of 2005.

The power sector is generally viewed in the context of greenhouse gas mitigation. However, it is also the case that the sector is itself significantly vulnerable to projected changes in climate.

Climate change impacts on the energy sector

The power sector's vulnerability to projected climate changes includes the following:

- Increases in water temperature are likely to reduce generation efficiency, especially where water availability is also affected.
- Increases in air temperature will reduce generation efficiency and output as well as increase customers' cooling demands, stressing the capacity of generation and grid networks.
- Changes in precipitation patterns and surface water discharge, as well as an increasing frequency and/or intensity of droughts, may adversely impact hydropower generation and reduce water availability for cooling purposes to thermal (including nuclear) power plants.
- Extreme weather events, such as stronger and/or more frequent storms, can reduce the supply and potentially the quality of fuel (coal, oil, gas), reduce the input of energy (water, wind, sun, biomass), damage generation and grid infrastructure, reduce output, and affect security of supply. This may be of particular significance in countries where projects are located or planned in water-stressed areas or where water is scarce.

- Rapid changes in cloud cover or wind speed (which may occur even in the absence of climate change) can affect the stability of those grids with a sizable input of renewable energy, and longer-term changes in these and precipitation patterns can affect the viability of a range of renewable energy systems.
- Sea level rise can affect energy infrastructure in general and limit areas appropriate for the location of power plants and grids.

While the exposure and vulnerability to climate will depend upon the nature and type of infrastructure as well as its location, the power sector is one whose output and efficiency are highly dependent on climate conditions. Projected changes in these conditions are expected to impact the sector significantly.

Adaptation to climate change[2]

Adaptation measures can generally be divided into engineering and non-engineering options. In a number of circumstances, it may be best to promote "no-regret" or "low-regret" adaptation strategies that deliver development benefits regardless of the nature and extent of changes in climate. This is a useful and practical approach wherever uncertainty is high regarding climate change, and where large climate-proofing capital investments cannot be easily justified. In other circumstances, such climate-proofing investments may be justified. On the other hand, a "do nothing" response may occasionally be more appropriate and cost-effective.

Engineering adaptation measures include the following:

- In general, more robust design specifications will allow structures to withstand more extreme conditions (such as higher wind or water velocity) and function effectively under higher air and/or water temperatures. In some circumstances, it may also be necessary to consider relocating or retrofitting extremely vulnerable existing infrastructure. Furthermore, decentralized generation systems may reduce the need for large facilities in high-risk areas and minimize climate risk. Finally, the reliability of control systems and information and communications technology components may improve from redundancy in their design and from being certified as resilient to higher temperatures and humidity.
- For thermal power facilities, enlarged or retrofitted cooling systems (including air cooling) may be considered where water is expected to be increasingly scarce; designing facilities to be waterproofed may be an option where increased flooding is expected.
- For nuclear power facilities, redundant cooling systems should be considered, and it may be possible to assure robust protection from floods, tsunamis, or other extreme events that can otherwise damage backup generation and essential cooling systems.
- For hydropower facilities, where discharge is expected to change over the life of the system, it may be necessary to consider diverting upstream tributaries, building new storage reservoirs, modifying spillways, and installing turbines that are better suited to expected conditions. Greater discharge (whether from glacial melting or increased precipitation) may require higher and more robust dams and/or small upstream dams.
- Where wind speeds are likely to increase, it may be possible to capture greater wind energy with taller towers, or to design new systems better able to capture the energy of increased wind speeds.

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[2] From ADB (2012b).

- For solar photovoltaic systems, where temperature increases or significant heat waves are expected, it will be useful to consider solar modules with a higher temperature coefficient. String or micro inverters should be included in the design, since they are easy to cool down.
- For solar-concentrating or sun-tracking systems, where higher wind speeds, more intense storms, and gusts are likely, it may be necessary to consider more robust structures, tracking motors, and mountings, and to consider air or waterless cooling in water-restricted areas.
- For biomass and biofuels, in addition to adaptations for thermal systems in general, more robust feedstock may be designed (e.g., tolerant to heat, salt, or water), and it may be possible to expand or introduce more efficient irrigation systems, depending on expected climatic changes.
- For geothermal, specifications might require greater protection where floods are likely to increase. Where cooling water is reduced with climate change, it may be possible to substitute air-cooled systems, although it may be less expensive to develop new water sources.
- For ocean power, only sea wave and tidal power generation are approaching commercial viability. It may be possible to design systems to withstand extreme (100-year) waves or alternatively specify designs that are sufficiently inexpensive that the financial loss from destruction is less than preventative measures. For sea wave power generation, floating systems may be climate proofed with protection mechanisms against storm surges (e.g., automated lowering of expensive components to the sea floor, designs that can cope with extreme conditions, or mechanisms to disconnect or shut down during extreme events).
- For transmission and distribution (T&D) (including substations), specifying redundancy in control systems, multiple T&D routes, relocation, and/or underground distribution for protection against wind, high temperatures, corrosion, and flooding may be considered. Where stronger winds are expected, higher design standards for distribution poles may be adopted. Where temperatures are likely to increase, more effective cooling systems for substations and transformers can be put in place.
- For electricity end use, adaptation measures to cope with increased demand with temperature rises are of three types: (i) increasing generation (megawatt-hours) and capacity (megawatts) to meet the higher demand (business as usual approach); (ii) improving the efficiency of power supply (generation, transmission, distribution system improvements); and (iii) improving end-use efficiency for buildings, facilities, and energy-intensive appliances and machinery, thus requiring less investment in generation and distribution (and yielding lower carbon dioxide emissions).

Non-engineering adaptation measures include the following:

- In general (including generation technologies not listed below), it may be cost-effective to put in place more robust operational and maintenance procedures, improved and better-coordinated land use planning (e.g., rezoning land use so future power infrastructure is in less vulnerable areas), policies and enforceable regulations to improve energy security, decentralized local planning and generation, integration of adaptation and mitigation planning, integration of climate change and disaster management planning, improving forecasting of demand changes and supply–demand balance with climate change, integrating power sector planning with that of other sectors (including water supply), and improving localized models used to predict storms and flood hazards. It may be of interest to set up rapid emergency repair teams to repair damaged facilities quickly.

- For nuclear power, it may be appropriate to develop more stringent safety regulations against extreme events, including flooding.
- For hydropower, new operating rules, improved hydrologic forecasting, and coordinating power planning and operations with other water-use projects may be useful. For existing hydro infrastructure, localized climate modeling might suggest operational changes to optimize reservoir management and improve energy output by adapting to changes in rainfall or river flow patterns. Integrated water resource management strategies that take into account the full range of downstream environmental and human water uses may prove necessary. Restored and better-managed upper catchments, including afforestation to reduce floods, erosion, silting and mudslides, may provide useful protection to existing infrastructure.
- For wind power, it may be possible to choose sites taking into account expected changes in wind speeds, storm surges, sea level rise, and river flooding during the lifetime of the turbines.
- For solar photovoltaic power, it may be possible to select locations where expected changes in cloud cover, airborne grit, snowfall, and turbidity are relatively low.
- For solar concentrating or tracking systems, avoiding locations with high, gusting winds or expectations of increased cyclones/extreme events may be an option.
- For wind and solar technologies, it may be possible to improve the reliability of expected output with better climate projections.
- For biomass/biofuels, early warning systems for rainfall and temperature anomalies, emergency harvesting arrangements for an imminent extreme event, and provision of crop insurance can be appropriate options.
- For T&D, new mandatory design codes for lines, transformers, and control systems may be adopted to cope effectively with the expected changes.
- For electricity end use, mandatory minimum energy efficiency standards for buildings, manufacturing facilities, and energy-intensive appliances can increase resilience of the sector.

The measures described above provide general guidance regarding possible adaptation measures in the energy sector. However, detailed local assessments on the projected changes in climate conditions, the impacts of these changes on variables of interest to the power sector (e.g., projected changes in rainfall having an impact on water availability), and the nature and feasibility of adaptation options are necessary when investment projects are designed and their viability assessed.

Developing an adaptation methodological approach

This publication, *Guidelines for Climate Proofing Investment in the Energy Sector* (henceforth *Guidelines*) aims to present a step-by-step methodological approach to assist project teams to assess and incorporate climate change adaptation measures into energy investment projects. While the focus of the *Guidelines* is at the project level, an improved understanding of climate change impacts should also be used to incorporate climate change considerations into energy planning and policy at the country level.

The methodological approach presented in this publication for building adaptation into energy sector investment projects is divided into six different sets of activities (Figure E1). The process begins with scoping the project and defining the assessment and its objectives. The core activities related to project design fall under impact assessment, vulnerability assessment, and adaptation assessment. Finally, the process ends with defining implementation arrangements and monitoring frameworks. To facilitate the implementation of the methodological approach, these six sets of activities are subdivided into 20 steps (Figure E2).

A climate change assessment is best integrated into the activities of the project preparation technical assistance, following the identification of climate change as a potential risk/opportunity factor to the project at the concept stage. For this purpose, a risk screening tool has been developed and is currently being tested by the Asian Development Bank (ADB).

The outcome of the adaptation assessment activity may result in one of three types of decisions:

Decision of Type 1: Invest in climate proofing the project at the time the project is being designed or implemented.

A decision of Type 1 may result from circumstances where

(1) the costs of climate proofing now are estimated to be relatively small while the benefits (the avoided expected costs from climate change impacts), even though realized only under future climate change, are estimated to be very large. This is occasionally referred as a *low-regret* approach; and/or
(2) the costs of climate proofing at a later point in time are expected to be prohibitive or climate proofing at a later point in time is technically not possible; and/or
(3) among the set of climate-proofing options, option(s) exist that deliver net positive economic benefits regardless of the nature and extent of climate change, including the current climate conditions. Such options are referred as *no-regret* climate-proofing options; and/or
(4) the set of climate-proofing options includes option(s) that not only reduce climate risks to the project, but also have other social, environmental, or economic benefits. Such options are referred as win-win climate-proofing options.

Decision of Type 2: Do not invest now in climate proofing but ensure that the project is designed in such a way as to be amenable to be climate proofed in the future if and when circumstances indicate this to be a better option than not climate proofing.

For example, while current sea level rise and storm surge scenarios may not warrant the construction today of sea dykes suitable to projected higher sea level and stronger storm surges in a distant future, the base of the sea dyke may nonetheless be built large enough today to accommodate a heightening of the sea dyke at a later point in time.

A decision of Type 2 aims to ensure that the project is "ready" to be climate proofed if required. As such, the concept of climate readiness is often referred to. This concept is akin to the real options approach to risk management.

Decision of Type 3: Make no changes to project design, monitor changes in climate variables and their impacts on the infrastructure assets, and invest in climate proofing if and when needed at a later point in time.

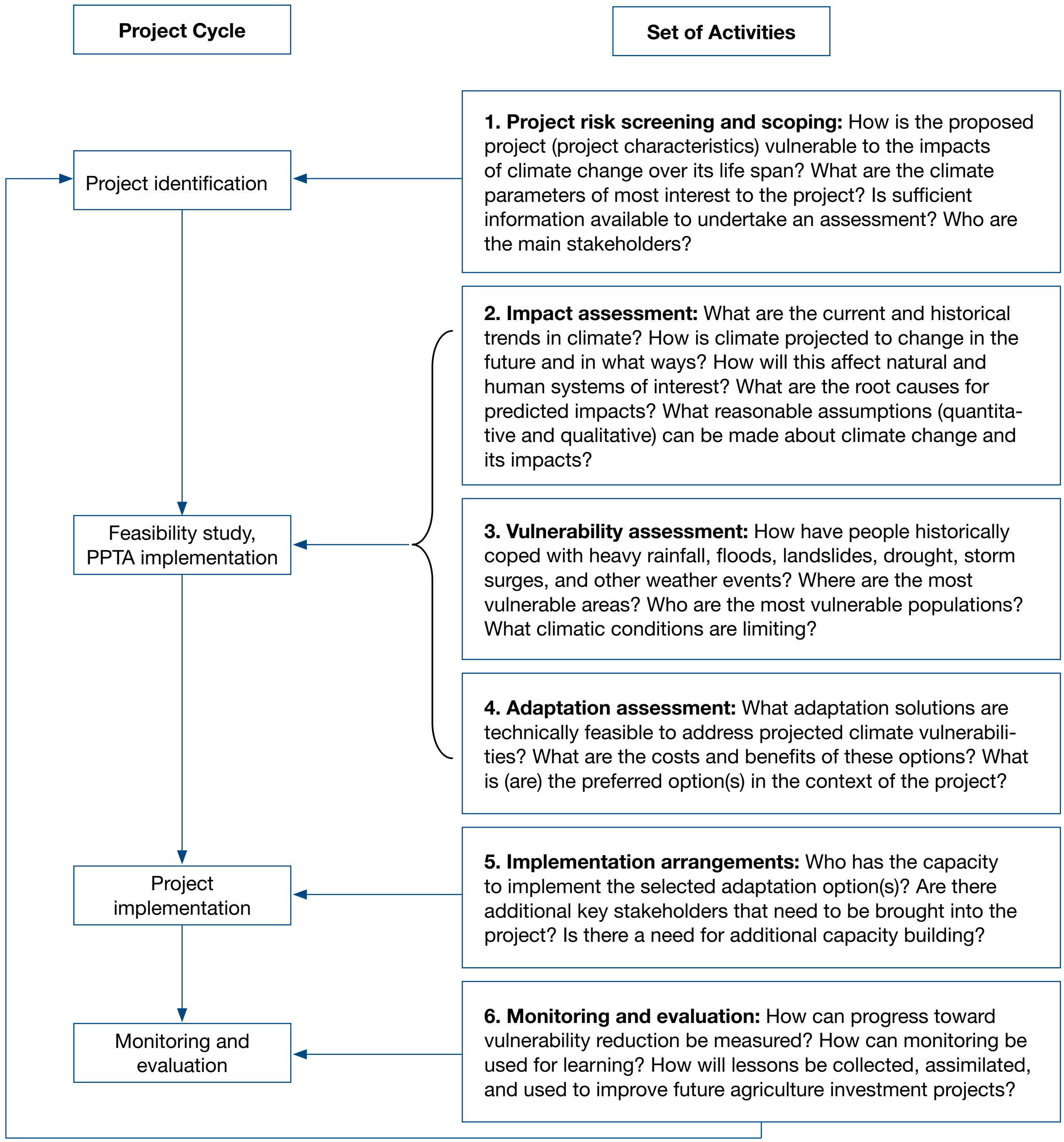
A decision of Type 3 may result from circumstances where

(1) the costs of climate proofing now are estimated to be large relative to the expected benefits; and/or
(2) the costs (in present value terms) of climate proofing (e.g., retrofitting) at a later point in time are expected to be no larger than climate proofing now; and/or

(3) the expected benefits of climate proofing are estimated to be relatively small.

Decisions of types 2 and 3 may be referred as ***adaptive management***, which consists of putting in place incremental adaptation options over the project's lifetime. In a Type 2 decision, project design will ensure "readiness" for climate proofing, while a decision of Type 3 will require no changes at all to project design.

Figure E1. Assessing Adaptation Needs and Options: 6 Sets of Activities



1. Project risk screening and scoping: How is the proposed project (project characteristics) vulnerable to the impacts of climate change over its life span? What are the climate parameters of most interest to the project? Is sufficient information available to undertake an assessment? Who are the main stakeholders?

2. Impact assessment: What are the current and historical trends in climate? How is climate projected to change in the future and in what ways? How will this affect natural and human systems of interest? What are the root causes for predicted impacts? What reasonable assumptions (quantitative and qualitative) can be made about climate change and its impacts?

3. Vulnerability assessment: How have people historically coped with heavy rainfall, floods, landslides, drought, storm surges, and other weather events? Where are the most vulnerable areas? Who are the most vulnerable populations? What climatic conditions are limiting?

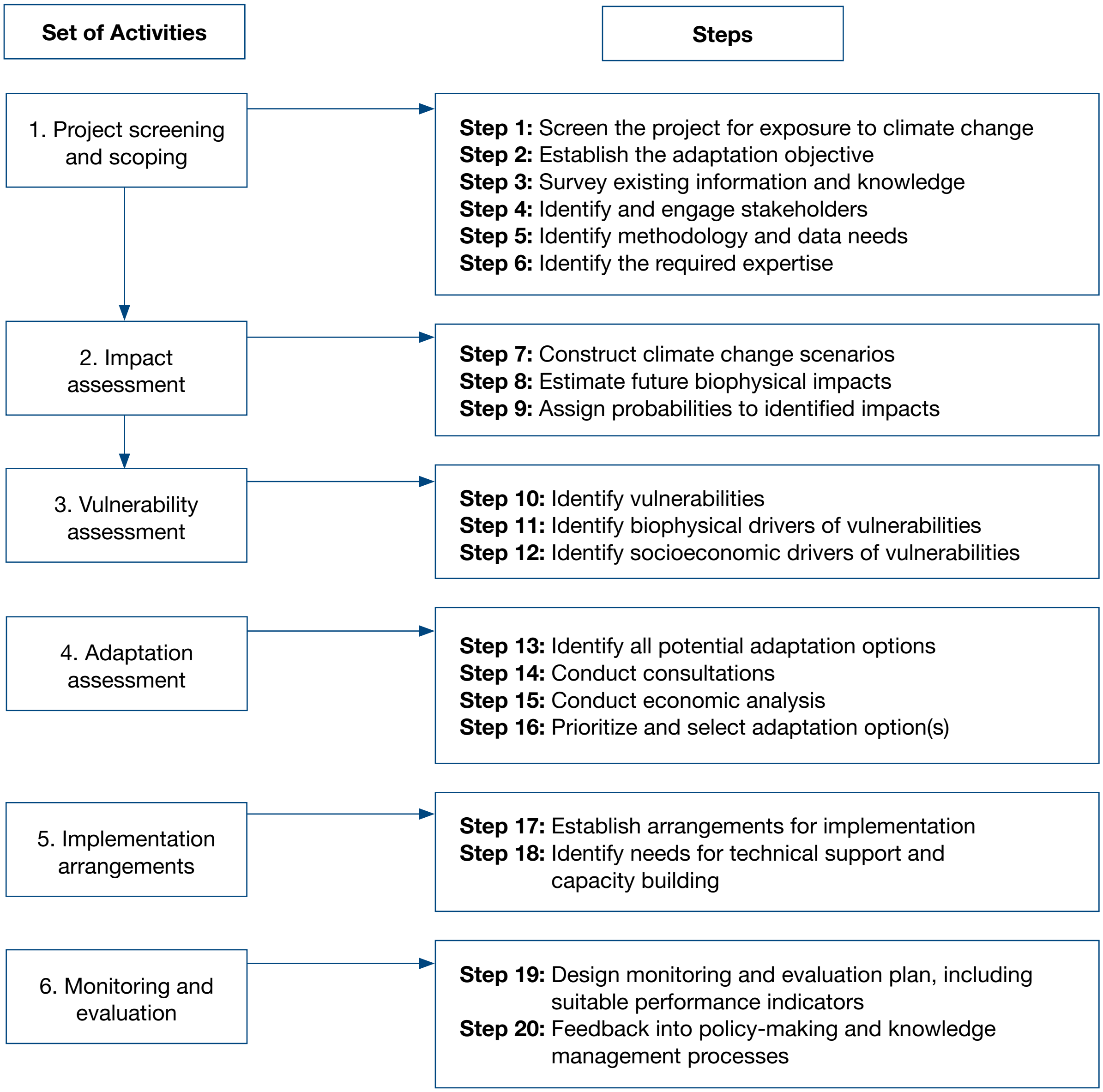
4. Adaptation assessment: What adaptation solutions are technically feasible to address projected climate vulnerabilities? What are the costs and benefits of these options? What is (are) the preferred option(s) in the context of the project?

5. Implementation arrangements: Who has the capacity to implement the selected adaptation option(s)? Are there additional key stakeholders that need to be brought into the project? Is there a need for additional capacity building?

6. Monitoring and evaluation: How can progress toward vulnerability reduction be measured? How can monitoring be used for learning? How will lessons be collected, assimilated, and used to improve future agriculture investment projects?

PPTA = project preparation technical assistance.

Figure E2. Assessing Adaptation Needs and Options: 6 Sets of Activities and 20 Steps



Introduction

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The energy sector is likely to remain an important sector of investment. Between 2005 and 2030, primary energy demand in the region is expected to grow at an annual rate of 2.4% (ADB 2009b). Electricity demand is projected to increase more rapidly, at an average annual rate of 3.4%, with DMCs accounting for 86.5% of the total increase. ADB's projections indicate that electricity use in DMCs in 2030 will be approximately 2.3 times that of 2005.

The power sector is generally viewed in the context of greenhouse gas mitigation. However, it is also the case that the sector is itself significantly vulnerable to projected changes in climate.

Adaptation measures can generally be divided into engineering and non-engineering options. In a number of circumstances, it may be best to promote no-regret or low-regret adaptation strategies that deliver development benefits regardless of the nature and extent of changes in climate. This is a useful and practical approach wherever uncertainty is high regarding climate change, and where large climate-proofing capital investments cannot be easily justified. In other circumstances, such climate-proofing investments may be justified. On the other hand, a "do nothing" response may occasionally be more appropriate and cost-effective.

However, due to the complexity and uncertainty of the factors that define climate risks and vulnerability, particularly at a project scale and in specific socioeconomic contexts, climate proofing can be a challenging activity. There are gaps in the guidance materials and information resources currently available to facilitate the climate proofing of investment projects within the region. In response, ADB is developing a technical resource package to assist both its own operational staff and those of DMC partners to manage climate-related risks throughout the project cycle. This package will encompass preliminary risk-screening tools, climate projections, and guidance in their interpretation and use. It also includes technical notes for climate proofing vulnerable investments in critical development sectors. The package reflects the growing experience of ADB and its partners in pilot testing a wide range of climate-proofing approaches, methods, and tools on diverse projects in various settings.

This publication is the third in a series of technical notes covering various sectors.[3] It is a companion to an earlier report, *Climate Risk and Adaptation in the Electric Power Sector,* which highlights the climate change risks faced by the sector and the nature of the possible adaptation options. This technical note aims to provide guidance to project teams as they integrate climate change adaptation and risk management into each step of project processing, design, and implementation. The technical note encompasses lessons learned and good practices identified through several completed and ongoing ADB energy projects. We hope that it improves—and simplifies—the work of development professionals in their efforts to enhance the climate resilience of energy sector projects. We welcome comments and feedback, which will improve subsequent versions of this note.

Part A presents a discussion of the possible impacts of climate change on the energy sector and the nature of the adaptation options available. Part B describes a step-by-step approach to assessing climate vulnerabilities as well as adaptation needs and options relevant to the power sector. Part C discusses adaptation at the national and sector planning levels.

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[3] Guidelines for climate proofing investments in the transport sector and in the agriculture, rural development, and food security sectors are available.

Part A: Climate Change and Energy[4]

The Energy Sector in Asia and the Pacific

Historically, electricity has dominated ADB energy sector assistance. Over the period 1967–2010, this support reached $33.0 billion in cumulative loans (representing 20% of all ADB loan finance) and $651 million in grants (representing 10% of all grant assistance). Over the period 1990–2006, loans to improve electric power production, distribution, efficiency, and security totaled $27.9 billion, compared with $2.7 billion for oil and gas (ADB 2009a).

Between 2005 and 2030, primary energy demand in Asia and the Pacific is expected to grow by 2.4% per year (ADB 2009b) or more.[5] Electricity demand is projected to increase more rapidly, at an average annual rate of 3.4%, with DMCs accounting for 86.5% of the total increase (Figure 1).

The investments required to meet this level of demand will be substantial. The Asia Pacific Energy Research Center (APERC 2009) estimates that the electricity and heat industry in the Asia–Pacific Economic Cooperation region will require between $6,400 and $8,700 billion from 2006 through 2030 (in constant 2006 US dollars). Asia is expected to account for about $3,300–$4,600 billion, or more than 50% of the total. Of this, about 65% is required for generation, 25% for transmission, and 10% for distribution.[6]

ADB projections indicate that electricity use in DMCs in 2030 will be about 2.3 times that of 2005. Projections over several decades are inevitably imprecise. Although the rates of change in generation technologies and fuel mixes are highly uncertain, energy demand in Asia is projected to grow rapidly; energy supply will remain a key area of ADB support

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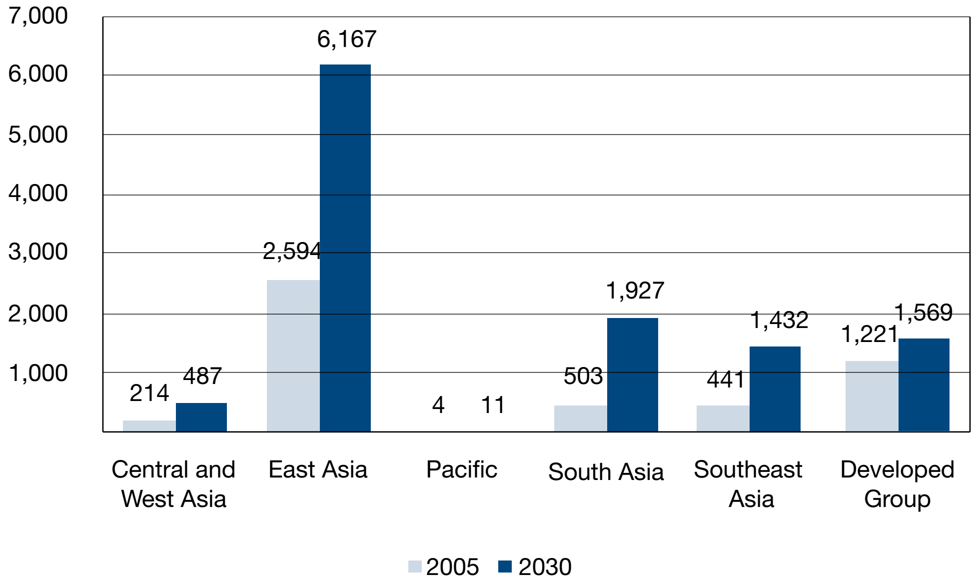
[4] In most of this publication, the use of the word "energy," unless indicated otherwise, refers to electric power supply.

[5] A more recent report indicates a higher expected rate of growth in Asia's energy demand, 3.4% annually from 2000 to 2030 (ADB 2011). However, the earlier report has more detailed coverage of future demand for electric power and overall energy in ADB developing member countries. The differences in assumed growth rates do not affect the analysis or conclusions of this report.

[6] The International Energy Agency (IEA 2011) estimates a global energy sector investment requirement in 2011–2035 of $38,000 billion in 2010 dollars, of which two-thirds is outside of OECD member countries. Of the total, 45% is expected to be for the electric power sector, of which 60% is for generation and 40% for transmission and distribution.

Figure 1. Electricity Demand in 2005 and 2030 by Region (terawatt-hours)



Source: Adapted from ADB. 2009. *Energy Outlook for Asia and the Pacific*. Asian Development Bank with the Institute of Energy Economics, Japan.

for some decades, and coal will continue to dominate fuel use for electric power generation.

As shown in Table 1, East Asia is the largest generator of electricity. However, its share of electricity in the Asia and Pacific region is expected to decrease from approximately 67.2% in 2005 to 60.6% in 2030. South Asia's share of overall generation is expected to increase from 15.7% to 20.8%. Pakistan's share of electricity generation in the Central and West Asia region is projected to increase from 32.3% to approximately 46.2%. The People's Republic of China, India, and Papua New Guinea will continue to be the largest electricity generators in their respective regions. In Southeast Asia, Indonesia's share of electricity generation will decrease from 25.1% to 19.7%, while Viet Nam's share will increase from 10.5% to 14.5% between 2005 and 2030. The Lao People's Democratic Republic's share will significantly increase from 0.8% of the region's total in 2005 to 3.7% in 2030.

In 2030, fossil fuels are expected to provide more than 71% of DMC electricity generation, led by coal (54.8%) and gas (15.0%) with oil accounting for only 1.6% (Table 2). Hydropower (12.5%) and nuclear (12.0%) are expected to provide far more electricity than non-hydro renewable energy technologies (including solar, wind, geothermal, and biomass, with a total of 4.1%), although these will grow rapidly from a very low base of 0.8% in 2005. In all regions, coal, oil, and natural gas will provide most of the electricity

Table 1. Electricity Generation in 2005 and 2030 (terawatt-hours)

Region	**Member Economy**	**Electricity Generation** (terawatt-hours)		**% of National Contribution to Regional Total**	
		2005	**2030**	**2005**	**2030**
Central and West Asia	Afghanistan	1	16	0.34	2.45
	Armenia	6	10	2.05	1.53
	Azerbaijan	21	59	7.19	9.02
	Georgia	7	15	2.40	2.29
	Kazakhstan	68	120	23.29	18.35
	Kyrgyz Republic	16	27	5.48	4.13
	Pakistan	94	302	32.19	46.18
	Tajikistan	17	22	5.82	3.36
	Turkmenistan	13	21	4.45	3.21
	Uzbekistan	48	61	16.44	9.33
	Subtotal	292	654	6.22[b]	5.33
East Asia	People's Republic of China	2,500	6,374	79.29	85.81
	Hong Kong, China	38	63	1.21	0.85
	Korea, Rep. of	388	624	12.31	8.40
	Mongolia	4	9	0.13	0.12
	Taipei,China	224	359	7.10	4.83
	Subtotal	3,153	7,428	67.21	60.58
Pacific	Fiji	1	2	20.00	15.38
	Papua New Guinea	3	8	60.00	61.54
	Timor-Leste	0[a]	1	20.00	7.69
	Other Pacific islands	0	1	0.00	7.69
	Subtotal	5	13	0.11	0.11
South Asia	Bangladesh	23	87	3.13	3.41
	Bhutan	2	12	0.27	0.47
	India	699	2,414	94.97	94.70
	Maldives	0	1	0.00	0.04
	Nepal	3	8	0.41	0.31
	Sri Lanka	9	27	1.22	1.06
	Subtotal	736	2,549	15.69	20.79

continued on next page

Table 1. continued

Region	Member Economy	Electricity Generation (terawatt-hours) 2005	Electricity Generation (terawatt-hours) 2030	% of National Contribution to Regional Total 2005	% of National Contribution to Regional Total 2030
Southeast Asia	Brunei Darussalam	3	4	0.59	0.25
	Cambodia	1	8	0.20	0.49
	Indonesia	127	318	25.10	19.65
	Lao PDR	4	60	0.79	3.71
	Malaysia	85	265	16.80	16.38
	Myanmar	6	56	1.19	3.46
	Philippines	57	165	11.26	10.20
	Singapore	38	105	7.51	6.49
	Thailand	132	400	26.09	24.72
	Viet Nam	53	235	10.47	14.52
	Subtotal	506	1,618	10.79	13.20
Total All Regions		4,691	12,261		

[a] All "0" figures result from rounding to nearest integer.

[b] Regional contributions to total of all regions.

Source: Adapted from ADB. 2009. *Energy Outlook for Asia and the Pacific*. Asian Development Bank with the Institute of Energy Economics, Japan.

Table 2. Electricity Generation Mix in 2005 and 2030 (%)

Generation	Regions: Central and West Asia	East Asia	Pacific	South Asia	Southeast Asia	All Regions
Coal						
2005	17.4	72.1	0	65.5	23.6	62.3
2030	17.5	60.3	0	61.2	34.6	54.8
Oil						
2005	12.6	3.3	64.9	4.8	14.0	5.3
2030	11.1	0.5	50.9	2.1	1.4	1.6
Natural gas						
2005	38.2	4.0	0	11.1	47.0	11.8
2030	41.4	6.8	20.8	13.8	43.9	15.0
Hydro						
2005	30.0	12.8	35.1	15.1	11.5	14.1
2030	27.4	11.5	23.6	10.8	13.7	12.5
Nuclear						
2005	1.8	7.6	0	2.4	0	5.6
2030	2.6	16.3	0	8.5	1.8	12.0
Others						
2005	0	0.3	0	1.2	3.9	0.8
2030	0	4.6	4.7	3.5	4.5	4.1

Source: Adapted from ADB. 2009. *Energy Outlook for Asia and the Pacific*. Asian Development Bank with the Institute of Energy Economics, Japan.

generation. The People's Republic of China and India together accounted for 43.8% of global coal-fired power generation in 2010; this is projected to rise to 57.0% by 2030 (Refocus 2011).

In short, Asia and the Pacific is expected to experience a significant increase in energy demand, which will trigger large investments in electricity supply facilities. The bulk of these investments is projected to be in thermal power plants. To a large extent, these projected developments do not account for the possible impacts of climate change on both the demand and supply side of the electric power sector, which is known to be highly sensitive to environmental and climate conditions.

The Case for Action

In early 2007, the Intergovernmental Panel on Climate Change (IPCC) released its Fourth Assessment Report.[7] In this report, the IPCC noted that over the period 1906–2005, global average surface temperature increased by 0.76°C, and that most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in atmospheric greenhouse gas (GHG) concentrations linked to anthropogenic (human) GHG emissions.[8] It is generally believed that this global warming has caused changes in precipitation patterns, increased the frequency and/or intensity of extreme weather events, and caused a rise in mean global sea levels.

Looking into the future, the IPCC (2007) concluded the following:[9]

- Even if greenhouse gas concentrations were to stabilize at existing levels, anthropogenic warming will continue for decades and sea level rise for centuries due to the time scales associated with climate processes and feedback effects. This phenomenon is generally referred to as *climate change commitment* (Solomon et al. 2009).
- World temperatures may rise by between 1.1°C and 6.4°C during the 21st century (relative to the period 1980–1999),[10] depending on the emissions scenario that is realized (the "best estimate" range is between 1.8°C and 4.0°C). Important sources of uncertainty with respect to projected world temperatures pertain to the future role of land and oceans in acting as carbon sinks (Canadell et al. 2007)as well as the possible release of large quantities of carbon from non-anthropogenic sources, especially from thawing permafrost (De Conto et al. 2012).
- Sea levels will rise by 18–59 centimeters by 2100 (Box 1), with thermal expansion of the oceans

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[7] The first, second, and third assessment reports were released in 1990, 1995, and 2001. They are available online at www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml

[8] In the language of the IPCC, "very likely" stands for "with a probability greater than 90%." Lean and Rind (2008) and Foster and Rahmstorf (2011) have shown that the global warming signal becomes even more evident once time series of global temperature are adjusted to remove the estimated impact of known factors on short-term temperature variations such as El Niño/southern oscillation, volcanic aerosols, and solar variability.

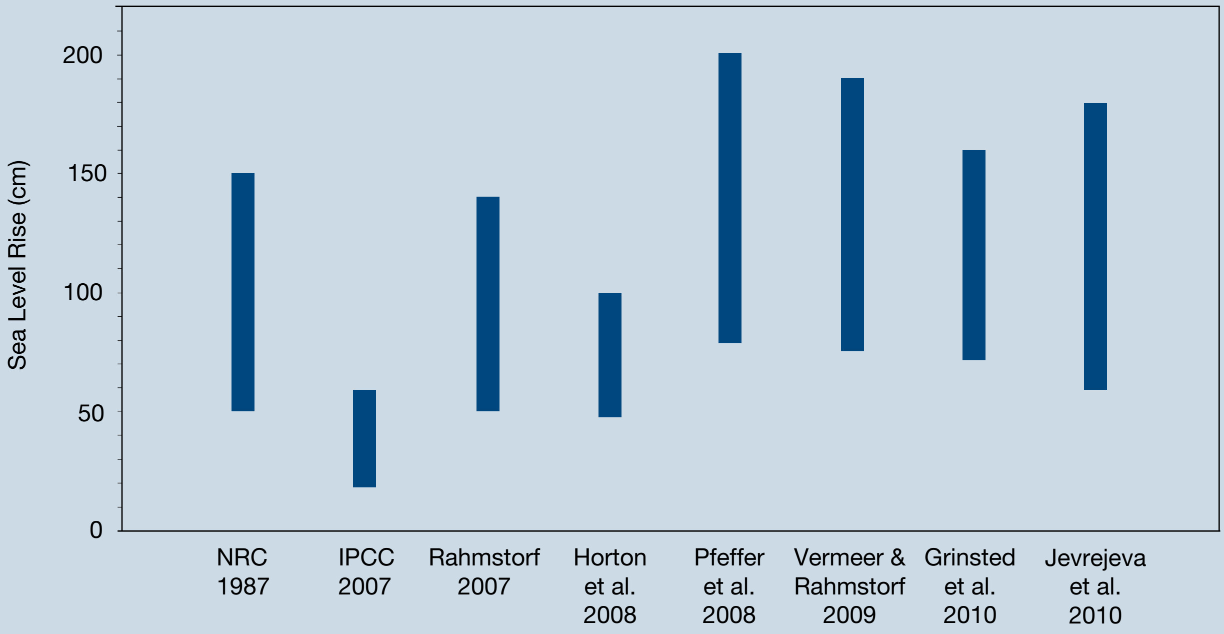
[9] More specifically, these conclusions were presented by IPCC's Working Group I, which focused on the physical science of climate change.

[10] More precisely, 1.1°C is the lower bound estimate of the range of likely increase under the B1 emissions scenario, while 6.4°C is the upper bound estimate of the range of likely increase under the A1FI emissions scenario (IPCC 2007).

being the single most significant contributor to the rise in sea level.[11] However, the IPCC itself pointed out that its projections did not include changes within the polar ice sheets.[12] The IPCC noted that the upper values of projected sea level rise presented in its report are not to be considered upper bounds and that higher rises in sea level cannot be ruled out.

Box 1. Sea Level Rise

IPCC (2007) projects a rise in sea level ranging between 18 cm and 59 cm by 2100. This range has been criticized by many experts as being too conservative (Krabill et al. 2004; Overpeck et al. 2006; Rahmstorf 2007). Recent projections suggest that sea level may be 0.6 to 1.5 meters higher than present by 2100 (Hansen and Sato 2011; Jevrejeva et al. 2010; Horton et al. 2008; and Rahmstorf 2007), and up to 2 meters higher under extreme warming scenarios (Pfefferet et al. 2008; Vermeer and Rahmstorf 2009; Grinstedet al. 2010). As shown in the figure below, IPCC's projections of sea level rise presented in its Fourth Assessment Report rank among the lowest.



Source: United States Geological Survey (USGS). Available at http://wh.er.usgs.gov/slr/sealevelrise.html

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[11] Domingues et al. (2008) estimated that the thermal expansion of oceans contributed to approximately 40% of observed sea level rise over the period 1961–2003, glaciers and ice caps contributed 35%, and large polar ice sheets of Antarctica and Greenland contributed only 25%. Over the period 2003–2008, large polar ice sheets are estimated to have contributed to 40% of the observed sea level rise, with glaciers and ice caps contributing another 40% and thermal expansion 20% (Cazenave et al. 2008). However, as warming continues, melting and dynamic changes in the polar ice sheets on Antarctica and Greenland will become increasingly important.

[12] The dynamics of ice sheets and glaciers is not yet sufficiently understood (Vermeer and Rahmstorf 2009).

- There is a greater than 90% confidence level that there will be more frequent warm spells, heat waves, and heavy rainfall.
- There is a greater than 66% confidence level that future tropical cyclones will be more intense.

While the exposure and vulnerability to climate will depend upon the nature and type of infrastructure as well as its location, the power sector is one whose output and efficiency are highly dependent on climate conditions. Projected changes in these conditions are expected to impact the sector significantly.

Vulnerability of the Energy Sector to Climate Change[13]

The energy sector is vulnerable to projected changes in *mean* climate conditions (such as mean temperature and rainfall), in climate *variability* (climate variability is expected to increase in a warmer climate), and in the frequency and intensity of extreme weather events and changes in sea level.

The power sector's vulnerability to projected climate changes includes the following:

- Increases in water temperature are likely to reduce generation efficiency where water is used for cooling purposes. The loss of power generation may be more significant where water availability is also affected (Box 2).
- Increases in air temperature may have numerous impacts, including (i) reduced generation efficiency and output as well as an increase in customer cooling demands, stressing the capacity of generation and grid networks; (ii) hydrological changes, especially in river basins fed by melting snow and glaciers (Box 3); and (iii) increase line losses in the transmission and distribution systems.[14]
- Changes in precipitation patterns and surface water discharges, as well as an increasing frequency and/or intensity of droughts, may adversely impact hydropower generation and reduce water availability for cooling purposes to thermal and nuclear power plants. Reduced water availability may also result from increased competition over water use for hydropower production, irrigation, and in-stream flow protection (Casola et al. 2005).
- Extreme weather events, such as stronger and/or more frequent storms, can reduce the supply and potentially the quality of fuel (coal, oil, gas), reduce the input of energy (water, wind, sun, biomass),[15] damage generation and grid infrastructure, reduce output, and affect security of supply (Box 4).[16]
- Rapid changes in cloud cover or wind speed (which may occur even in the absence of climate

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[13] An extensive review of the vulnerability of the electric power sector to climate change is provided by ADB (2012b), NETL (2007), Paskal (2009), Troccoli (2009), and Williamson et al. (2009).

[14] Electric transmission lines have greater resistance in warmer temperatures. Hence, where climate change results in higher ambient air temperatures, line losses will also increase. As noted in Feenstra et al. (1998), for a country with 8% line losses, a 3°C temperature increase will cause an increased need for generation of about 1%.

[15] Sharples and Sharples (2010) assess the impacts of cyclones on wind farms in the United States. Rose et al. (2012) show that in the most vulnerable areas now being considered by wind energy developers on the east coast of the United States, nearly half the turbines are likely to be destroyed in a 20-year period.

[16] Engineering the Future (2011) identifies flooding resulting from sea level rise, increased heavy rainfall, and greater probability of storms and storm surges as key risks in the energy sector.

Box 2. Water and Power Plants

The United States Geological Survey estimated that thermoelectric generation accounted for approximately 41% of all freshwater withdrawals in the country in 2005, ahead of agricultural irrigation, which represented 37% of withdrawals (USGS 2009). Bull et al. (2007) have estimated that each kilowatt-hour of electricity generated by a steam cycle process requires approximately 95 liters of water.

Carbon capture technologies will significantly increase those water requirements. The additional withdrawal and consumption could increase by approximately 50%–100% depending on the power generation technology.

Estimated Water Withdrawal and Consumption with and without Carbon Capture

	Withdrawal (liter/MWh)	**Consumption** (liter/MWh)
Subcritical pulverized coal without carbon capture	2,300	1,800
Subcritical pulverized coal with carbon capture	4,100	3,020
Supercritical pulverized coal without carbon capture	2,080	1,580
Supercritical pulverized coal with carbon capture	3,600	2,600
Integrated gasification combined cycle without carbon capture	1,510	1,130
Integrated gasification combined cycle with carbon capture	2,340	1,960

MWh = megawatt-hour

Source: National Energy Technology Laboratory. 2010. *Estimating Freshwater Needs to Meet Future Thermoelectric Generation Requirements—2010 Update.* DOE/NETL-400/2010/1339. US Department of Energy. Washington, DC.

Changes in water temperature and availability could significantly impact thermoelectric generation.

In August 2007, the southeastern United States experienced severe drought conditions. As a result, some reactors of nuclear and coal-fired power plants within the system operated by the Tennessee Valley Authority were forced to shut down (NETL 2009).

In the summer of 2003, more than 30 nuclear power plants in Europe had to reduce power production because of limitations on discharging cooling water (IAEA 2004). In France alone, 17 nuclear reactors had to be powered down or shut off. The resulting reduction in generation capacity forced Electricite de France to buy power on the open market. It is estimated that this heat wave cost the utility approximately 300 million euros (Kanter 2007).

Box 3. Glacier Melting, Glacial Lake Outburst Floods, and Hydropower in Nepal

Glaciers are considered to be sensitive indicators of increased air temperature. While the global average temperature has risen by about 0.75°C in the last 100 years (IPCC 2007), the warming in the Nepal Himalayas increased by 0.15°C to 0.60°C every 10 years during the last 3 decades (Shrestha et al. 1999).

One of the most visible impacts in most of the Himalayan region is the faster rate of retreat of its glaciers compared with those of other mountain ranges. This accelerated melting of glaciers causes increased river flows and flooding in the short term and a decrease in glacial runoff and river flows in the long term, affecting the water supply for hydropower plants (Pathak 2010). Extreme events such as glacial lake outburst floods can cause catastrophic damage to hydropower infrastructure. Nepal has experienced 24 such floods in recent years including that of the Dig Tsho in 1985, which destroyed the nearly completed Namche hydro project (Thomas and Rai 2006).

Continuing glacial melting and the impossibility of reliably predicting a specific occurrence of glacial lake outburst floods based on existing knowledge (ICIMOD 2011) highlights the vulnerability of hydropower systems in glacial mountain regions.

Khimti 1 is a 60-megawatt hydro installation 100 km east of Kathmandu that generates 350 gigawatt-hours per year. Winter mean temperature is projected to increase 0.8°C–3.4°C by the 2030s, rising to 2.0°C–5.0°C by the 2060s. Summer increases are projected at 0.5°C–2.0°C by the 2030s and 1.1°C–3.5°C by the 2060s. For precipitation, the mean projection is a 7% decrease in winter by the 2030s (12% by 2060s), while for summer, rainfall will increase by 2% by the 2030s (8% by the 2060s). However, the rainfall estimates are uncertain and baseline data do not allow an informed estimate of the increased risk of flooding.

Rainfall and temperature changes pose the following risks (IFC 2011):

- significantly lower dry season generation (high confidence in rainfall/output link but low confidence in rainfall model);
- no change to wet season generation or revenue (as Khimti operates at full capacity);
- extreme flooding with sedimentation and damage to intake structures (low confidence, poor baseline data);
- landslides blocking and flooding the river upstream and/or blocking road access, affecting generation and revenue (qualitative assessment only);
- decreased yields by subsistence farmers (but low confidence in models and minimal impact on Khimti output);
- increased risk of glacial lake outburst floods due to widespread and accelerating loss of glacier mass and deterioration of moraine dams (but low confidence in estimating financial impact due to poor baseline data); and
- pressure to increase minimum flow to increase downstream irrigation (with high confidence in adverse effects on output and revenue).

Source: International Finance Corporation. 2011. *Climate Risk Study: Khimti 1 Hydropower Scheme Himal Power Limited—Nepal.* Washington, DC.

Box 4. Vulnerability of the Energy Sector in Ho Chi Minh City

Two of Ho Chi Minh City's power plants (Phu My and Hiep Phuoc) fall within the projected flood zone, even with flood control measures in place, and may be exposed to extreme floods by 2050. A third thermal plant (Thu Duc) is only 0.1 km away and its operations could also be disrupted directly or through loss of cooling water. Ho Chi Minh City's transmission and distribution (T&D) networks could be affected by inundation of water; high winds and storms; and increased humidity, temperature, and salinity. Power lines designed to withstand winds of 30 meters per second have already been extensively damaged during storms. Flooding can affect aboveground lines and substations. Increased humidity can increase the risk of corrosion of steel infrastructure. Salt accumulation in soils and increased dryness and hardness of soils surrounding underground T&D cables can cause corrosion problems and increase transmission losses.

Many electricity substations and transmission lines are also within or close to areas where extreme flooding events are predicted for 2050 and are at risk of damage. All six existing and all four planned 500-kilovolt (kV) substations are at high risk, as are many 110-volt stations and high-voltage (500 kV) transmission lines.

Finally, projected temperature increases by 2050 in Ho Chi Minh City are likely to lead to increased power demand and lower generation and transmission efficiency

Source: Asian Development Bank. 2010. *Ho Chi Minh City: Adapting to Climate Change.* Summary Report. Manila.

change) can affect the stability of those grids with a sizeable input of renewable energy, and longer-term changes in these and precipitation patterns can affect the viability of a range of renewable energy systems.[17]
- Sea level rise can affect energy infrastructure in general and limit areas appropriate for the location of power plants and grids.

While the exposure and vulnerability to climate will depend upon the nature and type of infrastructure as well as its location, the power sector is one whose output and efficiency are highly sensitive to climate conditions. Projected changes in these conditions are expected to impact the sector significantly.

In particular, in Asia and the Pacific approximately 80% of the total electricity is produced by thermoelectric power plants (Table 2), which depend on the availability and temperature of large quantities of water for cooling purposes. Van Vliet (2012) estimates that climate change could bring about a summer average decrease in capacity of power plants of 6.3%–19.0% in Europe, and 4.4%–16.0% in the United States, as a result of the combined impacts of lower summer river flows and higher river temperatures.[18] Similarly, energy output from hydropower plants may be adversely impacted by changes in river discharge resulting from changes in rainfall patterns. In particular, the possibility for longer or more intense dry seasons, as is most often

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[17] For a review of the climate change impacts on wind energy, see Pryor and Barthelmie (2010).

[18] See also Bull et al. (2009), Ebinger and Vergara (2011), Florke et al. (2011), Forster and Lilliestam (2010), Greis et al. (2009), Harrison et al. (2009), Koch and Vogele (2009), Koch et al. (2012), Kopytkoa and Perkins (2011), McDermott and Nilsen (2011), Mideksa and Kallbekken (2010), NETL (2007, 2009), and Rubbelke and Vogele (2011b).

Box 5. Impacts of Climate Change on Hydropower Projects in India, Sri Lanka, and Viet Nam

Climate change is expected to have different impacts in India, Sri Lanka, and Viet Nam. However, in all 3 countries, it is generally projected that precipitation may concentrate even more during the rainy season and that the dry season may have less precipitation than it currently does. This could have impacts on power output of hydropower plants.

Iimi (2007) assessed the impacts of climate on 3 hydropower projects: (i) the Vishnugad Pipalkoti Hydro Electric Project (VPHEP) in India; (ii) the Upper Kotmale Hydro Power Project (UKHPP) in Sri Lanka; and (iii) the Thac Mo Hydropower Station Extension project (TMHSEP) in Viet Nam. The VPHEP is a typical "run-of-river" station with a small storage capacity for diurnal variations. The UKHPP includes a daily reservoir of approximately 800,000 m^3, while the TMHSEP relies on water resources from the existing Thac Mo Reservoir.

In both the VPHEP and TMHSEP cases, it is projected that the rainy season would have higher levels of water than the respective baselines and that in the lean season, water resources may become even more limited. Without a large storage capacity, the VPHEP could not exploit the projected large increase in river discharge in the rainy season. On the other hand, in the lean season, the project is likely to face severe water constraints, impacting its power output. Despite the presence of a large reservoir, the negative impacts of lower water levels in the dry season also appear to be dominant since the reservoir may not absorb the increased river discharge. However, in the UKHPP case, a projected increase in year-round water flow may allow generation of more energy than the baseline level, provided that the installed capacity is large enough to absorb increasing water flow.

Source: Iimi, A. 2007. *Estimating Global Climate Change Impacts on Hydropower Projects: Applications in India, Sri Lanka, and Viet Nam.* Policy Research Working Paper 4344. Finance, Economics, and Urban Development Department, The World Bank. Washington, DC.

projected (IPCC 2007), may be a source of concern to power plant operators (Box 5).

A summary of the potential impacts of climate change on the energy sector is presented in Table 3.

Adaptation Options in Energy Sector Investments

Adaptation measures can generally be divided into engineering and non-engineering options. In a number of circumstances, it may be best to promote no- or low-regret adaptation strategies that deliver development benefits regardless of the nature and extent of changes in climate. This is a useful and practical approach wherever uncertainty is high regarding climate change, and where large climate-proofing capital investments cannot be easily justified. In some circumstances, such climate-proofing investments may be justified. In others, a "do nothing" response may occasionally be more appropriate and cost-effective.

Table 3. Potential Impacts of Climate Change on the Energy Sector

Climate Change	Potential Impacts on the Energy Sector
Fossil Fuel Extraction and Transport	
Temperature increase	• Damage to pipelines by melting permafrost (as soil subsidence threatens structural integrity)
Precipitation increase; flooding	• Reduced coal quality (higher moisture content of opencast mining) • Increased coal availability (e.g., if coal seam fires are extinguished) • Reduced output (if floods affect mines) or availability (if floods affect transport)
Drought or precipitation decrease	• Reduced coal availability (less water for mine air conditioning and operations, higher probability of seam fires) • Reduced shale oil or gas availability (very large water demands for drilling and removing drilling mud) • Soil shrinkage due to drought could affect oil and gas pipelines
Storm strength and/or frequency increase	• Reduced coal production (if storms affect opencast excavation equipment) • Reduced oil production (if storms affect coastal or offshore oil platforms)
Thermal Power	
Precipitation increase or decrease	• Increase could cause reduced coal quality (and combustion efficiency) due to higher moisture content of coal • Decrease could affect availability of freshwater for cooling (all thermal systems).
Higher air temperature	• Lowered generation efficiency • Decreased integrated gasification combined cycle system efficiency (converting coal to gas) • Lowered combined cycle gas turbine efficiency
Higher wind speed	• Damage to infrastructure • Wider pollutant dispersion
Sea level rise	• Increased sea levels and storm surges could damage coastal infrastructure
Extreme events (including flooding)	• Hurricanes, tornadoes, ice storms, severe lighting, etc. can destroy infrastructure and disrupt supplies and offshore activities • Possible soil erosion and damage to facilities
Nuclear Power	
Precipitation Changed river flows Higher air temperature	• Insufficient cooling water (drought, temperature, competing uses), particularly for inland plants • Decreased generation efficiency (temperature rise) for inland plants • Loss of on-site power, leading to severe interruptions and safety and operations for inland and coastal plants
Sea level rise Floods Extreme events	• Flooding from heavy rainfall, storm surges, or sea level rise • Catastrophic failure with radioactive leaks and widespread evacuations of population, particularly for coastal locations
Hydropower	
Precipitation (including drought)	• Changing annual or seasonal patterns can affect river flows and water levels behind dams, either reducing or increasing power output • Siltation can reduce reservoir storage capacity • Increased uncertainty in water flows can affect power output and generation costs
Extreme events (glacier melting, floods)	• Floods and glacial lake outburst floods can damage or destroy infrastructure

continued on next page

Table 3. continued

Climate Change	Potential Impacts on the Energy Sector
Higher air temperature, wind speeds, and humidity	• Can increase surface evaporation, reducing water storage and power output
Wind Power	
Wind speed	• Changes in wind speed can reduce generation (turbines cannot operate in very high or very low winds) • Within operational wind speeds, output is greatly affected by wind speed. • Changes in wind patterns and duration affect output (e.g., ability to forecast output)
Air temperature	• Changes in extreme cold periods can affect output (e.g., through turbine blade icing)
Storm surges	• Damage to offshore wind farms
Extreme events	• Damage to infrastructure • Difficult access to offshore locations (e.g., for maintenance)
Solar Photovoltaic Power	
Temperature increases	• Lowers cell efficiency and energy output • Lowers capacity of underground conductors if high ambient temperature increases soil temperature
Precipitation increases	• Can wash away dust (short term) but reduces panel efficiency (less solar radiation) • Snow accumulation on panel reduces efficiency
Wind speed; turbidity	• Increased efficiency and output with cooling effect of wind • Scouring of panel and lower output if air is gritty/dusty
Cloud cover	• Increase lowers efficiency/output • Rapid fluctuations in cloud cover can destabilize grid
Extreme events	• Can damage systems (e.g., lightning strikes)
Concentrated Solar Power	
Wind; extreme events (cyclone)	• Highly vulnerable to damage to infrastructure from high or fluctuating winds
Precipitation decrease	• Water is required for steam; less water will result in reduced power • Possible damage from overheating with insufficient cooling water
Temperature increase	• Increased water required for cooling with temperature rise
Cloud cover increase	• Reduced efficiency with increased cloud cover
Biomass Energy and Biofuels	
Floods/ precipitation	• Land degradation/erosion with possibly lower fuel supply and less electricity output
Precipitation or temperature changes	• Temperature and rainfall changes could increase or decrease electricity output depending on feedstock productivity • Higher rainfall can increase moisture content of feedstock, lowering energy content • Changing precipitation patterns could affect availability of freshwater for cooling
Extreme events	• Possible damage to fuel supplies and generation infrastructure
Transmission and Distribution	
Temperature increase	• Can reduce electricity carrying capacity of lines • Can increase losses within substations and transformers

continued on next page

Table 3. continued

Climate Change	Potential Impacts on the Energy Sector
Precipitation and flooding	• Heavy rains and flooding can undermine tower structures through erosion • Snow and ice can damage transmission and distribution lines (e.g., through sagging) • Drought can increase dust damage • Flooding can damage underground cables and infrastructure in general
High wind speeds	• Strong winds can damage transmission and distribution lines
Extreme events (flood, typhoons, drought)	• High temperatures, storms, erosion, or flooding can damage control systems through loss of information and communications technology service or reduce quality of service • Ice storms can do devastating damage to power transmission and distribution networks

Source: Adapted from ADB. 2012. *Climate Risk and Adaptation in the Electric Power Sector.* Manila.

Engineering Options[19]

Engineering adaptation measures include the following:

- In general, more robust design specifications could allow structures to withstand more extreme conditions (such as higher wind or water velocity) and provide them with the ability to cope safely with higher air and/or water temperatures (Girard and Mortimer 2006). In some circumstances, it may also be necessary to consider relocating or refitting extremely vulnerable existing infrastructure. Furthermore, decentralized generation systems may reduce the need for large facilities in high-risk areas and minimize climate risk. Finally, the reliability of control systems and information and communications technology components may improve from redundancy in their design and from being certified as resilient to higher temperatures and humidity.
- For thermal power, enlarged or retrofitted cooling systems (including air cooling) where water is expected to be increasingly scarce may be considered; where increased flooding is expected, designing facilities to be waterproofed may be an option.
- For nuclear power, redundant cooling systems may be considered, and it may be possible to assure robust protection from floods, tsunamis, or other extreme events that can otherwise damage backup generation and essential cooling systems.
- For hydropower, where water flows are expected to change over the life of the system, it may be possible to consider diverting upstream tributaries, building new storage reservoirs, modifying spillways, and installing turbines better suited to expected conditions. Greater water flows (whether from glacial melting or increased precipitation) may require higher and more robust dams and/or small upstream dams.
- Where wind speeds are likely to increase, it may be possible to design turbines and structures better able to handle higher wind speeds and gusts, to capture greater wind energy with taller towers, or to design new systems better able to capture the energy of increased wind speeds.
- For solar photovoltaic systems, where temperature increases or significant heat waves are expected, it may be useful to consider designs

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[19] Ebinger and Vergara (2011) refer to this set of climate-proofing measures as “technological” measures.

that improve passive airflow beneath mounting structures (reducing panel temperature and increasing power output); to specify heat-resistant cells, modules, and components; and to consider distributed systems to improve grid stability and micro-inverters for each panel to improve both output and grid stability where cloud cover fluctuates rapidly (e.g., with higher winds).

- For solar-concentrating or sun-tracking systems, where higher wind speeds, more intense storms, and gusts are likely, it may be necessary to consider more robust structures, tracking motors, and mountings, and to consider air or waterless cooling in water-restricted areas.
- For biomass and biofuels, in addition to adaptations for thermal systems in general, more robust feedstock may be designed (e.g., tolerant to heat, salt, or water), and it may be possible to expand or introduce more efficient irrigation systems, depending on expected climatic changes.
- For geothermal, specifications might require greater protection where floods are likely to increase. Where cooling water is reduced with climate change, it may be possible to use air-cooled systems, although it may be less expensive to develop new water sources.
- For ocean power, only sea wave and tidal power generation are approaching commercial viability. It may be possible to specify the ability of systems to withstand extreme (100-year) waves or alternatively specify designs that are sufficiently inexpensive that the financial loss from destruction is less than the cost of preventative measures. For sea wave power generation, floating systems may be climate proofed with protection mechanisms against storm surges (e.g., automated lowering of expensive components to the sea floor, designs that can cope with extreme conditions, or mechanisms to disconnect or shut down during extreme events).
- For transmission and distribution (T&D) (including substations), specifying redundancy in control systems, multiple T&D routes, relocation, and/or underground distribution for protection against wind, high temperatures, corrosion, and flooding may be considered. Where stronger winds are expected, higher design standards for distribution poles may be adopted. Where temperatures are likely to increase, more effective cooling systems for substations and transformers can be put in place.
- For electricity end use, adaptation measures to cope with increased demand with temperature rises are of three types: (i) increasing generation (megawatt-hours) and capacity (megawatts) to meet the higher demand (business as usual approach); (ii) improving the efficiency of power supply (generation, transmission, distribution system improvements); and (iii) improving end-use efficiency for buildings, facilities, and energy-intensive appliances and machinery, thus requiring less investment in generation and distribution.

Non-Engineering Options[20]

Non-engineering adaptation measures include the following:

- In general (including generation technologies not listed below), it may be cost-effective to put in place more robust operational and maintenance procedures, improved and better coordinated land use planning (e.g., rezoning land use so future power infrastructure is in less vulnerable areas), policies and enforceable regulations to improve energy security, decentralized local planning and generation, integration of adaptation and mitigation planning, integration of climate change and disaster management planning, improved forecasting of demand changes and

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[20] Ebinger and Vergara (2011) refers to this set of climate-proofing measures as “behavorial” measures.

supply–demand balance with climate change, processes to integrate power sector planning with that of other sectors (including water supply), and improved localized models used to predict storms and flood hazards. It may be of interest to set up rapid emergency repair teams to repair damaged facilities quickly.

- For nuclear power, it may be appropriate to develop more stringent safety regulations against extreme events, including flooding.
- For hydropower, new operating rules, improved hydrologic forecasting, and coordinating power planning and operations with other water-use projects may be useful. For existing hydro infrastructure, localized regional climate modeling might suggest operational changes to optimize reservoir management and improve energy output by adapting to changes in rainfall or river flow patterns. Basin-wide management strategies that take into account the full range of downstream environmental and human water uses may prove necessary. Restored and better-managed upstream land, including afforestation to reduce floods, erosion, silting and mudslides, may provide useful protection to existing infrastructure.
- For wind power, it may be possible to choose sites that take into account expected changes in wind speeds, storm surges, sea level rise, and river flooding during the lifetime of the turbines.
- For solar photovoltaic power, it may be possible to select locations where expected changes in cloud cover, airborne grit, snowfall, and turbidity are relatively low.
- For solar concentrating or tracking systems, avoiding locations with high, gusting winds or expectations of increased cyclones/extreme events may be an option.
- For wind and solar technologies, it may be possible to improve the reliability of expected output with better weather predictions.
- For biomass/biofuels, early warning systems for rainfall and temperature anomalies, emergency harvesting arrangements for an imminent extreme event, and provision of crop insurance can be appropriate options.
- For T&D, new mandatory design codes for lines, transformers, and control systems may be adopted to cope effectively with the expected changes.
- For electricity end use, mandatory minimum energy performance standards for buildings, manufacturing facilities, and energy-intensive appliances can increase resilience of the sector.

The measures described above provide general guidance regarding possible adaptation measures in the electric power sector. However, detailed local assessments on the projected changes in climate conditions, the impacts of these changes on variables of interest to the power sector (e.g., projected changes in rainfall having an impact on water availability), and the nature and feasibility of adaptation options are necessary when investment projects are designed and their viability assessed.

Do Nothing Option

In some cases, it is plausible that sufficient risk allowance has been built into the project to account for climate change, or that the nature of the changes are too uncertain or minimal, or that the consequences of climate change are too severe to justify in situ adaptation. In the latter circumstance, the best course of action maybe to allow the infrastructure to deteriorate and be decommissioned. In other cases, the up-front capital investment associated with any technically feasible adaptation option may be so large as to outweigh any possible benefits associated with the climate proofing of the infrastructure. Not investing in adaptation in the context of a particular project may be the best course of action (from both a technical and economic assessment).

Part B: Climate Proofing Energy Investment Projects

Overview

In this *Guidelines*, the expression "climate proofing" is meant as a process that aims to identify risks that an investment project may face as a result of climate change, and to reduce those risks to levels considered to be acceptable. It does not imply a complete mitigation of the potential risks of climate change. The expression is used in a way similar to the meaning provided in ADB (2005):

> Climate proofing is a shorthand term for identifying risks to a development project, or any other specified natural or human asset, as a consequence of climate variability and change, and ensuring that those risks are reduced to acceptable levels through long-lasting and environmentally sound, economically viable, and socially acceptable changes implemented at one or more of the following stages in the project cycle: planning, design, construction, operation,and decommissioning.

The expression is used in a way similar to the meaning provided in UNDP (2011):

> Climate proofing refers to the explicit consideration and internalization of the risks and opportunities that alternative climate change scenarios are likely to imply for the design, operation, and maintenance of infrastructure. In other words, integrating climate change risks and opportunities into the design, operation, and maintenance of infrastructure.

A similar meaning of "climate proofing" is used by Ebinger and Vergara (2011):

> Climate Proofing: Actions taken to lessen, or perhaps eliminate, the potential negative impacts of weather and climate variability and of climate change through the life cycle of a project (p. 75).

The methodological approach presented in this *Guidelines* for building adaptation into energy investment projects is divided into six different sets of activities (Figure 2). The process begins with scoping the project and defining the assessment and its objectives. The core activities related to project design fall under impact assessment, vulnerability assessment, and adaptation assessment. Finally,

Box 6. Adaptation Science

Meinke et al. (2009) define “adaptation science” as “the process of identifying and assessing threats, risks, uncertainties and opportunities that generates the information, knowledge and insight required to effect changes in systems to increase their adaptive capacity and performance.”

The adaptation science process requires the following steps (in sequential order):

1. Understand the existing system and scope possible changes to norms and values.
2. Identify likely core issues and decision criteria; clarify who, what, and when.
3. Assess climate impacts and trends, including their uncertainty.
4. Evaluate if impacts matter.
5. Assess the adaptation options and their broader consequences.
6. Design and evaluate implementation options.

the process ends with defining implementation arrangements and monitoring frameworks. To facilitate the implementation of the methodological approach, these six sets of activities are broken into 20 steps (Figure 3). A process similar to the one described above has been referred as “adaptation science” (Box 6).

A climate change assessment is best integrated into the activities of the project preparation technical assistance, following the identification of climate change as a potential risk/opportunity factor to the project at the concept stage. To facilitate the screening for climate risk or opportunity, a rapid risk screening tool has been developed and is currently being tested by ADB (Appendix 1).

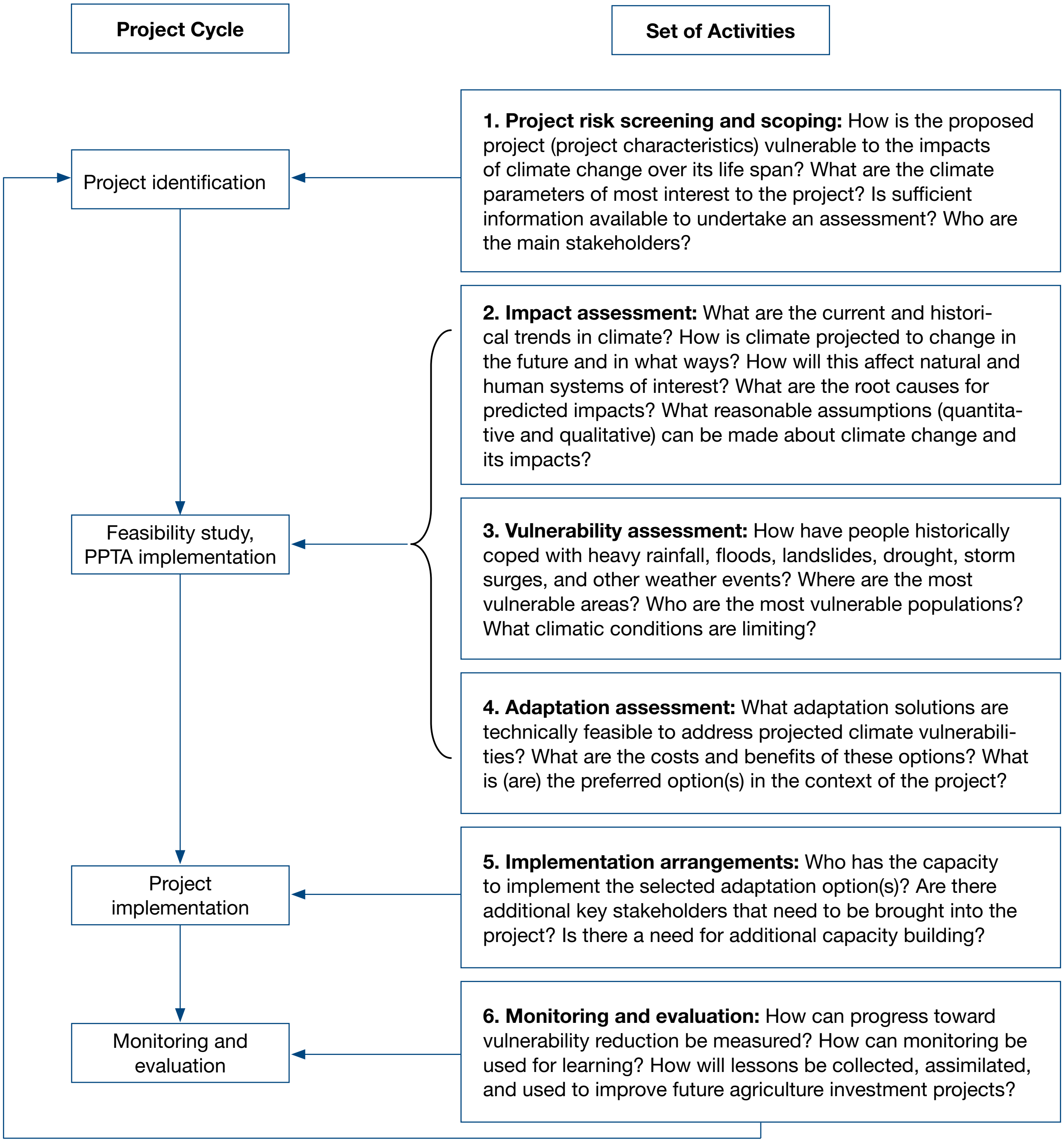


Figure 2. Assessing Adaptation Needs and Options: 6 Sets of Activities

1. Project risk screening and scoping: How is the proposed project (project characteristics) vulnerable to the impacts of climate change over its life span? What are the climate parameters of most interest to the project? Is sufficient information available to undertake an assessment? Who are the main stakeholders?

2. Impact assessment: What are the current and historical trends in climate? How is climate projected to change in the future and in what ways? How will this affect natural and human systems of interest? What are the root causes for predicted impacts? What reasonable assumptions (quantitative and qualitative) can be made about climate change and its impacts?

3. Vulnerability assessment: How have people historically coped with heavy rainfall, floods, landslides, drought, storm surges, and other weather events? Where are the most vulnerable areas? Who are the most vulnerable populations? What climatic conditions are limiting?

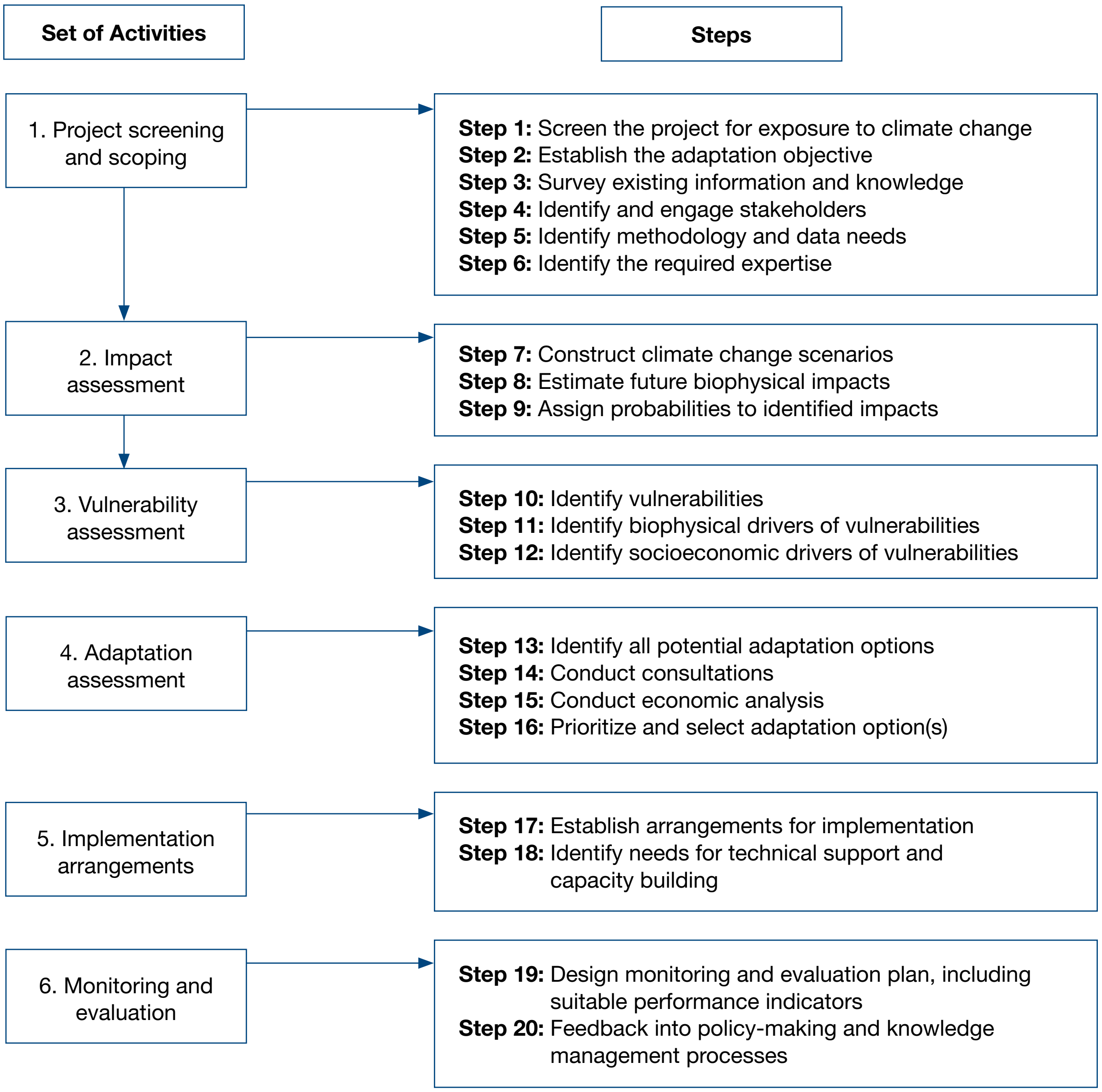
4. Adaptation assessment: What adaptation solutions are technically feasible to address projected climate vulnerabilities? What are the costs and benefits of these options? What is (are) the preferred option(s) in the context of the project?

5. Implementation arrangements: Who has the capacity to implement the selected adaptation option(s)? Are there additional key stakeholders that need to be brought into the project? Is there a need for additional capacity building?

6. Monitoring and evaluation: How can progress toward vulnerability reduction be measured? How can monitoring be used for learning? How will lessons be collected, assimilated, and used to improve future agriculture investment projects?

PPTA = project preparation technical assistance

Figure 3. Assessing Adaptation Needs and Options: 6 Sets of Activities and 20 Steps



Set of Activities	Steps
1. Project screening and scoping	**Step 1:** Screen the project for exposure to climate change **Step 2:** Establish the adaptation objective **Step 3:** Survey existing information and knowledge **Step 4:** Identify and engage stakeholders **Step 5:** Identify methodology and data needs **Step 6:** Identify the required expertise
2. Impact assessment	**Step 7:** Construct climate change scenarios **Step 8:** Estimate future biophysical impacts **Step 9:** Assign probabilities to identified impacts
3. Vulnerability assessment	**Step 10:** Identify vulnerabilities **Step 11:** Identify biophysical drivers of vulnerabilities **Step 12:** Identify socioeconomic drivers of vulnerabilities
4. Adaptation assessment	**Step 13:** Identify all potential adaptation options **Step 14:** Conduct consultations **Step 15:** Conduct economic analysis **Step 16:** Prioritize and select adaptation option(s)
5. Implementation arrangements	**Step 17:** Establish arrangements for implementation **Step 18:** Identify needs for technical support and capacity building
6. Monitoring and evaluation	**Step 19:** Design monitoring and evaluation plan, including suitable performance indicators **Step 20:** Feedback into policy-making and knowledge management processes

Project Screening and Scoping

The goal of project risk screening in this context refers to determining the potential nature and extent of risk the project may be exposed to as a result of climate change.

The goal of project scoping is to identify how climate change impacts can affect the overall project objective, and to set the boundaries within which the assessment of adaptation options will be undertaken.

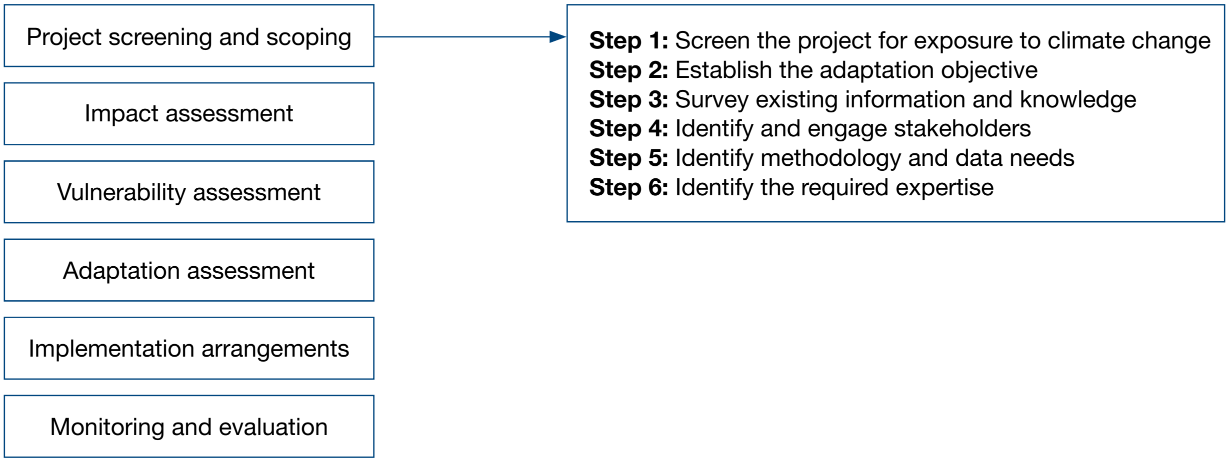
Step 1: Screen the Project Exposure to Climate Change

Risk screening tools have been developed by a number of organizations to rapidly assess the risks posed to a planned project, or caused by a planned project, as a result of climate change and natural hazards. These are meant to alert a project officer to the potential risk of climate change to the project and to determine whether further assessment is warranted. While different risk screening tools use slightly different approaches, expert opinion and judgment, based on awareness and knowledge of climate change and hazards, remain essential for all (Box 7).

ADB has developed a project risk screening tool that is being tested by a number of member countries (see Appendix 1). This tool screens for risks from both climate change and natural hazards, and may be of interest at the stage of identifying and assessing project feasibility. A revised version of the risk screening tool is under development.

Alternatively, a series of screening questions specific to energy projects can be applied, such as those listed in Table 4.

Figure 4. Project Screening and Scoping



Step 1: Screen the project for exposure to climate change
Step 2: Establish the adaptation objective
Step 3: Survey existing information and knowledge
Step 4: Identify and engage stakeholders
Step 5: Identify methodology and data needs
Step 6: Identify the required expertise

Box 7. Selected Climate Change Risk Screening Tools

Department for International Development, United Kingdom: Opportunities and Risks of Climate Change and Disasters (ORCHID) and Climate Risk Impacts on Sectors and Programmes. http://tinyurl.com/ccorchid

The Netherlands Climate Assistance Programme. www.nlcap.net

World Bank: Climate Change Knowledge portal including ADAPT tool. http://sdwebx.worldbank.org/climateportal

International Institute for Sustainable Development: Community-based Risk Screening Tool—Adaptation and Livelihoods (CRiSTAL). www.iisd.org/pdf/2011/brochure_cristal_en.pdf

Table 4. Climate Risk Screening: Example of Screening Questions

Screening questions	Yes	No	Remarks
Is the project area exposed to climate hazards such as floods, droughts, landslides, tropical cyclones, storm surges, etc.?			
Could changes in precipitation patterns or evaporation rates over the life span of the project affect its power output, cost, and sustainability?			
Are there any demographic or socioeconomic aspects of the project and project area that increase the vulnerability of the project to climate change?			
Could the project potentially increase the vulnerability of the surrounding area (e.g., by increasing runoff or by reducing available water supply)?			

One purpose of the risk assessment exercise at the project level is to identify the high-risk hazards (i.e., the climate change events that are most likely to severely affect the performance of an energy project). The impacts from these high-risk hazards can subsequently be the point of departure for identification and discussion of adaptation options.

The project scoping for adaptation will need to cover the following aspects of climate change impacts:

- direct threats to the project (e.g., effect of extreme weather events on infrastructure),
- underperformance of the project (e.g., cooling systems that become unreliable as discharge patterns change), and
- new opportunities to improve project performance that may arise from climate change and could be captured if factored into project design.

Step 2: Establish the Adaptation Objective

The adaptation-related activities should seek to minimize these potential negative effects. Establishing how climate change may affect the project site and outcomes will assist in ensuring that the right data is collected throughout, that the right expertise is recruited from the outset, and that the most appropriate national or regional partners are brought in to the project. The vulnerability, impact, and adaptation assessments that follow are intended to assist in further refining how climate change may impact on a project, and options for managing these impacts.

Step 3: Survey Existing Information and Knowledge

A large amount of work related to climate change is ongoing in many countries, including governmental planning and policy processes as well as research and development programs such as those under the United Nations Framework Convention on Climate Change (UNFCCC). Identifying existing available information can help to avoid duplication of effort and ensure that coordination efforts within countries and between donors are being supported. Each country has a climate change focal point[21] under the UNFCCC and will, in most cases, have prepared a national communications to the UNFCCC, which is a good starting point for understanding the government's efforts related to climate change.[22] Least developed countries have also prepared national adaptation programs of action to identify their most urgent adaptation needs.[23] While some of these documents may benefit from being revised and updated, they may provide a good basis for identifying country needs and a focal point around which to coordinate the multiple climate change initiatives underway.

In addition, the Global Environment Facility's Adaptation Learning Mechanism provides a list of country-level adaptation initiatives, together with relevant technical resources relating to climate change impacts and vulnerability assessments.[24]

Step 4: Identify and Engage Stakeholders

Having an initial scope for the adaptation work as well as a survey of existing information will likely expand the relevant stakeholders to include climate change focal points, disaster risk reduction focal points, and possibly flood management agencies. A number of institutions and research organizations may be conducting work relevant to the project. Further, specific engagement of local communities, nongovernment organizations, and small to large businesses operating in the area will be important for conducting a vulnerability assessment and for engagement in selecting the most effective adaptation strategies.

Step 5: Identify Methodology and Data Needs

A preliminary identification of the climate parameters of greatest interest to the project should be initiated at the concept stage and can be further developed in later stages. Climate change parameters of interest (including variability and seasonal patterns) to energy projects include the following:

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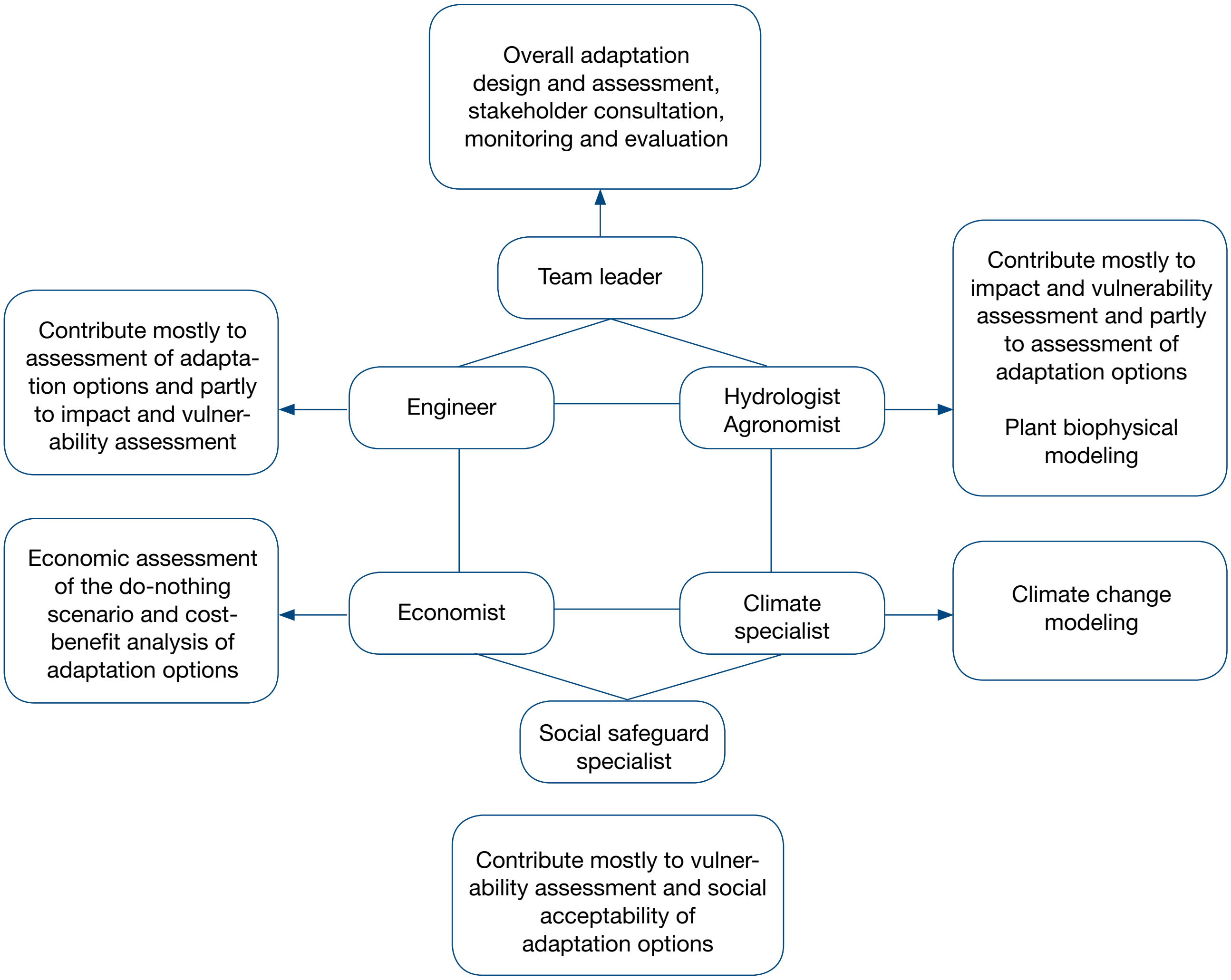
[21] Details of the national focal points are available at http://maindb.unfccc.int/public/nfp.pl

[22] National communications submitted by developing country parties to the UNFCCC are available online at http://unfccc.int/2979.php

[23] The following ADB developing member countries have prepared national adaptation programs of action: Afghanistan, Bangladesh, Bhutan, Cambodia, Kiribati, Lao PDR, Maldives, Nepal, Samoa, Solomon Islands, Tuvalu, and Vanuatu. They are available at http://unfccc.int/4585.php

[24] These country profiles can be accessed at www.adaptationlearning.net/country-profiles

Figure 5. Assessing Adaptation Needs and Options: A Web of Interaction



- temperature (mean, maximum, minimum),
- precipitation,
- humidity,
- sunshine hours, and
- wind velocity.

Specifying these requirements at the outset is important as it will guide the choice and extent of the information to be collected and used for assessing possible impacts and vulnerability. Identifying the method(s) for the assessment and prioritization of options, such as cost-benefit analysis or multi-criteria analysis (among other possible methodological approaches), will also determine the data needed and ensure that it is collected during project preparation.

Step 6: Identify the Required Expertise

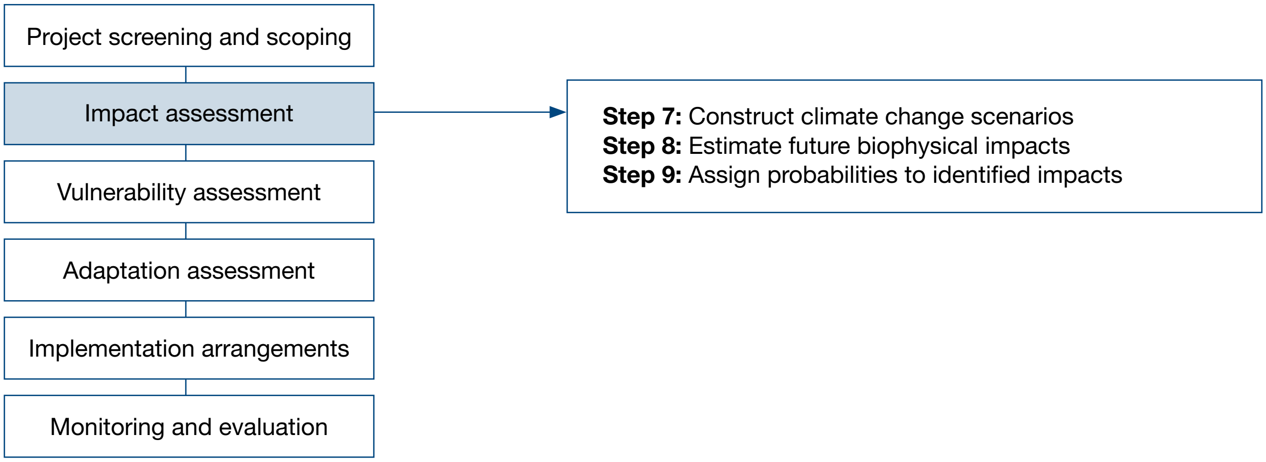
The assessment of adaptation options requires interaction between different experts (Figure 5). Many of the activities required to develop a climate change adaptation assessment for a project can be undertaken through an expansion of the tasks of a classic project preparation team, such as the project engineer and environmental specialist. Similarly, the economist conducting the economic analysis of the overall project may be in a position to assess the costs and benefits of the project with and without adaptation.

Appendix 2 provides examples of additional integrated activities for existing team members and a set of detailed terms of reference for impact, vulnerability, and adaptation assessments. These are meant to indicate the general nature of the tasks and deliverables that may be required, rather than providing a comprehensive list of such tasks and deliverables.

Impact Assessment

The goal of the impact assessment is to identify and evaluate, in physical terms, the effects of climate change on natural and human systems. Typically, this entails (i) the analysis of current trends in relevant climate parameters and observed impacts of these climatic trends on the natural and human systems; (ii) development of climate, sea level, and socioeconomic scenarios for the relevant time frame and at appropriate temporal and spatial scales; (iii) assessment of biophysical impacts of socioeconomic and associated climatic changes as well as sector- and system-specific analytical tools.

Figure 6. Impact Assessment



For any given project, the decision of which emissions scenarios and climate projections to use or develop is based on a number of factors, including the need to account for a wide range of uncertainty, time frames, budget, and data availability. In an increasing number of cases, climate change projections have already been developed through national and regional climate change initiatives, such as the national communications to the UNFCCC, and may be adapted for use by the project. In other cases (such as in Viet Nam), the government has adopted an "official" set of climate change projections against which all line ministries must design their adaptation action plans (MONRE 2009). It is thus important to begin by identifying whether climate projections are already available, as developing such projections can be costly and time-consuming. It is also important to recognize that even with "localized" climate projections, these may not be to a desired spatial resolution at the project level. In all cases, understanding the history of climate (temperature, rainfall, storm surges, and extreme weather events) is always a necessary first step.

Step 7: Construct Climate Change Scenarios

Climate change projections and scenarios represent the response of the climate system to emissions or concentration of greenhouse gases. They are typically based on simulations by climate models. Climate change projections can be useful in determining how climate variables such as temperature and precipitation may change in the future. However, projections based on climate model outputs are limited by the imperfect representation of the climate system within climate models, in addition to uncertainties associated with future greenhouse gas emissions. Therefore, climate projections are not forecasts or predictions, but provide plausible alternative characterizations of future climate conditions. They are helpful in exploring "what-if" questions; they do not aim to provide accurate predictions of how climate will behave in the future.

The Intergovernmental Panel on Climate Change (IPCC)'s Task Group on Data and Scenario Support for Impact and Climate Assessment (TGICA) provides general guidance on the use of data and scenarios in impacts and adaptation assessments through a revised set of guidelines.[25] This guidance document also includes common sources of data for constructing climate scenarios. Individuals tasked to develop climate scenarios should consult this document. In addition, the following points provide further information on the development of climate change scenarios.

Identifying the needs for climate scenarios

The construction of climate scenarios begins with an understanding of what climate scenario information is needed for impact assessment. Individuals creating climate change scenarios need to discuss data needs with the team of experts assessing impacts for the energy project. The impact assessment experts must identify the variables they need as well as the required spatial and temporal resolution (e.g., 100 square kilometers at a daily time step). The climate expert then will be in position to determine how to meet the expressed needs for information.

Establishing the climate baseline

A climate baseline is generally needed to develop climate scenarios, given that biases are often found in climate model simulations. Observed meteorological

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[25] Available at www.ipcc-data.org/guidelines/TGICA_guidance_sdciaa_v2_final.pdf

data is also more reliable than climate models when it comes to representing climate variability on the project site. The analysis of historical data helps to identify trends in the relevant climatic variables and also allows for the ground-truthing of the simulation results from climate models. Historical climatic data can be used to assess the ability of a given climate model to reproduce local climate conditions (skill score)[26] by validating (calibrating) model simulations against the observational record. In addition, a climate baseline is needed to serve as a benchmark against which potential impacts of projected climate change can be assessed.

Impact assessments typically use observed meteorological data to define the "current climate baseline." This baseline can be used to calibrate impact models and to quantify climate change impacts with respect to the climate baseline. This historical analysis can then shed light on the climate variables that crucially affect components of energy projects sensitive to climate.

In general, detailed climatic data can be obtained from the national meteorological service of a given country. The main challenge in using local climate data is the availability of hydrometeorological stations with sufficient and consistent data representative of climate conditions at the project site. In many countries,weather data is often found to be inconsistent (e.g., the weather station changed location) or incomplete (e.g., the weather station was not operational for periods of time). Furthermore, the weather station network may not cover the project area—the closest station may be far away from the project site. In such circumstances, spatial interpolation techniques may be used to solve coverage problems and data generation algorithms can improve completeness and consistency of data.

Using outputs from general circulation models

Climate change scenarios are normally derived from outputs of *general circulation model* (GCM) simulations. GCMs are computer models used to simulate the earth's climate systems. GCMs are the main tools used to project future climate changes due to the continued anthropogenic inputs of greenhouse gases. The major advantage of using GCMs as the basis for creating climate change scenarios is that they estimate changes in climate for a large number of climate variables, such as temperature, precipitation, pressure, wind, humidity, and solar radiation, in a physically consistent manner.

However, an analyst faces a number of issues when it comes to constructing climate scenarios using outputs from GCMs:

- **Model errors and biases**: GCMs may underestimate or overestimate current temperatures and precipitation and hence may not properly represent the climate in a region.
- **Uncertainty**: An additional disadvantage of GCM-based scenarios is that a single GCM, or even several GCMs, may not represent the full range of potential climate changes in a region.
- **Resolution**: GCMs do not produce information on geographic and temporal scales fine enough for many impact assessments at the project level. GCMs typically provide projections at a horizontal resolution of hundreds of kilometers, and are generally reported at monthly or seasonal time scales.

Downscaling: From global to local climate projections

The limitation that pertains to the coarse resolution of GCMs can be overcome by a process known

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[26] See for example Tebaldi et al. 2006.

as downscaling. Downscaling methods increase both spatial resolution (e.g., from hundreds to tens of kilometers) and temporal resolution (e.g., from monthly to daily).

There are two main approaches[27] for downscaling: dynamical downscaling (e.g., using regional climate models) and statistical downscaling (e.g., using statistical relationships between large-scale upper air indexes and local weather parameters). Each downscaling method has its strengths and limitations and the appropriate method for a given application will depend on the specific needs of the impact assessment, data availability, and budget. However, it is important to note that since downscaling is a transformation of GCM outputs, it cannot add skill or accuracy that is not present in GCMs. If GCMs do not accurately project changes in large-scale atmospheric circulation patterns, downscaling techniques cannot correct the errors.

The IPCC's TGICA also developed detailed guidelines on how to construct and use climate scenarios from regional climate model outputs[28] and from statistical downscaling methods.[29]

It is also important to note that when used for specific areas over a specific period of time, model calibration will have to be performed. As discussed previously, such calibration will depend on meteorological data. The availability and quality of such data could create serious practical limitations to model calibration. Inadequate calibration would shed doubts on the quality and reliability of climate projections.

Appendix 3 provides further details on the different downscaling approaches that can be used to construct regional and/or local climate scenarios. The best approach to use for a given project is chosen based on the adaptation decision context, availability of data, time frame, and budget.

Sea level rise

It is important to note that sea level rise is not a direct output of most GCMs. Methods to derive sea level rise include both global (global thermal expansion and meltwater from glaciers, ice caps, and ice sheets) and local (local land subsidence and local water surface elevation) components. Estimates of local relative sea level rise take into account the vertical movement of land and coastal erosion. In spite of the importance of global sea level rise scenarios, when assessing impacts it is the local change in relative sea level that matters, not the global average. Relative—or observed—sea level is the level of the sea relative to the land. Subsidence of the land results in a relative sea level rise that is higher than the global average rise, whereas uplift of the land leads to a relative rise that is less than the global average. This indicates that using global estimates of sea level rise (as provided by the IPCC, for example) may not be appropriate given local circumstances.

Accurately estimating sea level rise at a project site requires extensive data collection. The most relevant variables are (i) coastal geomorphology and topography, (ii) historical relative sea level changes, (iii) trends in sediment supply and erosion and accretion

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[27] For a comprehensive discussion on the topic of downscaling, see Wilby and Wigley (1997), Wilby et al. (1998), Wood et al. (2004), and Wilby and Fowler (2011).

[28] Available at www.ipcc-data.org/guidelines/dgm_no1_v1_10-2003.pdf

[29] Available at www.ipcc-data.org/guidelines/dgm_no2_v1_09_2004.pdf

patterns, (iv) hydrological and meteorological characteristics, and (v) oceanographic characteristics. Using this data, digital elevation and hydrodynamic models can be used to estimate inundated area for a given assumption about the extent of sea level rise. For many countries where information on coastal elevations is lacking, surveying (sometimes airborne laser scanning) can be conducted to provide these most basic and essential data for sea level rise projections.

IPCC's TGICA also developed detailed guidance on how to construct local relative sea level rise scenarios and on possible data sources.[30] Individuals tasked to develop sea level rise scenarios should consult the guidelines provided.

Due to the fact that coastal surveying and hydrodynamic simulations can be quite expensive, an acceptable alternative to identify geographic areas that may be exposed to any given level of sea rise is to use a geographic information system approach. An overlay of coastal elevation data from satellite measurements and different sea level rise conditions can produce a reasonable approximation of coastal impacts.

The output of Step 7 will be projections of future climate parameters (with temperature, rainfall, and wind speed often being of greater interest) for a specific location over a specific period of time. While these climate change scenarios may result from the downscaling of GCMs, it is important to note the following:

- While it is accepted that climate change involves rejecting basic assumptions about the stationarity of climate conditions (Milly et al. 2008), it does not imply that historical meteorological data must be avoided. In fact, in many circumstances, climate proofing sector investments based on observed existing climate variability may be an appropriate step toward ensuring the climate resilience of these investments. As observed in Lopez et al. (2011), "In parts of the world that suffer water stress under current climate, it makes sense to start any adaptation planning by making the system resilient to current climate variability, and build on that to think about adaptation" (p. 130).
- Climate change scenarios should not be interpreted as representing the most likely future values of the climate variables of interest unless the scenarios are expressed in probabilistic terms.[31] As such,the outcome of a downscaling exercise for the purpose of assessing the desirability of climate-proofing options may be more useful if establishing plausible lower and upper bounds to allow testing for climate sensitivity.

It is also worth noting that climate scenarios often need to be used in conjunction with scenarios for socioeconomic variables (e.g., gross domestic product, population, energy consumption) for assessing the vulnerability of an energy project to projected climate and socioeconomic changes or of communities to the planned energy project. If socioeconomic scenarios are required as inputs to impact and vulnerability assessments, it is advisable to maintain consistency between the socioeconomic

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[30] Available at www.ipcc-data.org/docs/Sea_Level_Scenario_Guidance_Oct2011.pdf?bcsi_scan_97e98328e2b67804=0&bcsi_scan_filename=Sea_Level_Scenario_Guidance_Oct2011.pdf

[31] As such, climate change projections should not be interpreted as predictions.

assumptions underpinning the climate scenarios (e.g., *Special Report on Emissions Scenarios* and the socioeconomic scenarios being used to assess impacts and vulnerability. The IPCC TGICA provides guidance and sources of data on the development and use of socioeconomic scenarios through the Data Distribution Centre (www.ipcc-data.org).

Step 8: Estimate Future Biophysical Impacts

Once climate change scenarios have been constructed, key relationships between changes in climate parameters—such as average temperature, average precipitation, temperature and precipitation extremes, sea level rise, and storm surges—and impacts on power production and transmission must be quantified.

Biophysical models constitute one way to analyze the physical interactions between climate and an exposure unit such as a watershed or a road. Here are some examples of how different biophysical models can be used:

- *Dose-response models*: These models can elicit the effects of changes in average precipitation and temperature on the maintenance costs, construction costs, and service life of the electric power infrastructure.
- *Hydrologic models (rainfall-runoff models)*: These models translate changes in precipitation and temperature into changes in runoff and water levels. They can be useful to determine changes in future extremes (floods and droughts).
- *Hydraulic and/or hydrodynamic models*: These models can be used to predict future inundated areas based on precipitation and the deployment of protective infrastructure. They can also predict the flood extent of an estimated sea level rise.

It is important to note that the results of these impact assessments will have significant implications for the cost of the project. Therefore, these assessments should provide, in addition to the estimates of biophysical impacts, an explicit account of the caveats and uncertainties associated with the methods (including the underlying climate and sea level scenarios) and resulting impacts.

Step 9: Assign Probabilities to Identified Impacts

Conducting a quantitative assessment of the need for adaptation measures requires an estimate of how likely a given climate change (and its impacts) may be. This is yet another task that requires expertise.

The IPCC uses a likelihood scale based on a probabilistic assessment of some well-defined outcome that may have occurred in the past or may occur in the future (Table 5). The use of return periods and of changes in return periods aims to attach probabilities or changes in probabilities to extreme weather events.

Despite the uncertainty inherent in the attribution of probabilities, methods exist to estimate what future probabilities may look like. These include the following:

- One method to infer probabilities for different conditions related to climate change involves *counting the number of climate and impact models* in which the event occurs (see Tebaldi and Knutti 2007) and constructing a probability distribution based on the frequency of occurrence.
- Another method to estimate probabilities at the project level is the *Monte Carlo-type simulation*[32] based on climate scenarios, climate sensitivity,

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[32] See New and Hulme (2000) and New et al. (2007) for more details.

Table 5. Likelihood Scale Used by the Intergovernmental Panel on Climate Change

Terminology	Likelihood of the Occurrence
Virtually certain	> 99% probability of occurrence
Very likely	> 90% probability of occurrence
Likely	> 66% probability of occurrence
About as likely as not	33 to 66% probability of occurrence
Unlikely	< 33% probability of occurrence
Very unlikely	< 10% probability of occurrence
Exceptionally unlikely	< 1% probability of occurrence

Box 8. Additional Resources for Scenario Development and Impact Assessments

General Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessment, Version 2, June 2007. Intergovernmental Panel on Climate Change(IPCC) Task Group on Data and Scenario Support for Impact and Climate Assessment. www.ipcc-data.org/guidelines/TGICA_guidance_sdciaa_v2_final.pdf

Opportunities and Risks of Climate Change and Disasters (ORCHID). Institute of Development Studies. www.ids.ac.uk/climatechange

Climate Information Portal (weADAPT).
http://wikiadapt.org/index.php?title=The_Climate_Change_Explorer_Tool

SERVIR. United States Agency for International Development. www.servir.net

World Bank Climate Change Knowledge Portal. http://sdwebx.worldbank.org/climateportal/home.cfm?page=globlemap

The Data Distribution Centre of the IPCC. www.ipcc-data.org

and local change projections. This method can be used to produce probability distributions for changes in temperature and precipitation based on climate change projection scenarios. The climate data generated through Monte Carlo simulations can then be input for impact assessment models, such as rainfall-runoff models, to generate probability distributions of climate change impacts.

Additional sources of information for scenario development and impact assessments are presented in Box 8.

Vulnerability Assessment

The goal of the vulnerability assessment is to identify current and future vulnerabilities and to understand the key determinants of this assessed vulnerability. A vulnerability assessment attempts to identify the root causes for a system's vulnerability to climate change. This work helps to compensate for uncertainties in the modeling and to ensure that adaptation measures are locally beneficial and sustainable because of their explicit relevance in the socioeconomic context in which adaptation may be taking place.

Step 10: Identify Vulnerabilities of the Planned Project and Area

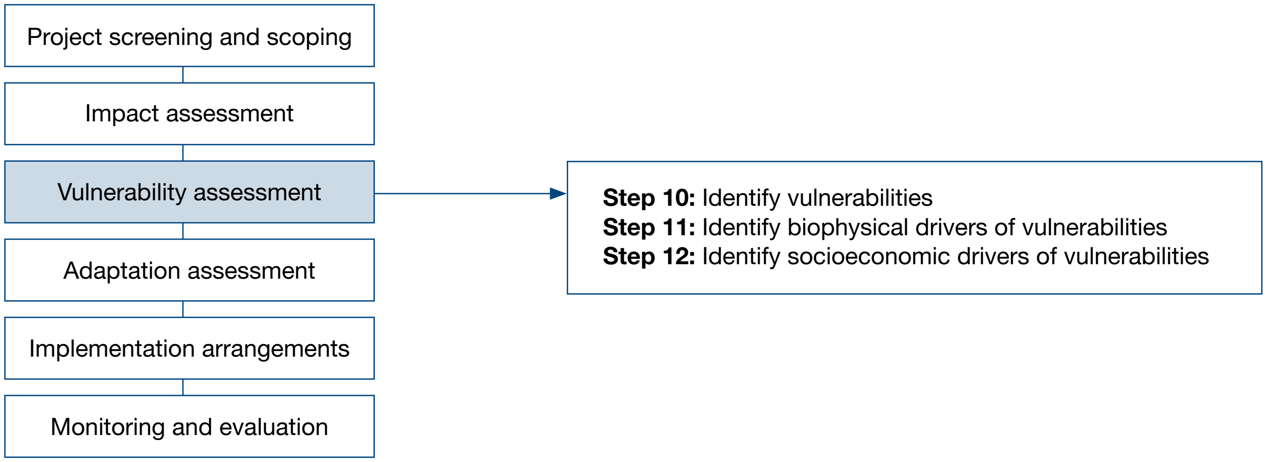
Vulnerability refers to the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed; its sensitivity; and its adaptive capacity.

Vulnerability and, in particular, adaptive capacity also manifest themselves locally. Indeed, the specific nature and degree of the vulnerability is very much site specific and must be assessed at the project level.

As such, identification and assessment of vulnerability at the local level will increase the likelihood that the proposed adaptation measures are relevant. Both vulnerability and adaptive capacity are also results of the interaction between socioecological factors and processes such as income level and income diversification, education, settlement patterns, infrastructure, ecosystem and human health, gender, political participation, and individual behavior (OECD 2009).

Hence, the information gathered during a vulnerability assessment may include local experiences related to

Figure 7. Vulnerability Assessment



shifting precipitation patterns and water availability, effects of warming on vegetative health, incidence of extreme climate events such as floods, and melting of permafrost. These are relevant to designing both engineering and non-engineering solutions. They are based on observable information and can be both qualitative and quantitative. Extrapolating from the present to predict how vulnerability may change in the future, given both climate and non-climate trends, is an essential step to capture the climate change impacts.

Step 11: Identify Biophysical Drivers of Vulnerability

Some biophysical drivers of vulnerability include poor land management, deforestation, slash and burn agriculture, monoculture cropping, slope instability, and geophysical instabilities. Some ecosystems, such as mountain ecosystems, are also inherently more sensitive to changes, while others are more exposed to climate changes and risks, such as low-lying coastal areas.

As a first step, it is useful to construct maps reflecting exposure to projected climate change. For example,

- future flood hazard maps can be developed using existing flood risk maps, historical rainfall maps, and projected rainfall change maps for the years 2020 and 2050;
- future drought hazard maps can be developed using existing drought hazard maps, historical rainfall and temperature maps, and projected rainfall and temperature change maps for the years 2020 and 2050; and
- maps can be developed to show the potential impacts of sea level rise.

Using geographic information systems, it is then possible to map areas that are particularly vulnerable to a combination of local conditions and climate variability. This assessment can be conducted in the context of initial environmental and social assessments for an energy project. The mapping can point out areas that are vulnerable because of their geographic as well as socioeconomic characteristics, such as

- areas that are sensitive due to topography (e.g., steep slopes), soil composition, geophysical instabilities, or elevation (e.g., meters above sea level);
- areas in a watershed that are exposed to climate-related hazards, including floods, landslides, and droughts; and
- areas with a large number or concentration of poor households.

From this type of assessment, it is then possible to develop a significant understanding of the areas and populations most exposed and most vulnerable to climate change.

Step 12: Identify Socioeconomic Drivers of Vulnerability

In addition to biophysical drivers of vulnerability, socioeconomic drivers should be included in the overall vulnerability assessment to provide a clear understanding of possible areas of intervention. For this purpose, biophysical vulnerability maps can be extended to examine overlaps with population area as well as projected populations based on future growth scenarios. It is useful at this stage to identify those socioeconomic factors that influence adaptive capacities. Common indicators of adaptive capacity include human development indexes, population density, level of economic diversification, and extent of dependence on agriculture for livelihoods. Education levels and literacy rates have also been associated with a population's ability to adapt to changes.

While it is important to recognize that climate risks may change over the lifetime of an investment project, it is equally important to recognize that adaptive capacity can also change. This particularly may be the case in developing countries where socioeconomic conditions are often rapidly changing and population is rapidly growing. For example, an area with low population may become highly populated over the lifetime of the project. Hence, the assessment of the adaptation options may be considerably different if based on an assumption of *existing* population, ignoring that *future* population may be considerably different over the lifetime of the project. These changes in vulnerability need to be explicitly accounted for in the assessment, including the costs and benefits of the adaptation options identified during the vulnerability assessment.

Although such assessments can be time-consuming, many countries have prepared development assessments that can be drawn from, such as the country profiles and international human development indicators produced by the United Nations Development Programme (http://hdr.undp.org/en/countries). ADB also collects key development statistics and publishes them on the Data and Research area of its website, www.adb.org/Economics/default.asp. Finally, community participation in identifying vulnerabilities and adaptation strategies promotes good governance and ensures that measures are relevant and sustainable (Box 9). As indicated earlier, the involvement and awareness of local communities in identifying vulnerability and adaptation options contribute to the community acceptance of project activities.[33]

Where there can be co-benefits between climate change adaptation and other economic or social objectives, there will be increased motivation for early action. Affected stakeholders can often identify risks, benefits, and lessons from past experiences that can be factored into the design of the adaptation strategy. These factors, which are not always easily quantifiable, can contribute to the decision-making process leading to the selection of adaptation strategies.

Adaptation Assessment

The goal of the adaptation assessment is to identify and prioritize the most appropriate adaptation measures to incorporate into the project. This includes the identification of strategies to minimize damages caused by the changing climate and to take advantage of the opportunities that a changing climate may present.

Step 13: Identify All Potential Adaptation Options

Based on an understanding of expected and current climate change impacts and vulnerabilities, the project team can identify a wide range of adaptation options (Table 6).

The adaptation assessment results in a prioritized list of adaptation options for implementation, which are selected from among several options such as changes in engineering designs, biophysical and ecosystem based measures, alignment changes, and business-as-usual or “do nothing.” They can be prioritized based on an assessment of their respective benefits and costs in the context of the project goals,and also on opportunities for synergies, national priorities, or co-benefits that cannot be easily quantified. In reality, project developers often have access to imperfect data and therefore more qualitative methods of selection, such as multi-criteria analysis, can be used. Often, the method used will be dependent on the needs of decision makers and financiers.

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[33] The ADB manual on consultation and participation tools, techniques, and templates offers further specialized information on this subject. While many of these tools do not specifically focus on climate change, they can be adjusted to include such inquiries. Many countries have prepared national adaptation programs of action with an emphasis on community-level vulnerability analysis.

Box 9. Additional Resources on Community Participation

Strengthening Participation for Development Results: An Asian Development Bank Guide to Participation. http://www.adb.org/documents/strengthening-participation-development-results-asian-development-bank-guide-participation

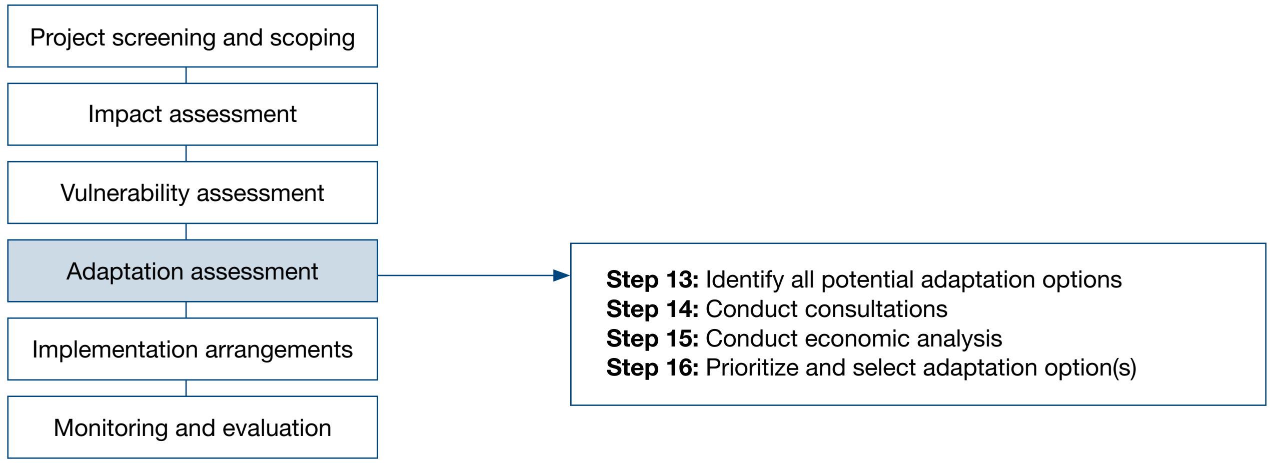
Asia-Pacific Adaptation Network (APAN). www.apan-gan.net

Community Based Adaptation Exchange (CBA-X), a shared resource supporting the exchange of up-to-date and relevant information about community-based adaptation to climate change. This page contains initiatives, case studies, and lessons learned from several adaptation projects around the world. Project descriptions can be retrieved for evaluation and comparison among similar communities and ecosystems. http://community.eldis.org/cbax

Web-based tools such as the Community-based Risk Screening Tool—Adaptation and Livelihood (CRiSTAL). These are specifically developed to assist community-based programs and provide adaptation options for farming practices and sustainable livelihoods. www.cristaltool.org

International Institute for Environment and Development website. www.iied.org

Figure 8. Adaptation Assessment



Step 13: Identify all potential adaptation options
Step 14: Conduct consultations
Step 15: Conduct economic analysis
Step 16: Prioritize and select adaptation option(s)

Table 6. Potential Adaptation Options to Climate Change in the Energy Sector

Climate Change	Potential Adaptation Options
Fossil Fuel Extraction and Transport	
Temperature increase	• Design more robust and structurally flexible pipelines.
Precipitation increase Flooding	• Build or enlarge reservoirs to reduce flooding risk. • Build dykes, berms, and spillways. • Carry out flood hazard assessments. • Relocate fuel storage away from flood-prone areas.
Drought or precipitation decrease	• Build or enlarge reservoirs to reduce water shortages. • Develop/reroute water sources.
Storm strength and/or frequency increase	• Improve robustness of designs, particularly offshore. • Build/improve dykes, berms, and spillways onshore. • Improve models used to predict storms.
Thermal Power	
Precipitation increase or decrease	• Protect fuel storage including coal stockpiles. • Withdraw less water from source and consume less water internally (once-through or recirculating system). • Increase volume of water treatment works and/or develop new water sources. • Redesign cooling facilities (water recovery from condenser and heat exchangers, reduction of evaporative losses, secondary or wastewater usage, construction of dry cooling towers). • Restore/afforest/reforest land.
Higher air temperature	• Concentrate investment in locations where temperatures are likely to be cooler. • Decentralize generation.
Higher wind speed	• Develop and implement higher structural standards for new or renovated buildings.
Sea level rise	• Develop flood control (embankments, dams, dikes, reservoirs, polders, ponds, relocated flood defense barriers, and higher channel capacity). • Construct improved coastal defenses (seawalls and bulkheads). • Constructor relocate to less exposed places. • Raise level of structures. • Improve drainage and reroute water pipes. • Protect fuel storage.
Extreme events (including flooding)	• As above • Develop and implement higher structural standards for new or renovated buildings. • Build concrete-sided buildings instead of metal (more resistant to wind and corrosion).
Nuclear Power	
Precipitation Changed river flows Higher air temperature	• Formulate long-term strategies to respond to climate-related disruptions. • Install additional cooling towers and modify cooling water inlets at coastal locations. • Use dry or hybrid cooling systems with lower water requirements. • Develop more efficient pumps and heat exchangers.

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Table 6. continued

Climate Change	Potential Adaptation Options
Sea level rise Floods Extreme events	• Require more stringent safety investments. • Incorporate gradual sea level rise, increased storm events, and associated tidal surges design criteria. • Formulate long-term strategies to respond to climate-related disruptions.
Hydropower	
Precipitation (including drought)	• Develop improved hydrological forecasting techniques and adaptive management operating rules • Develop basin-wide management strategies that take into account the full range of downstream environmental and human water uses • Restore and better manage upstream land including afforestation to reduce floods, erosion, silting, and mudslides • Analysis to estimate likely range of projected climate variations over infrastructure lifetime • Identify cost-effective designs (new plants) and modifications (existing plants) to deal with specific risks identified for the site
	• Increase dam height and/or build small dams upstream (if flow is expected to increase). • Construct or augment water storage reservoirs. • Modify spillway capacities and install controllable spillway gates to flush silted reservoirs. • Modify number and type of turbines more suited to expected water flow rates. • Modify canals or tunnels to handle expected changes in water flows. • Optimize reservoir management and improve energy output by adapting to changes in rainfall or river flow patterns.
Extreme events (glacier melting, floods)	• Design more robust dams and infrastructure for heavier flooding and extreme events. • Design for increased flows from glacier melting.
Higher air temperature, wind speeds, and humidity	• Construct or augment water storage reservoirs.
Wind Power	
Wind speed	• Design turbines able to operate with and withstand higher wind speeds, gusts, and direction changes • Install taller towers to capture stronger winds at higher altitudes. • Choose sites that take into account expected wind speed changes during the lifetime of the turbines. • Consider developing and commercializing vertical axis wind turbines (more output per m^2 of land area; can operate in wider range of wind speeds).
Air temperature	• Consider effects of extreme temperatures on turbine and blade selection and operation.
Storm surges	• Design stronger structures.

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Table 6. continued

Climate Change	Potential Adaptation Options
Extreme events	• Design offshore turbines to withstand expected increases in wind–sea wave forces. • Insure against impact of storms on long-term power yields and damage. • Ensure presence of rapid emergency repair teams.
Solar Photovoltaic Power	
Temperature increases	• Improve airflow beneath mounting structure to reduce heat gain and increase outputs. • Specify heat-resistant PV cells and module components designed to withstand short peaks of very high temperature.
Precipitation increases	• Select appropriate tilt panel angle to clean dust. • Select module surface conducive to self-cleaning. • Choose locations with lower probability of dust, grit, snow if practical.
Wind speed; Turbidity	• Design structures to withstand higher winds. • Assure free space (panels and mounting) so snow can slide off panel. • In dry areas, consider panel rinsing system to remove dust and grit.
Cloud cover	• Consider distributed systems (rather than feeding power into single part of the grid) to ameliorate cloud impact. • Site photovoltaic systems where expected changes in cloud cover are relatively low. • Consider micro-inverters for each panel (in place of small numbers of large centralized inverters) to improve stability and increase power output.
Extreme events	• Specify stronger mounting structure. • Specify cabling and components that can deal with high moisture content and flooding.
Concentrated Solar Power	
Wind; extreme events (cyclone)	• Specify robust structures that can handle high and fluctuating winds. • Avoid tracking systems where cyclones are expected to increase in strength.
Precipitation decrease	• Where water shortages are expected, consider air cooling.
Temperature increase	• Consider air cooling.
Cloud cover increase	• Choose locations where cloud cover is not expected to increase.
Biomass Energy and Biofuels	
Floods/ precipitation	• Soil and nutrient management • Improved water harvesting and use • Resilient ecosystems • Use of trees and shrubs in agricultural systems can improve soil fertility and soil moisture through increasing soil organic matter.
Precipitation or temperature changes	• Expand rainwater harvesting, water storage and conservation techniques, water reuse, desalination, water use and irrigation efficiency, adjustment of planting dates and crop varieties, crop relocation, and improved land management. • Use salt-tolerant plants (halophytes) or robust crops with high biological heat tolerance and water stress tolerance. • Improve flood protection. • Expand irrigation systems or improve efficiency of irrigation.

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Table 6. continued

Climate Change	Potential Adaptation Options
Extreme events	• Increase the robustness of biomass power plants. • Use behavioral adaptation measures including early warning systems for rainfall and temperature anomalies, support for emergency harvesting for an imminent extreme event, and provision of crop insurance systems.
Transmission and Distribution	
Temperature increase	• Specify more effective cooling for substations and transformers. • Specify certified information and communications technology (ICT) components that are resilient to higher temperatures and humidity.
Precipitation and flooding	• Build a resilient high-capacity transmission system. • Design improved flood protection measures for equipment mounted at ground level in substations. • Forbid the construction of power lines near dikes and ban “permanent” trees next to existing dikes. • Protect masts, antennae, switch boxes, aerials, overhead wires, and cables from precipitation (water ingress, snow melt); wind; snow (weight); unstable ground conditions (flooding, subsidence); and changes in humidity.
High wind speeds	• Reinforce existing transmission and distribution (T&D) structures and build underground distribution systems. • Require higher design standards for distribution poles.
Extreme events (flood, typhoons, drought)	• Increase the system’s ability to return to normal operations rapidly if outages do occur. • Change routes of overhead lines along roads away from trees, rigorously prune trees, use covered and/or insulated conductors, and use more underground cables, especially in wooded areas. • Increase decentralized energy generation (with less T&D grid requirements). • Allow increased rerouting during times of disruption. • Include lightning protection (earth wires, spark gaps) in the distribution network. • Design redundancy into information and communication technology (ICT) systems. • Develop and use “smart transformers” and “smart grids.”

Source: Adapted from ADB 2012b. *Climate Risk and Adaptation in the Electric Power Sector.* Manila.

In some cases, the best adaptation solutions may be beyond the scope of an existing project but should be taken up as part of upstream planning and can be “flagged” for such higher-level discussions, as discussed in Part B of this report. For example, improved upstream land management may be the most effective way of reducing damages from flooding downstream but can be difficult to address in the context of a specific energy project.

Nevertheless, this observation can be used to revise policies and plans to prioritize more integrated or “climate resilient” energy sector planning and management. For this reason, casting the identification of adaptation options widely is encouraged in order to influence both the project and policy levels. In some cases, project implementation arrangements are flexible enough to incorporate adaptation measures that are not specific to the power sector, as can be the case with executing agencies with cross-cutting mandates (Box 12). The expertise required is multidisciplinary and as such is one of the more challenging aspects of adaptation planning. Options must be scientifically

Box 10. Improving the Climate Resilience of the Hydropower Sector in the Kyrgyz Republic

The Kyrgyz Republic is a small, landlocked, mountainous Central Asian country. An estimated 94% of the country is more than 1,000 meters above sea level and 40% is above 3,000 meters. The mountainous regions are largely covered by snow, and glaciers make up to 4% of the territory.

The country is endowed with large hydropower potential. Hydroelectric power plants (HEPPs) produce 81% of the total installed generation capacity (3,863 megawatts). Toktogul and HEPPs in the downstream Naryn cascade between Toktogul Lake and the border with Uzbekistan produce 92% of the country's total electricity output.

Climate scenarios developed for the Second National Communication to the UNFCCC show temperature increase between 4.7°C and 8.2°C by 2100, a 25% decrease in summer season rainfall, and a 20% increase in winter season rainfall. Furthermore, glaciers have already lost 14% of their total volume over the last 60 years. Estimates of future glacier volume loss range from 15%–40% of the volume in the coming 40 years to 64%–95% by 2100—initially adding to river flows as they melt. These climatic changes will have a significant impact on hydropower, mostly through changes in river flows, and in particular changes in the seasonal distribution of river flows. Studies specifically on the Naryn river basin forecast that, in the most extreme case, annual runoff in the Naryn river basin could decline between 20% and 30% by 2050. Finally, anecdotal evidence suggests that increasingly common and intense climatic events (e.g., storms and landslides) may cause damage to HEPP infrastructure and potentially lead to catastrophic failure.

A funding proposal recently submitted to the Global Environment Facility aims to address the situation by improving understanding of the possible impacts of climate change and by climate proofing HEPP infrastructure of the Naryn cascade. Expected outcomes and outputs of the project are presented below.

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Box 10. continued

Expected Outcomes	Expected Outputs
Information on the impacts of climate variability and change on energy production in the Naryn cascade is available to multiple users.	Climate change scenarios, including projections of extreme events, developed. Impacts of climate variability and change assessed on evaporation, water runoff, sedimentation, dam safety, overtopping of concrete dam and earth-fill, and energy production Adaptation options identified (including early warning systems, biological measures, adapting operating rules, strengthening institutional, and adapting physical configuration and infrastructure Cost-benefit analysis and prioritization of adaptation options Design of a system for real-time river flows monitoring carried out
The Naryn cascade is more resilient to climate variability and change.	Establishment of a system for real-time river flow monitoring and information dissemination Implementing and piloting of priority measures (such as watershed management, reforestation, river bank strengthening, adjustment of operating rules for spillways and water levels, and dam rehabilitation) Establishment of a monitoring and evaluation system to assess effectiveness of measures
The hydropower generation sector is more resilient to climate change.	Institutional strengthening of the Electric Power Plant Company and the Ministry of Energy Assessment of needs and priorities for energy consumption at the community and household levels, and implications for energy sector planning and operations Assessment of alternative strategic approaches to adaptation, including alternative financing, alternative power production, and risk management approaches to climate changes Guidance on how to incorporate climate change concerns into long-term development of the hydropower sector Cross-learning and sharing lessons with other hydropower generation projects

Source: ADB. 2012. *Improving the Climate Resilience of the Hydropower in the Kyrgyz Republic.* Mimeo. Manila.

sound, socially beneficial, and economically viable. Roundtable discussions involving different stakeholders can work well and can include, for example, the project engineers, environmental specialists, social safeguards experts, nongovernment organizations, implementing entities, and national climate change representatives.

Step 14: Conduct Consultations

As may be understood from the partial list of adaptation options presented in Part A, the identification of adaptation options will necessarily involve inputs from a number of stakeholders. Conducting roundtable consultations provides useful input for the process of identifying and appraising the whole range of adaptation options.

Step 15: Conduct Economic Analysis

The goal of the economic analysis of adaptation options is to provide decision makers with information pertaining to the expected costs and benefits of each technically feasible option and to rank these options according to the net total benefit (measured in present value terms) that each delivers. In circumstances where all adaptation options are expected to deliver exactly the same benefits, it is sufficient to undertake a cost-effectiveness analysis where adaptation options are compared simply in terms of the cost of achieving the stated benefits. In this sense, the cost-benefit analysis of adaptation options is no different than for any other investment project and will be implemented along a similar stepwise process.[34]

This being said, a specific feature of climate change pertains to the uncertainty associated with its various impacts. For example, will extreme weather events become more frequent or more severe, and if so, by how much? Or will the recurrence of flood or drought events increase? Given the significant uncertainty associated with the predicted impacts of climate change, conducting a cost-benefit analysis of adaptation options requires paying particular attention to the treatment of risk and uncertainty (arguably more so than any other exogenous factors impacting a project's costs and benefits).

This process is described in more detail below.

The methodological approach to cost-benefit analysis of adaptation options

The cost-benefit analysis of climate change adaptation options is to a large extent similar to the type of cost-benefit analysis developed in the context of natural disaster risk management.[35] As such, it is important to recognize that the economist's task is to monetize the impacts of climate change and of the adaptation options that have been identified and quantified by other experts (engineers, hydrologists, etc.). As illustrated in Figure 4, the economic assessment of the adaptation options is not undertaken in isolation and requires inputs from all team experts.

A key feature of the approach is to recognize that the costs and benefits of adaptation options must be assessed by identifying and quantifying the climate change impacts along two scenarios:

Scenario 1: What are the *expected* impacts of future climate change on the project if no adaptation measures were in place?

Scenario 2: What are the *expected* impacts of future climate change on the project if there were adaptation measures in place?

Once these two scenarios are described, the benefit of the adaptation options is assessed as the difference in the quantified and monetized impacts "with vs. without" the adaptation options in place (Figure 9).

The cost-benefit analysis of alternative adaptation options should account at least for the following three important factors:

- While all adaptation options aim to climate proof the project, some adaptation options may also deliver benefits additional to the climate-proofing benefits (co-benefits). For example, the reforestation of a hillside in order to protect

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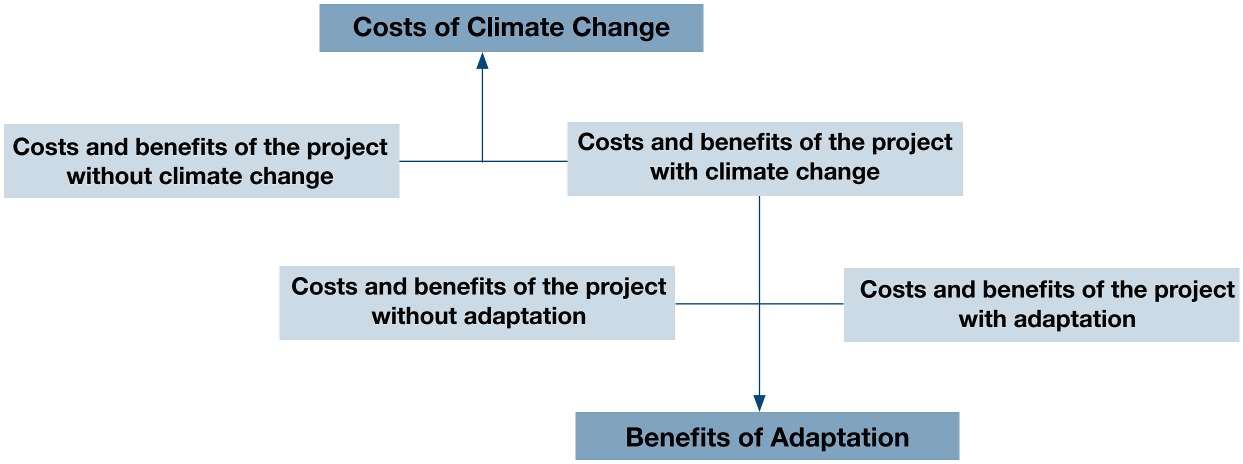
[34] See Boardman et al. (2010) for a description of the stepwise process.

[35] See for example Mechler (2005).

Figure 9. Assessment of the Economic Benefits of Adaptation



a hydropower reservoir from sedimentation may also deliver fruit crops, or the planting of mangroves to protect power substations or transmission lines may also serve as habitat for shrimp fisheries. These positive additional benefits need to be considered in the cost-benefit analysis and may affect the ranking of the adaptation options based on a net present value criterion.

- While all adaptation options aim to climate proof the project, some adaptation options may do so at the expense of other sectors of the economy. For example, a floodwater diversion option may keep a power infrastructure functional but increase flooding in another area. These impacts, whether intentional or not, need to be accounted for in the cost-benefit analysis.
- Finally, as pointed out earlier, it is important to recognize that climate change hazards may change over the lifetime of an investment project, but it is equally important to recognize that vulnerability also may change. Hence, the assessment of the benefits of adaptation may be considerably different if based on an assumption of *existing* population, ignoring that *future* population may change considerably over the lifetime of the project. These changes in vulnerability need to be explicitly accounted for in the cost-benefit analysis.

While the overall framework presented above remains simple, a key issue is related to the treatment of risk and uncertainty in the cost-benefit analysis. While all cost-benefit analyses of any investment project are conducted in the presence of risk and occasionally uncertainty, this issue is felt to be particularly acute in the context of climate change. It is briefly addressed below.

Cost-benefit analysis of adaptation: Accounting for risk and uncertainty

Conducting any cost-benefit analysis implies looking into the future and asking what the “universe of interest” might look like *without* the project and *with* the project (the impacts of the project being the difference between these two scenarios). The exercise is fraught with incomplete information, risk, and uncertainty; this is true of all cost-benefit analyses, whether related to climate change or not. Hence, the same analytical tools currently available to account for risk and uncertainty in the conduct of a project cost-benefit analysis are of relevance in the context of assessing the costs and benefits of climate change adaptation options.

The following two approaches may be applied to explicitly account for risk and uncertainty within the framework of the cost-benefit analysis.[36]

Approach 1: Sensitivity analysis

The technique most widely applied to account for risk and uncertainty is known as sensitivity analysis (or sensitivity testing).

For conducting a cost-benefit analysis of an adaptation option, this simple type of analysis involves changing the value of one or more uncertain variables at a time and recomputing the option's net present value for each change. This exercise may be repeated as much as necessary.

In sensitivity testing, *switching values* are often computed, where a switching value is the value of a specific variable that makes the net present value *switch* from positive to negative, or conversely.

The purpose of such sensitivity testing is to raise the level of confidence one has when recommending the adoption or rejection of an adaptation option.

A key advantage of sensitivity testing is that it is extremely easy to conduct.[37] However, it has a number of severe limitations, including the following:

- Sensitivity testing is highly subjective in that there is often no specific reason justifying the direction (smaller or larger) or the extent to which the value of a specific variable may be assumed to change.
- More importantly, sensitivity testing does not take into account the *probability* that the value of any specific variable may differ from the value originally estimated. As a result of this serious limitation, while sensitivity analysis allows computing a range of net present values within which the actual net present value of the adaptation option may fall, it does not allow computing the *expected* net present value of the adaptation option.

This last shortcoming explains the second approach used to account for risk and uncertainty in the cost-benefit analysis.

Approach 2: Probabilistic (or risk) analysis

Conducting a "probabilistic cost-benefit analysis" involves attaching a probability distribution for the possible value of any given specific cost or benefit component of the project instead of attaching a single deterministic value. Such probability distributions may be constructed using historical data.

Probabilistic (or risk) analysis allows selecting multiple variables that can all be varied simultaneously according to the specific probability distribution attached to each variable. This process, known as a Monte Carlo simulation analysis, involves randomly generating a specific value for each individual variable (cost component or benefit component) according to the specific probability distribution attached to each variable. For any given draw of specific values, the net present value of the adaptation option is calculated.

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[36] For more details, see ADB (2002) and Rayner et al. (2002).

[37] Almost every economic analysis presented in project appraisals includes sensitivity testing.

This process, by means of computer, is then repeated many thousands of times.

The outcome of the analysis is a probability distribution of net present values. This probability distribution allows the computation of an "expected" net present value of the option, instead of solely a given net present value or a range of net present values. The same probability distribution also allows computing the probability that the net present value of the adaptation option will be negative.

Conducting probabilistic (or risk) analysis can be demanding if performed manually. However, packaged software allows Monte Carlo simulation analyses to be completed relatively simply.[38] It is important to note that the conduct of probabilistic cost-benefit analysis is an important recommendation already found in ADB (2002) to supplement the simplistic use of sensitivity analysis.

In a number of circumstances, there may exist low-regret or no-regret options which provide positive net economic benefits regardless of the actual realization of climate in the future. In effect, the possibility of exploiting low-regret or no-regret options reduces the sensitivity of the outcome of the economic analysis to specific parameterization of the probabilistic analysis.

Decision rule

It should not be presumed that adaptation (climate proofing) should be pursued wherever technically feasible. From an economic point of view, not climate proofing a project may indeed be the best course of action in a number of specific circumstances. The outcome of the economic analysis of adaptation options, summarized as the net present value (NPV) of these options, will guide the nature of the recommendations.[39]

The decision rule guiding the selection of adaptations is similar to the decision rule for any investment project. If only one *technically* feasible adaptation option exists, then the decision rule is as follows:

If expected NPV > 0	Recommend implementing the adaptation option based on the outcome of the economic analysis.
If expected NPV < 0	Recommend rejecting the adaptation option (do nothing) based on the outcome of the economic analysis.

If more than one technically feasible adaptation option exists, then the decision rule is to select the option with the largest expected NPV. If all adaptation options yield a negative expected NPV, then the best option is to do nothing.

Step 16: Prioritize and Select Adaptation Option(s)

The adaptation assessment results in a prioritized list of adaptation options for implementation, which

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[38] Without endorsing these packages, two widely used software programs are @RISK (built as an Excel template) and Crystal Ball.

[39] While other criteria may be used to select an adaptation option (such as the economic internal rate of return), the NPV criterion is generally preferred, especially when one adaptation option has to be selected from a set of mutually exclusive adaptation options. In such circumstances, the use of the economic internal rate of return may lead to recommending an option that does not maximize society's welfare. A similar issue may arise with the use of the benefit-cost ratio criterion to rank adaptation options.

are selected from among several possibilities. Their prioritization can be based on an assessment of their technical feasibility, their benefits and costs, their social acceptability, and the opportunities they may offer for synergies with national priorities. While the use and outcome of a cost-benefit analysis are often given more weight in the prioritization process, it is important to recognize that other factors and criteria may also influence decision making.

The expertise required to prioritize and select adaptation options is multidisciplinary and as such is one of the more challenging aspects of adaptation planning. Options must be scientifically sound, socially beneficial, and economically viable. Roundtable discussions involving different stakeholders can work well and can include, for example,the project engineers, environmental specialists, social safeguards experts, nongovernment organizations, implementing entities, and national climate change representatives.

The ingredients of multi-criteria analysis are objectives, alternative measures/interventions, criteria (or attributes), and scores that measure or value the performance of an option against the criteria, and weights (applied to criteria). Table 7 presents an example of the application of multi-criteria analysis to evaluate adaptation options in energy projects. As indicated in the IPCC (2007) report,

> Responding to climate change involves an iterative risk management process… taking into account actual and avoided climate change damages, co-benefits, sustainability, equity, and attitudes to risk. Risk management techniques can explicitly accommodate sectoral, regional and temporal diversity, but their application requires information about not only impacts resulting from the most likely climate scenarios, but also impacts arising from lower-probability but higher-consequence events and the consequences of proposed policies and measures.

The outcome of the adaptation assessment activity may result in three different types of decisions:

Decision of Type 1: Invest in climate proofing the project at the time the project is being designed or implemented.

A decision of Type 1 may result from circumstances where

(1) the costs of climate proofing now are estimated to be relatively small while the benefits (the avoided expected costs from climate change impacts), even though realized only under future climate change, are estimated to be very large. This is referred as a *low-regret* approach; and/or
(2) the costs of climate proofing at a later point in time are expected to be prohibitive or climate proofing at a later point in time is technically not possible; and/or
(3) among the set of climate-proofing options, there are options that deliver net positive economic benefits regardless of the nature and extent of climate change, including the current climate conditions. Such options are referred as *no-regret* climate-proofing options; and/or
(4) the set of climate-proofing options includes one or more options that not only reduce climate risks to the project, but also have other social, environmental or economic benefits. Such options are referred as *win-win* climate-proofing options.

Decision of Type 2: Do not invest now in climate proofing but ensure that the project is designed in such a way as to be amenable to be climate proofed in the future if and when circumstances indicate this to be a better option than not climate proofing.

Table 7. Example of Criteria for Evaluating Adaptation Options

Assessment Indicators	Descriptions	Rating*					
		N/A	5	4	3	2	1
Policy and Institution							
Consistency and relevance with adaptation in national and sector policy goals	This will cover the degree of relevance of the options to the national policy, sector policy, plans, and programs						
Acceptability by implementing agency (e.g., agriculture extension)	Acceptability of the options to different organs of the implementing agencies						
Technical capacity of institution to implement adaptation options	All refer to an assessment of the capacity of the implementing agency to implement adaptation options						
Physical capacity of institution to implement adaptation options							
Financial capacity of institution to implement adaptation options							
Socioeconomic							
Acceptability by the community	Assess the familiarity and acceptability of the options to the community						
Sustainability of adaptation	Community will continue adaptation after withdrawal of support						
Probability of success in increasing adaptive capacity	Assess the degree to which an option will better prepare communities for climate change						
Economic and Financial							
Financial and technical affordability	As determined in the course of project design and feasibility analysis						
Economic returns	Assess the degree to which the option contributes to welfare						
Environmental							
Applicability and compatibility with local area farming system	Eco-specific applicability to field conditions						
Soil characteristics	Soil quality and its characteristics to support the option						
Land use	Degree of harmony with existing land use						
Water availability	Assess the degree to which the option contributes to water availability						
New pests and diseases	Possibility of intrusion of new pests and diseases as a result of the option						
	Total Scores						

*5 = very high, 4 = high, 3 = medium, 2 = low, 1 = very low

Source: Yu, W. 2010. *Climate Change Risks and Food Security in Bangladesh.* London: Earthscan.

For example, while current sea level rise and storm surge scenarios may not warrant the construction today of sea dykes suitable to projected higher sea level and stronger storm surges in a distant future, the base of the sea dyke may nonetheless be built large enough today to accommodate a heightening of the sea dyke at a later point in time.

A decision of Type 2 aims to ensure that the project is “ready” to be climate proofed if required. As such, the concept of *climate readiness* is referred to. This concept is akin to the *real options* approach to risk management.[40]

Decision of Type 3: Make no changes to project design, monitor changes in climate variables and their impacts on the infrastructure assets, and invest in climate proofing if and when needed at a later point in time.

A decision of Type 3 may result from circumstances where

(1) the costs of climate proofing now are estimated to be large relative to the expected benefits; and/or
(2) the costs (in present value terms) of climate proofing (e.g., retrofitting) at a later point in time are expected to be no larger than climate proofing now; and/or
(3) the expected benefits of climate proofing are estimated to be relatively small (Box 11).

Both decisions of Type 2 and 3 may be referred as *adaptive management,* which consists in putting in place incremental adaptation options over the project’s lifetime. A decision of Type 2 will differ from a decision of Type 3 in that project design will ensure ”readiness” for climate proofing while a decision of Type 3 will require no changes at all to project design. An example of adaptive management is presented in Box 12.

Doing Away with Climate Projections?

A number of authors have pointed out the inherent difficulty associated with undertaking the impact and vulnerability assessments described above given the degree of uncertainty associated with climate change. A key issue pertains to the efficacy of general circulation models (GCMs) for climate-proofing analysis. Kundzewicz and Stakhiv (2010) have noted that GCMs still cannot reconstruct the important details at smaller scales.

On the other hand, quantified climate projections do provide information which may be of interest to project designers and sector planners in some locations and for some climate variables (for example, it is well known that there is much less difference across models pertaining to temperature projections than there are for precipitation projections). As pointed out by Kundzewicz and Stakhiv (2010), “reliance on stochastics alone … would be tantamount to incomplete use of available information” (p. 1088).

As a result, a number of authors refer to the concept of *robust adaptation* to climate change. The decision outcome of undertaking a process leading to robust adaptation is largely similar to the types of decision described above, except for the specific use of a range of climate projections obtained from the downscaling of numerous GCMs (Box 13).

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[40] In the world of finance, the real options approach is analogous to the price paid to acquire a financial option as the price paid allows the possibility to invest in the full asset if and when required, but not the obligation.

Box 11. Town Electrification Investment Program in Papua New Guinea

The Papua New Guinea (PNG) Town Electrification Program includes the construction of two run-of-the-river hydropower plants (the Divuni River and Ramazon River hydropower projects, with an estimated 3.0 megawatts of installed generation capacity each) and one transmission interconnection (the Lake Hargy Interconnection). Because PNG has been assessed as "climate sensitive," a climate risk analysis was undertaken to assess the potential impacts of climate change on the proposed hydropower plants to be financed under the investment program.

Climate projections indicate that temperatures are expected to rise steadily through the middle of the 21st century, especially outside of the wet season. Projections also indicate increasing rainfall in the wet season, as well as increased variability and extremes, which may result in more severe rainfall and floods and more prolonged and intense droughts. The outcome of the analysis of the climate projections, impacts, and adaptation options resulted in no alteration to project design being recommended, except for the setting of the power station floor.

Potential Impacts	Projected Climate Change to Year 2050	Possible Affected Components	Adaptation of Project Design
Changes in frequency and intensity of extreme rainfall events which could result in increased flooding events	No estimates of increased occurrence of floods or extreme rainfall events are available Average rainfall increase of 2.2% to 8.9% is projected	Damage to hydropower intake structures through high water flow events	No alteration to design is proposed as intake structures are routinely designed for maximum flood events. During detailed design, the design flood level will be calculated to allow setting of the power station floor at an appropriate level. A new stream gauge and rain gauge will be installed to provide long-term monitoring of hydrological characteristics of catchment.
Increased return frequency and duration of droughts resulting in periodic reduction in stream flow available for hydropower generation	No projection for increased return frequency or duration of droughts is available Average temperature is anticipated to increase	Reduced water availability may impact the sizing of the hydropower plant	No alteration is proposed as only negligible impact on infrastructure is projected.

continued on next page

Box 11. continued

Potential Impacts	**Projected Climate Change to Year 2050**	**Possible Affected Components**	**Adaptation of Project Design**
Increased occurrence of landslides	No projection is available	Increased sedimentation in stream flow Damage to access roads, transmission poles, diversion canals, penstocks, and hydropower stations	No alteration to design is proposed given that the projects are run-of-the-river and sedimentation behind dam walls is not considered to be an issue. No additional activity will be undertaken apart from standard slope stability analysis of infrastructure siting.
Increased cyclone activity	No projection is available	Damage to transmission lines	No alteration is proposed as the cost of underground transmission lines is considered to be prohibitive.

Source: ADB. 2010.*Town Electrification Investment Program* (RRP PNG 41504). Manila.

Box 12. Climate Change and Hydropower in the Sutlej River Basin, Himachal Pradesh, India

The Satluj River system is the largest of the five main river systems in Himachal Pradesh. The Satluj flow is complex and is derived from contribution from rain, snow, and glaciers.

Projected impacts of climate change

- The whole basin is projected to warm significantly, with increases of 2°C with reference to the 1970s baseline likely by mid-century.
- The monsoon rainfall is projected to increase. The indications from regional climate models are that by mid-century, monsoon precipitation could increase by 15%–20%.
- Small increases in the number of days of heavy rain are projected to occur in the central region of the basin by mid-century. An impact of increased precipitation could be increased flood frequency and magnitude, and increased land instability and silt levels in the main Satluj River and its tributaries.
- Analysis of various data sources for the Spiti Valley show that there is an annual glacier loss of about 2.5%. A 2°C increase in temperature could increase melt by about 28%, and up to 45% if temperatures increase by 3°C. At present temperatures, the annual loss of 2.5% indicates a glacier loss of about 50% over 30 years. This could increase to about a 60% loss with a 3°C temperature increase. In the initial stages, the increased melt will result in increased stream flows, which could be up to 33%; however, gradually receding glaciers will reach a critical point when the melt will start to decline due to the reduced ice volume. There is no information as to when the critical point may occur.

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Box 12. continued

Climate change and hydropower

- Snow and glacier loss will gradually affect flows. In the initial period, reduced snow melt due to evaporation will be largely compensated by glacier melt, but in the longer term a gradual decline in the combined melt flows will occur. Surveys and research are very limited, but indications are that a 50%–60% glacier loss might occur over the next 30 years.
- Increased monsoon rainfall of about 15% over the next 30 years will benefit hydro schemes with catchments or parts of the catchment in the monsoon-affected part. Runoff will, however, be affected by increased evaporation, and the number of extreme rainfall events is expected to rise.
- The increased melt rates, increased monsoon activity, and likely increased number of intense rain events all point to increased silt levels. The strengthened monsoon season is also likely to increase the chance of incursion of monsoon rains into the desert areas of Spiti and the People's Republic of China, resulting in major increases in sediment load and destabilization, including avalanche blockages and glacier lake floods.

Adaptation strategy

Given the many gaps and unknowns, the incorporation of climate change into planning will depend on the following:

- the level of confidence of the projections—some projections are more robust than others; for example, projections for temperature rise are more robust than precipitation patterns;
- type and estimated design life of any investment—major investments/programs with long design life require incorporation of climate projections beyond 30 years whereas shorter, simpler initiatives may be designed to meet present climate variations. Major long-term investments based on low levels of projection confidence would be avoided;
- scope for flexibility of the adaptation design—incorporating facilities wherever possible to upgrade adaptation design step-by-step to meet progressive climate changes; and
- assessment of the incremental costs to meet the projected impacts—where incremental costs are low then it might be factored into the adaptation design, whereas measures with major cost implications maybe left out in the interim. The aspects of safety and implications of delayed action would be assessed.

Source: ADB. 2010. *India: Integrated Water Resources Management Scoping Study for Sutlej River Basin, Himachal Pradesh: Improving Capacity for Climate Change Adaptation*. Technical assistance consultant's report. Project Number 43169. Manila.

Wilby (2010) points out that "*characterizing* uncertainty through concerted scientific action may be a tractable proposition, but there appears to be no immediate prospect of *reducing* uncertainty in the risk information supplied to decision makers" (p. 1092).

The literature certainly contains warnings pertaining to the use of climate projections obtained from the downscaling of GCMs (Anagnostopoulos et al. 2010; Water Utility Climate Alliance 2009).

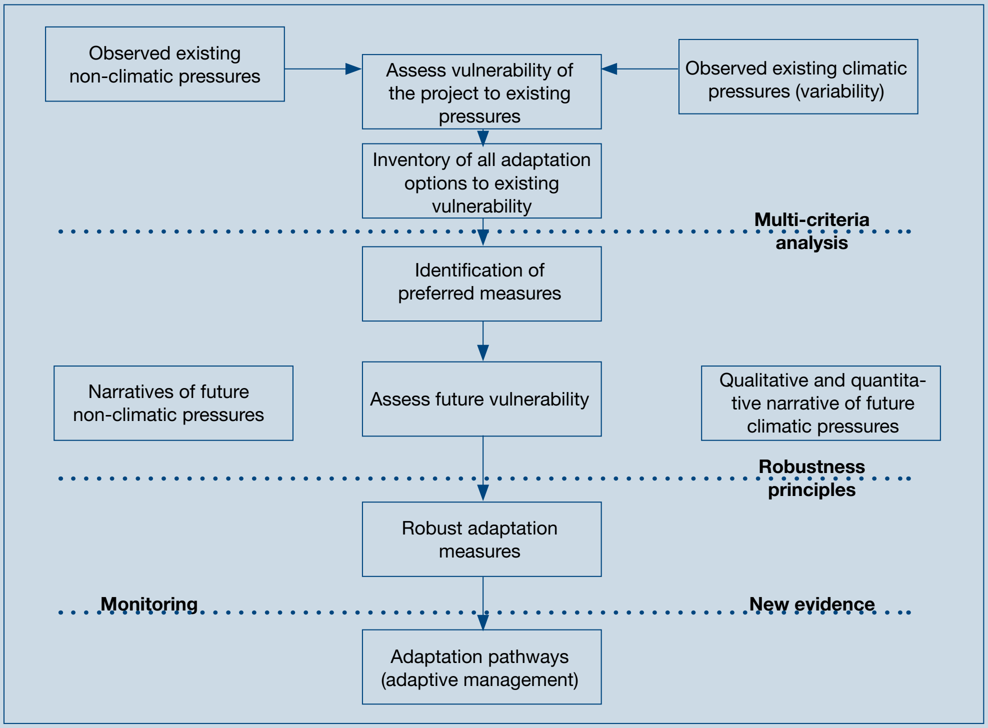
Box 13. Robust Adaptation to Climate Change

Wilby and Fowler (2011) note that “the sheer scale of the uncertainty to be sampled (but never entirely quantified) by hypermatrix experiments shows the fallacy of scenario-led adaptation, and sets the scene for an adaptation paradigm based on robustness, flexibility, monitoring, and review.”

Robust adaptation measures are defined as measures that satisfy a number of “robustness principles,” such as low-regret, reversible and flexible (to keep the cost of being wrong about future climate change as low as possible); incorporate safety or security margins to design criteria; and employ “soft” (e.g., institutional and planning) solutions (Hallegatte 2009).

The search for robust adaptation measures has been characterized as follows (Wilby and Dessai 2010):

Step 1: Construct an inventory of all adaptation options for the most significant risks caused by climate change.
Step 2: Through a process of screening and appraisal, identify “preferred” adaptation options that would reduce vulnerability under the present climate regime.
Step 3: Describe quantitatively and qualitatively plausible changes in climate and non-climate variables to identify future vulnerability.
Step 4: Among the set of “preferred” adaptation options (Step 2), identify those measures that are resilient to assessed future vulnerability.
Step 5: Establish an “adaptation” pathway that will be shaped by a careful monitoring of the changing climate and environmental conditions, the scientific evidence, and society’s attitudes to climate risk (adaptive management).



Source: Adapted from Wilby, R.L. and S. Dessai. 2010. Robust adaptation to climate change. *Weather.* 65 (7). pp. 180–185.

Implementation Arrangements

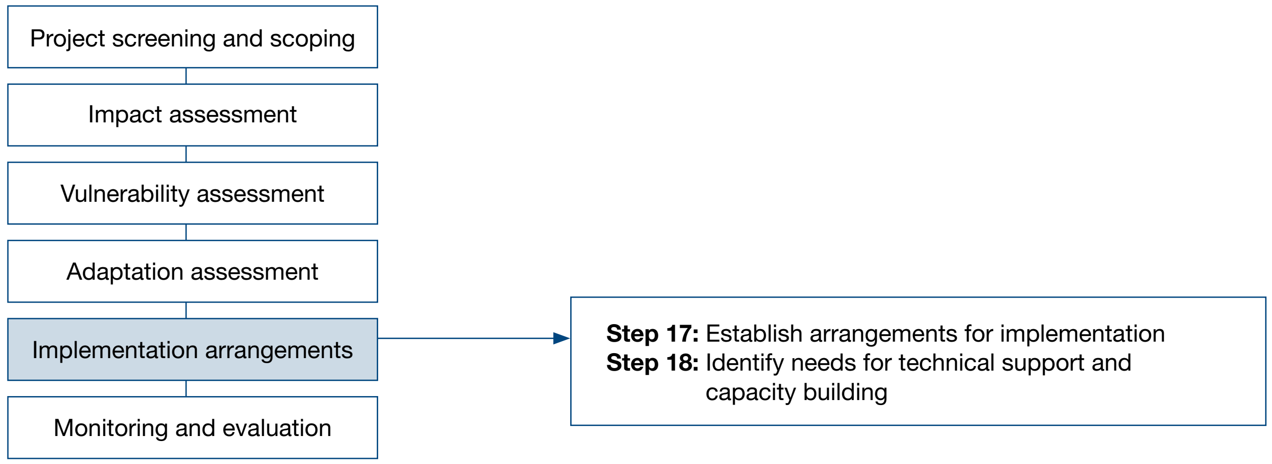
The goal of establishing implementation arrangements is to ensure the effective implementation of the identified adaptation option(s).

An ideal adaptation strategy will be fairly comprehensive and will include a mix of solutions. This is because the causes of vulnerability are diverse and will relate to social, environmental, engineering, policy, and institutional challenges. The effective implementation of adaptation strategies requires the establishment of roles and responsibilities, training needs, and a monitoring and evaluation framework. Also, recognizing that the policy processes include uptake of information and recommendations from the project level, opportunities to feed back into policy processes should be seized.

Step 17: Establishing Arrangements for Implementation

A lead organization should be selected to implement the adaptation measures. While this organization may be the main executing agency responsible for the energy sector project (such as a ministry of energy or a ministry of planning), involving other ministries, organizations, and institutes in the country may be needed given the nature of the adaptation activities, which may cut across sectors. For instance, climate change and disaster preparedness focal points and departments managing climate change and disaster data will need to be engaged where there are planned activities to improve the information base or early warning systems along selected roads. Many of the "low-risk" adaptation strategies, such as improved watershed management or mangrove rehabilitation to protect coastal infrastructure, may require engagement of land management and forestry experts and organizations.

Figure 10. Implementation Arrangements



In all cases, examining a project and its relationship to climate and projected climate change requires identifying executing partners with capacities and mandates to coordinate and manage adaptation-related projects. While it may not be appropriate for climate change experts to be responsible for implementing projects rooted in sector plans, scientific and technical backstopping from the climate change expertise in different countries may assist in building overall capacity in the country. Finally, community participation may not be limited to the identification of vulnerabilities and adaptation options and strategies, but may also include and play an important role at the implementation phase.

When the project partners are already selected, the scope of the project is likely to be limited by each partner's lines of responsibility. For instance, while the ideal adaptation approach may include engineering and environmental measures, the latter is likely to fall outside the roles and functions of a ministry of energy. This adds further reasons for addressing adaptation at the earliest stages of policy and strategy development, as will be discussed in Part C.

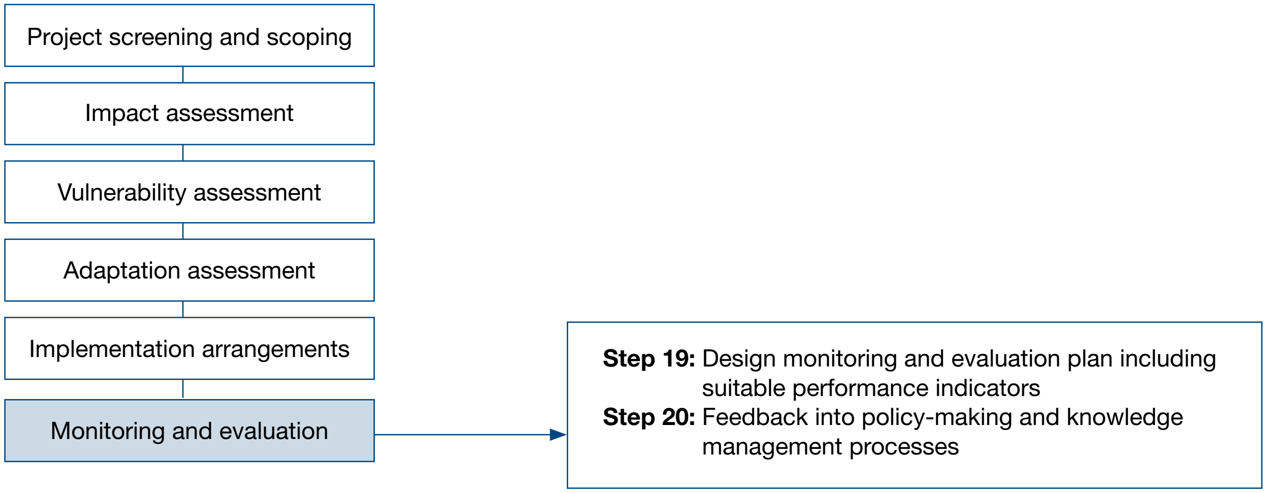
Step 18: Identify Needs for Technical Support and Capacity Building

Experience indicates that the capacity and awareness required for managing climate change and adaptation is currently limited. Provisions for training and capacity building will likely be needed for executing agencies, partner institutes, local communities, project management units, and contractors. An institutional assessment of existing capacity and gaps should inform this plan.

Monitoring and Evaluation

The goal of establishing monitoring and evaluation frameworks is to ensure accountability and that lessons are learned to inform future adaptation efforts.

Figure 11. Monitoring and Evaluation



Step 19: Design monitoring and evaluation plan including suitable performance indicators
Step 20: Feedback into policy-making and knowledge management processes

Finally, establishing monitoring and evaluation frameworks will ensure accountability and implementation and is important for collecting lessons learned about effective adaptation with a view to continuous improvement and replication of good practices.

Step 19: Design Monitoring and Evaluation Plan Including Suitable Performance Indicators

There is little experience worldwide in understanding how effective different adaptation options will be to reduce vulnerability to climate change in the energy sector. In such context, monitoring and evaluation are all the more important to develop this knowledge.

As indicated in Spearman and McGray (2011), monitoring and evaluation systems can provide critical support in learning "what works" in adaptation by helping understand

- how an adaptation intervention influences and is influenced by policies, institutions, and other factors;
- what factors contribute to autonomous adaptation;
- historical coping mechanisms and evidence of resilience to previous climate-related events;
- socially and economically acceptable levels of risk in decision making; and
- how to develop new adaptation strategies for addressing the effects of climate change.

Monitoring and evaluation systems can also provide information to

- adjust adaptation activities based on how successful they are in achieving intended adaptation objectives;
- adjust adaptation activities to address unexpected events and challenges;
- compare results across various interventions and/or different locations; and
- share learning about the outcomes of adaptation initiatives.

There are a number of challenges in developing monitoring and evaluation indicators, including the long-term nature of actual climate change, the need to acquire appropriate baseline data and metrics for measuring vulnerability, and isolating vulnerability to climate change from other sources of pressure.[41]

The development of outcome-level and output-level indicators is ongoing to assess the impacts of adaptation investments. ADB identifies three levels of results monitoring: impacts, outcomes, and outputs (ADB 2007).

Table 8 provides some examples of indicators at each level. Given the challenges related to measuring for impact, which may occur beyond the project life, output level indicators may be the most reliable.

Step 20: Feedback into Policy-Making and Knowledge Management Processes

An adequate adaptation strategy is likely to be composed of a number of activities including engineering measures, such as incorporating design changes, and non-engineering measures, such as ecosystem resilience measures and early warning systems for disasters. Lessons from adaptation measures undertaken at a project level should inform policy makers about appropriate approaches at the sector and/or national levels. This issue is discussed in greater detail below.

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[41] See the UNFCCC synthesis report on monitoring and evaluating adaptation for further details: http://unfccc.int/resource/docs/2010/sbsta/eng/05.pdf

Table 8. Example of Indicators for Measuring Adaptation Results in Energy Projects

Impacts indicators (long-term effect)	• Increased robustness of agriculture land use and irrigation planning design and long-term investment development • Improved decision making and sector planning based on climate change considerations
Outcome-level indicators (process indicators)	• Supply chains for different climate-resilient crops analyzed and economic impacts and market barriers assessed • Agricultural land use planning in flood- and drought-prone areas analyzed and alternative land use plans developed based on climate risk scenarios
Output-level indicators	• Agriculture sector planning documents include adaptation strategies • Number of hectares where climate-resilient cropping practices are introduced • Number of hectares/communities where rainfall capture and adaptive irrigation management are introduced • Area of mangrove planted to protect coastal agricultural land • Number of agricultural officers, extension workers, and farmer cooperatives in target districts trained in climate change impacts on agricultural production and potential community-based adaptation options

The adaptation assessment promoted here is fairly broad, where all options should be listed. A few scenarios may arise:

- The ideal mix of adaptation solutions is feasible in the context of the current project partners.
- The ideal mix of adaptation solutions require a broadening of the partnership base to include a wider range of executing partners. Some resources for increased coordination should be foreseen.
- The adaptation assessment highlights the need for critical decision making regarding major issues such as energy and land use planning, and revised country strategies and sector policies.
- The adaptation assessment highlights needs that may not be appropriately addressed in the context of a given project but warrant the development of a new unique project.

Part C: Building Adaptation into Policy and Sector Planning

Implications for Policies and Planning

Decisions pertaining to priority areas, alignment, land zoning, spatial planning, technology, and implementation plans are made at policy and sector planning levels. Many of the examples of comprehensive adaptation strategies rely on the participation of multiple partners, such as ministries of infrastructure and ministries of environment, which is more readily established if set at the policy level.

Countries undertake policy processes in order to establish overarching frameworks for making decisions and setting priorities. Enhancing decision making by factoring in climate change risks will require a different process than for project-level interventions, where many key parameters are established, such as geographic location, scale, and technology. Therein lies the difficulty with policy mainstreaming: merely mentioning climate change in policy documents does not ensure its implementation. In part, this is often because of lack of information about climate change, poor interministerial coordination, weak implementation capacity and resources, and a lack of experience in designing and implementing climate change adaptation in both developed and developing countries.

For these reasons, many of the first climate change adaptation funds have advocated learning by doing or through pilot project initiatives.[42] Establishing some implementation experience can inform the development of appropriate policy-level guidance. Another approach for developing policy experience that has been tested is policy-driven information gathering, or the explicit link between pilot project and policy mainstreaming. Adaptation strategies are tested and evaluated in the context of a given policy sphere and successful measures are fed back up into the given policy. This integration can help improve the policy's general direction and achievement of its objectives.

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[42] For example, see the following guidelines: Least Developed Countries Fund: www.thegef.org/gef/sites/thegef.org/files/publication/23469_LDCF.pdf?bcsi_scan _97E98328E2B67804=0&bcsi_scan_filename=23469_LDCF.pdf
Special Climate Change Fund: www.thegef.org/gef/sites/thegef.org/files/publication/23470_SCCF.pdf?bcsi_scan _9688B637A46568DB=0&bcsi_scan_filename=23470_SCCF.pdf
Adaptation Fund: http://adaptation-fund.org/policies_guidelines Also see UNFCCC Decision 5/CP.7 Decision 5/CMP.2:http://unfccc.int/files/cooperation_and_support/ldc/application/pdf/13a01p32.pdf

National Policy Processes

The Organisation for Economic Co-operation and Development (OECD 2009) identifies the national and sector levels as policy entry points that may be useful for adaptation mainstreaming. National policies and plans (note that in some countries the word policies is used while in others these are referred to as plans) include national visions, poverty reduction strategies, multiyear development plans, and national budgets. Sector development plans, such as energy development master plans and their budgets, often flow from national plans and policies. Projects support sector plans and in some cases also national plans, particularly those that are cross-sector, regional, and of extremely high priority. Therefore, influencing these overarching frameworks can affect which projects are prioritized and the criteria they must meet in order to be financed.

The OECD guidance recommends two main courses of action for integrating adaptation at this level:

- *A clear recognition of climate risks and the need for adaptation within relevant national policies.* Incorporating climate change at this level can ensure that it filters down into sector plans and other levels of decision making. In the case of electric power, and for infrastructure development generally, guidance intended to strengthen cross-sector cooperation between ministries can be very helpful. For instance, flood management around critical power infrastructure can be better managed between ministries of water and hydrology, meteorology, and energy. Integrated planning around geographically vulnerable areas can produce high-quality development plans for disaster-prone areas. Moreover, climate change impacts are not set by national boundaries; its effects require regional coordination (for example, in the Mekong subregion). Harmonization between national and regional road network development activities requires coordination at this level.
- *Applying a climate change lens in the formulation of national policies and strategies*. A climate lens is an analytical process/step/tool to examine a policy, plan, or program. It can be useful, for example, to identify areas of the country that are most vulnerable to climate change impacts and where priority action can be directed (Box 14).

The approach taken when analyzing adaptation in the sector should acknowledge the following:

- Climate impacts may not be the most important constraint on development objectives of the sector; climate considerations therefore need to be embedded in a planning process that considers all risks.
- The basis for adapting to the future climate lies in improving the ability to cope with existing climate variations. Climate change projections inform this process to ensure that current coping strategies are consistent with future climate change.
- In tackling current hazards, adaptation processes can draw on approaches to disaster risk reduction, as well as tackling gradual changes and new hazards.
- Because of uncertainty over future climate variability and change, management responses should build in flexibility to cope with a range of different potential future climate regimes.
- Managing climate impacts enables an examination of how wider development processes can contribute to reducing vulnerability to climate change.

Box 14. Applying a Climate Lens

The application of a climate lens at the national or sector level involves examining

(i) the extent to which the policy, strategy, regulation, or plan under consideration could be vulnerable to risks arising from climate variability and change;
(ii) the extent to which climate change risks have been taken into consideration in the course of program formulation;
(iii) the extent to which the policy, strategy, regulation, or plan could lead to increased vulnerability, leading to maladaptation or, conversely, to missing important opportunities arising from climate change; and
(iv) for preexisting policies, strategies, regulations, or plans that are being revised, what amendments might be warranted in order to address climate risks and opportunities.

A first quick application of the climate lens should enable a policy maker to decide whether a policy, plan, or program is at risk from climate change. If deemed to be at risk, further work is required to identify the extent of the risk, assess climate change impacts and adaptation responses in more detail, and identify possible recommendations and downstream actions.

Source: Organisation for Economic Co-operation and Development. 2009. *Integrating Climate Change Adaptation into Development Co-operation.* Paris.

Sector Policies and Plans

Sector-level policies are important for climate change because it is often at this stage that criteria such as engineering designs, alignment, technology, and priority areas will be established. Adaptation responses vary significantly by place and sector, and therefore this note seeks to develop some highly specific approaches for the energy sector. There is, however, little detailed experience at the policy level to draw from, with few energy ministries going beyond awareness raising and research.

Incorporating adaptation considerations into, for example, energy development master plans will further secure the likelihood of meeting the given energy-related objectives and may also identify new priorities. The simplest way for an energy development plan to incorporate climate change adaptation is to acknowledge the relationship between climate change impacts and the plan's goals (for example,a reliable and effective power network). The structure of this incorporation will vary from case to case. It may include stand-alone components within the energy strategy, such as conducting a climate change risk assessment for each project identified, or involve incorporating climate change adaptation within other subgoals of the energy plan.

Challenges faced by the physical infrastructure with respect to climate change cannot be separated from the interaction between the built environment and the natural environment. Infrastructural changes that do not address some of the root causes—such as deforestation, land degradation, and water use efficiency—will provide only a temporary and superficial fix. Power sector ministries will need to coordinate more effectively with other line ministries in dealing with climate change issues. There are a number of options for doing this:

- Establish or enhance cross-ministerial committees for managing adaptation to climate change, including for energy.
- Strengthen departments of disaster risk management and meteorology to improve information on which to make decisions.
- Introduce early warning and response systems for energy ministries to improve maintenance schedules and to respond quickly to post-disaster recovery needs.
- Promote low-regret or no-regret adaptation strategies that will have development benefits regardless of the nature of climate changes that may take place. This is a useful approach where uncertainty is high regarding climate change and capital investments cannot be justified for large-scale infrastructural changes.
- Incorporate climate change adaptation into environmental impact assessments and strategic environmental assessment guidelines. This can take place specifically in the power sector or, preferably, as part of the national standards. Energy ministries can test tools and adaptation approaches by applying strategic environmental assessments with climate change to their sector policies and plans.

Such intersectoral coordination and collaboration is more likely to lead in the assessment of a broader set of adaptation options which may not only provide multiple benefits across multiple sectors but also recognize that effective adaptation in one sector (e.g., energy) may lie in better operation or more investment in another sector (e.g., forestry).

Further, energy ministries can incorporate the following measures into their implementation plans:

- Introduce climate change vulnerability and adaptation considerations to criteria used for selecting projects for implementation and financing.
- Develop sector-specific and country-specific screening tools to identify projects at risk.
- Incorporate contingency budgets for specific adaptation interventions as the need arises.
- Adjust zoning regulations for power sector infrastructure (for example, to avoid flood or permafrost zones).
- Design flexible power infrastructure that can accommodate incremental changes over time.
- Incorporate climate change indicators into power sector planning budgeting frameworks to ensure accountability.

Mainstreaming Adaptation into Energy Sector Policies

Practical steps may be followed to incorporate climate change in energy planning and policy, even in the short term. Suggested actions include the following:

Conduct a climate change impact, vulnerability, and adaptation assessment of the energy sector at the national level

This assessment should cover the following aspects of climate change and energy sector investments:

- direct threats to investments (e.g., effect of extreme weather events on infrastructure),
- underperformance of investments (e.g., investments that fail to pay off when rainfall decreases), and
- the risk of forgoing opportunities that may arise from climate change and could be captured if factored into plans and projects.

Examples of the outputs from this activity are as follows:

- Scenarios for power production in the country are assessed on the basis of global and regional climate models.
- Flood- and drought-prone areas are analyzed and alternative land use plans developed based on climate risk scenarios.

Identify priority areas for intervention and implement pilot initiatives

Although this step is not fundamental in the policy mainstreaming work, it can generate grounded information about adaptation policy options and investments, their feasibility, and their potential for replication. Reviewing past pilot adaptation initiatives in the country can also be helpful at this stage.

The above set of actions can be implemented in the short term and guide the planning of climate-proofing investments (Box 15).

Box 15. Near-Term Climate Proofing Actions

Ebinger and Vergara (2011) identify the following set of near-term climate proofing actions:

Support awareness and knowledge exchange. Disseminate experience and learn from the increasing data and knowledge of climate impacts on the energy sector.

Undertake climate impact needs assessment. Quantify the impacts and risks through the energy life cycle to guide adaptation practice.

Develop project screening tools. Develop templates to screen individual projects for climate vulnerability and risks.

Develop adaptation standards for the energy sector. Such standards should cover engineering matters and information requirements.

Revisit planning timeframes and the use of historical data for future investments. Traditional planning approaches that use historical data may need to be revisited and adjusted to reflect anticipated climate trends.

Assess potential climate impacts when retrofitting existing infrastructure. Already available technologies, such as energy or environmental audits, can help identify any needed changes in operational and maintenance protocols, structural changes, and/or the relocation of existing plants.

Implement specific adaptation measures. Adaptation measures can include a range of off-the-shelf and innovative solutions, which may require investment in a pilot or demonstration project to illustrate their costs and benefits.

Identify policy instruments. They are needed to support climate impact management.

Support capacity building. Increase the capacity of key stakeholders including energy sector policy makers, regulators, and operators for climate risk management.

Source: Ebinger, J. and W. Vergara. 2011. *Climate Impacts on Energy Systems: Key Issues for Energy Sector Adaptation.* The World Bank. Washington, DC.

Identify relevant institutions, their role, and their mandate with respect to power and climate change to build capacity by disseminating results of previous steps

Institutions relevant for power and climate change considerations include ministries (such as energy or environment), departments, and institutes.

An example of an output from this activity is training sector planners from various ministries (e.g., energy, planning and investment, environment) to understand climate change risks for energy production and review policy options for enhanced climate resilience.

Hence, despite the uncertainty associated with climate risk, institutions can take a number of practical steps to reduce the climate vulnerability of the sector they manage and increase resilience to climate threats (Box 16).

Box 16. Nine Hallmarks of Institutions That are Adapting to Climate Change

1. Climate change champions are clearly visible, setting goals, advocating and resourcing initiatives on climate change adaptation.
2. Climate change adaptation objectives are clearly stated in corporate strategies and regularly reviewed as part of a broader strategic framework.
3. Flexible structures and processes are in place to assist institutional learning, upskilling of teams, and mainstreaming of adaptation within codes of practice.
4. Progress in adapting is monitored and reported against clearly defined targets.
5. Comprehensive risk and vulnerability assessments are being undertaken for priority activities at early stages of the planning cycle.
6. Scientifically based, workable guidance and training on adaptation is being put in place for operational staff.
7. Adaptation pathways are being guided by the precautionary principle in order to deliver low-regret solutions that are robust to uncertainty about future risks including, but not exclusively, climate change.
8. Multipartner networks are in place that are sharing information, pooling resources, and taking concerted action to realize complementary adaptation goals.
9. Effective communication with internal and external audiences is raising awareness of climate risks and opportunities, realizing behavioral changes, and demonstrating adaptation in action.

Source: Wilby, R.L. and K. Vaughan. 2011. Hallmarks of organizations that are adapting to climate change. *Water and Environment Journal.* 25 (2). pp. 271–281.

Conclusions

The energy sector is particularly vulnerable to projected changes in temperature and rainfall, increased frequency and intensity of extreme weather events such as flood and drought, a rise in sea level, and the intensification of storm surges. All of these changes have consequences for the design of energy investment projects. Inadequate attention to these impacts can increase the long-term costs of energy investments and increase the likelihood that such investments will fail to deliver the benefits for which they were intended.

This publication aimed to present a step-by-step methodological approach to assist project teams to assess and incorporate climate-proofing measures into energy investment projects. It is key to recognize that climate proofing, or more generally adaptation to climate change, is essentially characterized by decision making under uncertainty and incomplete information. Uncertainties associated with global, regional, and local climate projections, as well as national and local socioeconomic trends, require a pragmatic, participatory, and flexible approach to constructing climate and development scenarios and to assessing impacts, vulnerability, and adaptation.

Additional and predictable financing is needed to support the assessment of climate-proofing options at the project level and to fully integrate adaptation into development planning and processes. Most adaptation financing is now allocated by donors on a project-by-project basis, which forcibly separates adaptation activities from mainstream development work. While separating out funding for adaptation is important for accountability and transparency purposes, it can also add to the challenge of mainstreaming efforts, particularly when adaptation funds and sector budgets are administered independently.

Existing adaptation funds such as the Least Developed Countries Fund[43] and the Special

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[43] Specifically, the Least Developed Countries Fund was tasked with financing the preparation and implementation of national adaptation programs of action. Consistent with the findings of these action programs, the fund focuses on reducing the vulnerability of those sectors and resources that are central to development and livelihoods, such as water, agriculture and food security, health, disaster risk management and prevention, infrastructure, and fragile ecosystems. For more details, visit www.thegef.org/gef/LDCF

Climate Change Fund[44] administered by the Global Environment Facility, as well as the Adaptation Fund[45] established under the Kyoto Protocol, all aim to finance concrete adaptation projects and programs. While of significance, these funds are not necessarily amenable to supporting the design and assessment of climate-proofing options of specific sector investment projects and are not easily accessible for timely integration in the ADB project cycle. Alternative funding mechanisms may be required to facilitate this process.

While the focus of the *Guidelines* is at the project level, an improved understanding of climate change impacts should also be used to incorporate climate change considerations into energy planning and policy at the country level. Sector-based approaches have their limits, and regional ecosystem-based assessments and analysis are needed to influence integrated planning in the energy sector. Given that energy infrastructure has a long life cycle, its planning should be developed further and integrate new approaches such as green infrastructure planning. Most adaptation responses will require participation across ministries; coordination efforts are intense and should be supported.

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[44] The Special Climate Change Fund was established to support adaptation and technology transfer in all developing country parties to the UNFCCC. The fund supports both long-term and short-term adaptation activities in water resources management, land management, agriculture, health, infrastructure development, fragile ecosystems including mountainous ecosystems, and integrated coastal zone management. For more details, visit www.thegef.org/gef/SCCF

[45] The Adaptation Fund was established to finance concrete adaptation projects and programs in developing countries that are parties to the Kyoto Protocol and are particularly vulnerable to the adverse effects of climate change. For more details, visit www.adaptation-fund.org

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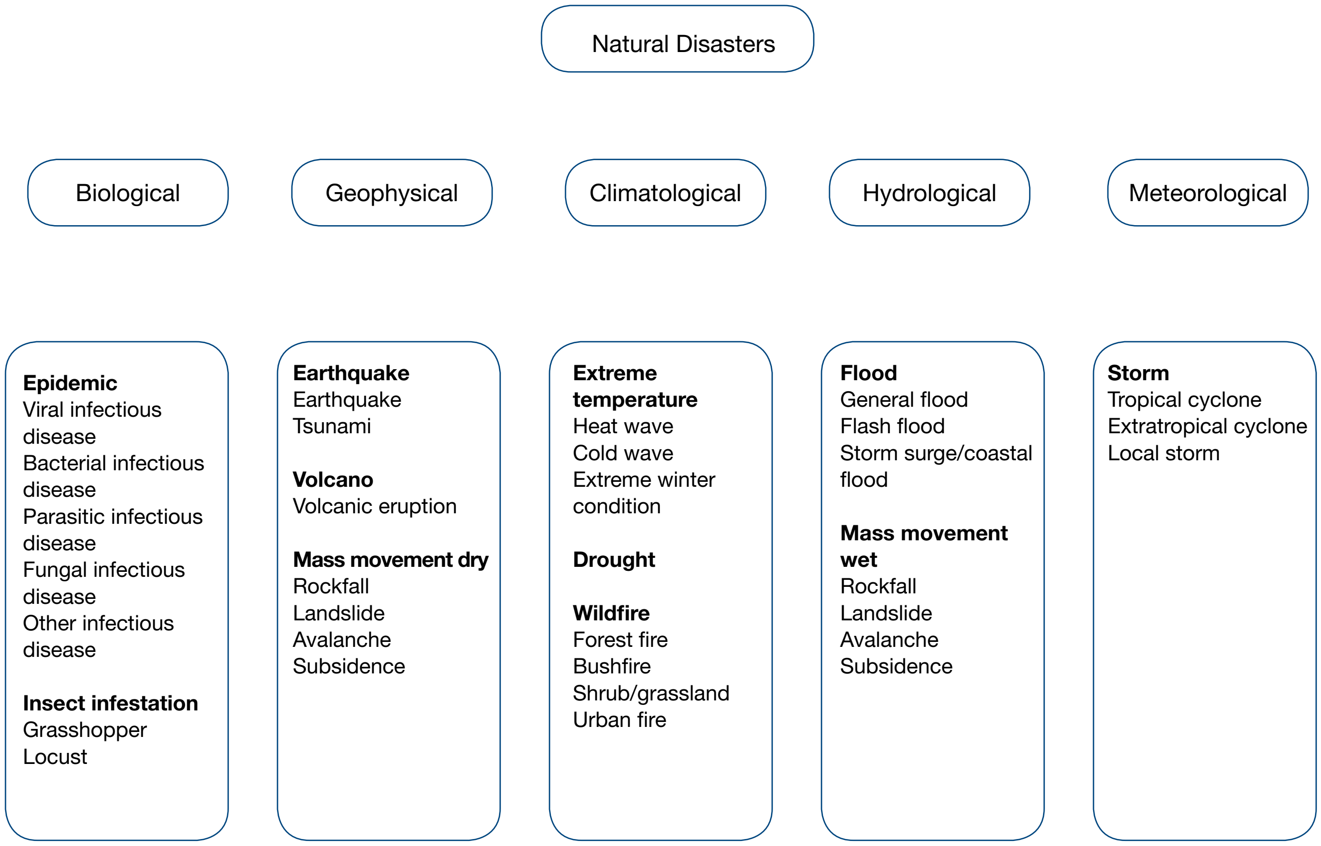
Appendix 1: ADB Draft Risk Screening Tool (September 2009)

1. The screening tool has been designed to take into account climate-induced risks and natural hazards of geophysical origin (as listed in Figure A1). This screening tool will expand the bank's risk assessment capacity within the ADB policy framework and project life cycle operations. This proposed risk screening exercise may be conducted before the project preparatory technical assistance fact-finding mission. It aims to make investments more resilient to risk, in alignment with ADB's Strategy 2020 and developing member countries' partnership strategies.
2. With the impacts of natural hazards and climate change expected to increase, ADB has developed this risk screening tool to rapidly assess impacts and associated risk at the project preparation stage. This snapshot of project risks helps project officers, mission leaders, environmental specialists, and project stakeholders consider the potential incorporation of risk management measures in project design, technical assistance concept papers, and project operations.
3. **Risk** is often regarded as a function of Hazard, Vulnerability, and Exposure and commonly expressed as **R = H** x **V** x **E**. The overall **risk** of damage or losses is determined by the nature, intensity, and frequency of the **hazard** (e.g., the frequency of flood at a certain level); the **exposure** to the hazard (e.g. the number of people living on a flood plain); and the **vulnerability** to the hazard—that is, the conditions determined by physical, social, economic, and environmental factors or processes, which increase the susceptibility of an ADB-funded project or a community to the impact of the hazard.
4. Some risks, such as damaging earthquakes and volcanic eruptions, may have return periods averaging hundreds of years. While such events may not appear in the historic record for the project area, this should not imply that such risks cannot occur.
5. As some risks may increase during the project design life (e.g., strengthening of cyclonic winds, sea level, frequency of landslides as the result of an increase in intense rainfalls), project design must take these potential changes into account. For example, where infrastructure with a design life of 20 years is constructed with a 1-in-50 year flood in mind, the project design must consider the 1-in-50 year flood applicable in 20 years' time.
6. Answers to questions in the risk screening tool, when totaled, generate a risk value of **High**, **Medium**, or **Low.** Where projects are deemed to be at medium or high risk, other risk management measures (such as climate risk mapping, vulnerability assessments to extreme events, risk reduction policies and practices) will need to be introduced during project design and implementation.

Figure A1. Internationally Accepted List of Hazards



Risk Screening Tool			
General Project Identification			
1. Date: 2. Country & Project Title: 3. Lending or Financing Modality: 4. Department & Division:			
Risk Assessment Category	**Risk Values**	**Total**	**Remarks**
Pre-determined impacts and risk factors			
1. Which physical environment best describes the project area?	Using Annex 1, add the score for the physical environment that best describes the project location.		
2. Categorize sectoral risk of project (See Annex 2)	Add risk value from 0–3.		
3. List individual hazards that may impact project (Figure A1 above)	Add risk value of 1 for each natural hazard (up to a maximum of 4). If hazards unknown, use 3 as a risk value		
4. Estimate the number of people in the project area “exposed” to risk after the project is completed	For <100 score = 0, 100–1000 score = 1, 1000–10,000 score = 2, >10,000 score = 3		
If the TOTAL value for the first 4 questions sums to 4 or less there is no need to complete the remaining questions.			
Stakeholder engagement and risk knowledge			
1. Do the project proponents have the institutional capacity to successfully incorporate, manage, and deliver risk management measures to the project?	Good capacity, risk value = 0; poor capacity, risk value = 1; very poor capacity, risk value = 2		
2. Will potential hazard impacts on communities, gender, indigenous peoples, or the social dimensions of risk be considered in the concept paper?	Yes/No (If No or unsure, add 1 risk value)		
3. Are there any demographic or socioeconomic variables (i.e., population increase, settlement patterns, biophysical and environmental conditions) that may increase exposure to hazard impacts?	Yes/No (If Yes or unsure, add 1 risk value)		
4. Is it likely that executing agency stakeholders have some practical knowledge of risk reduction measures for the project?	Yes/No (If No or unsure, add 1 risk value)		
5. Will the project reduce, leave unaltered, or increase the risk to project beneficiaries?	Reduce risk, score = 0; leave risk unaltered, score = 1; increase risk, score = 2		
6. Will the project reduce, leave unaltered, or increase the risk to the localized environment/project dependent ecosystem?	Reduce risk, score = 0; leave risk unaltered, score = 1; increase risk, score = 2		
7. Do country/institutional policies or environmental laws significantly promote risk management measures?	Yes/No (If No or unsure, add 1 risk value)		
8. Does the project require a risk expert to introduce risk reduction measures in project design, implementation, or operations and maintenance?	No = 0 Yes = 1 or 2 based on your assessment of the level of risk		
Total Risk Value (Range 0 to 25)	**High Risk: 17–25** **Moderate Risk: 8–16** **Low Risk: 0–7**		

Low Risk (0–7): This range indicates the project proposal has considered risk management measures to minimize hazard impacts and associated risks, and that the project may therefore have a potentially higher threshold against current and anticipated risks.

Moderate Risk (8–16): Project exposure to risk is **likely**. It is **recommended** that risk reduction measures be incorporated into project design and activities.

High Risk (17–25): Project exposure and vulnerability to potential risks is **very likely**. It is **highly recommended** that risk reduction measures be incorporated into project design and activities, and that a further review of the project proposal be undertaken.

Proposed Actions

1. Review/analyze expected natural hazard or climate impacts, and where appropriate, incorporate risk reduction measures in project preparation technical assistance (PPTA).
2. During fact-finding mission and PPTA development, the environment specialist and project officer/mission leader will consult with risk management specialist or other assistance to better identify potential risk reduction opportunities.
3. Insight gained from this risk screening tool will help the project officer/mission leader consider incorporating risk management measures into the project budget and in consultant terms of reference.
4. Consider (i) conducting impact and vulnerability assessments, (ii) cost-benefit analysis regarding climate adaptation and disaster risk reduction in the project, and (iii) and financing strategy to cover incremental hazard management costs.

Annex 1: Physical Environments

Physical Environment Risk Zones	Natural Hazards and Climate Change Impacts	Score
Arid/Semi-arid & desert environments	Low erratic rainfall of up to 500 mm rainfall per annum with periodic droughts and high rainfall variability. Low vegetative cover. Resilient ecosystems & complex pastoral and systems, but medium certainty that 10%–20% of drylands degraded; 10%–30% projected decrease in water availability in next 40 years; projected increase in drought duration and severity under climate change. Increased mobilization of sand dunes and other soils as vegetation cover declines; likely overall decrease in agricultural productivity, with rain-fed agriculture yield reduced by 30% or more by 2020. Earthquakes and other geophysical hazards may also occur in these environments.	**1 or 2**
Humid and sub-humid plains, foothills and hill country	More than 500 mm precipitation/yr. Resilient ecosystems & complex human pastoral and cropping systems. 10%–30% projected decrease in water availability in next 40 years; projected increase in droughts, heatwaves and floods; increased erosion of loess-mantled landscapes by wind and water; increased gully erosion; landslides likely on steeper slopes. Likely overall decrease in agricultural productivity & compromised food production from variability, with rain-fed agriculture yield reduced by 30% or more by 2020. Increased incidence of forest and agriculture-based insect infestations. Earthquakes and other geophysical hazards may also occur in these environments.	**1**
River valleys/deltas and estuaries and other low-lying coastal areas	River basins, deltas, and estuaries in low-lying areas are vulnerable to riverine floods; storm surges associated with tropical cyclones/typhoons and sea level rise; natural (and human-induced) subsidence resulting from sediment compaction and ground water extraction; liquefaction of soft sediments as result of earthquake ground shaking. Tsunami possible/likely on some coasts. Lowland agribusiness and subsistence farming in these regions at significant risk.	**2**
Small islands	Small islands generally have land areas of less than 10,000 km^2 in area, though Papua New Guinea and Timor with much larger land areas are commonly included in lists of small island developing states. Low-lying islands are especially vulnerable to storm surge, tsunami, sea level rise, and frequently coastal erosion, with coral reefs threatened by ocean warming in some areas. Sea level rise is likely to threaten the limited groundwater resources. High islands often experience high rainfall intensities, frequent landslides, and tectonic environments in which landslides and earthquakes are not uncommon with (occasional) volcanic eruptions. Small islands may have low adaptive capacity and high adaptation costs relative to GDP.	**3**
Mountain ecosystems	Accelerated glacial melting, rockfalls/landslides, and glacial lake outburst floods, leading to increased debris flows, river bank erosion and floods and more extensive outwash plains and, possibly, more frequent wind erosion in intermontane valleys. Enhanced snow melt and fluctuating stream flows may produce seasonal floods and droughts. Melting of permafrost in some environments. Faunal and floral species migration. Earthquakes, landslides, and other geophysical hazards may also occur in these environments.	**3**
Volcanic environments	Recently active volcanoes (erupted in last 10,000 years—see www.volcano.si.edu). Often fertile soils with intensive agriculture and landslides on steep slopes. Subject to earthquakes and volcanic eruptions including pyroclastic flows and mudflows/lahars and/or gas emissions and occasionally widespread ashfall.	**2**

Annex 2: Risks by Sector

Project Sectors	**RISKS** (Selected examples only. If the project is likely to be affected by any of the risks listed below, use the score suggested. If it will not be affected, a lower score may be used at your discretion.)	**Estimated RISK LEVEL**
1. Agriculture & Natural Resources	Impacts on crop production or yield resulting from drought, hail, floods, tropical cyclone/ depression winds and rains, storms, heatwaves, wildfires, insect infestations, widespread volcanic ash fall.	Very High (3)
	Possible changes in diversity resulting from changing precipitation and/or temperature regimes	
	Impacts on water availability for agricultural sector from El Niño, Indian Ocean Dipole and similar hemispheric weather influences	
	Impacts from glacial melt flooding, or estuarine or delta-based flooding from storm surges or tsunami	
	Impacts from salinization of soils by drought, storm surge or tsunami	
	Impacts of changes to ocean currents, and on physical & chemical regime of oceans	
	Impacts on land-sea interactions affecting sensitive habitats of marine species through changing water temperatures, increased incidents of marine pollution, greater incidents of coastal erosion, or incidents of algae blooms from warming of ocean areas	
	Impacts on fisheries as a result of changes in migration patterns, fish size and availability	
2. Water Supply, and other municipal infrastructure and services	Decrease in freshwater availability or adverse effects on quality due to drought or heatwaves, algal blooms, salinization by storm surge or tsunami, ground water rise or sea level rise.	
	Contamination of or interruption to water supply (or electricity) resulting from flood, storm surge, landslide, tsunami or earthquake. Adverse effects on treatment plants from volcanic ash fall.	
	Accelerated glacier melt likely to cause increase in the number and severity of glacial melt-related floods, slope and river bank destabilisation and a decrease in river flows as glaciers recede	
3. Education	School infrastructure is used for emergency shelter in most countries and should conform to the highest building codes and be sited as safely as possible with respect to all risks.	
4. Health and Social Protection	Health infrastructure should conform to the highest possible building codes and be sited as safely as possible with respect to all risks. Morbidity/mortality (e.g., fractures or severe trauma, burns, malnutrition, diarrhoeal, cardio-respiratory, or infectious diseases) from earthquakes, tsunami, heatwaves, floods, storms, cyclones, fires and droughts.	
	Changes in the distribution, frequency & burden of some vector-borne and water-borne diseases	
5. Transport & Communications	Damage to transport infrastructure due to earthquakes, volcanic eruption, landslides, sea-level rise, storm surge, or tsunami	High (2)
	Port operations affected by sea-level rise, storms, storm surge, tsunami, wave action, strong winds, or floods,	
	Overhead lines exposed to wind, ground shaking and liquefaction particularly in coastal areas, high country and on soft soils.	

continued on next page

table continued

Project Sectors	**RISKS** (Selected examples only. If the project is likely to be affected by any of the risks listed below, use the score suggested. If it will not be affected, a lower score may be used at your discretion.)	**Estimated RISK LEVEL**
6. Energy	Rainfall variability, floods, droughts, landslides, earthquakes, or glacial meltwater floods impacting surface water flow and/or downstream water recharge	High (2)
	Risk to oil and gas sector infrastructure in coastal locations from tropical cyclone winds and storm surge, floods, tsunami, earthquakes, or sea level rise	
	Overhead transmission and distribution lines exposed to wind, ground shaking and liquefaction particularly in coastal areas, high country and on soft soils. Pipelines subject to ground shaking, liquefaction, subsidence, erosion.	
7. Multisector	Subject to multiple risks similar to examples given throughout this table	
8. Housing Finance & Microfinance	Housing infrastructure and small businesses are vulnerable to all risks listed in Table 1 or elsewhere in this Appendix (may require higher Risk Level for specific projects).	Medium (1)
	All property can be affected by a range of the risks listed in this table	
9. Industry & Trade	Diverse sector investment subject to risks and market interruptions (e.g. procurement delays, merchandise transfer disruption)	
10. Technical, vocational training & skills development	Limited direct exposure to the types of risks discussed here	Negligible Risk (0)
11. Finance		
12. Public Sector Management		

Source: Adapted from *ADB Portfolio at Risk* (updated to 2009 Sector classification).

Appendix 2: Draft Terms of Reference

Sample Additional Activities for Project Preparation Team Members[46]

The project team will undertake the following activities in order to identify and recommend an adaptation strategy for the project, both in terms of protecting the investment and ensuring that the project does not increase the vulnerability of the relevant area and people. This work will include a detailed climate change impact, vulnerability, and adaptation assessment, including an economic assessment, in the project context.

The results of the assessment should be fully incorporated into the project design including the detailed engineering design, environmental management plan, social safeguards measures, monitoring and evaluation framework and budget. The inputs will consist of approximately 4 person-months by international consultants and 5 person-months of national consultants assisting the international consultants.

Team Leader (International, 1.0 person-month)

(i) Oversee and coordinate the implementation of the draft strategy for vulnerability, impact and adaptation assessment.
(ii) Identify and discuss the adaptation objective with all relevant stakeholders
(iii) Synthesize vulnerability and impact information collected by other members of the team into the decision matrix provided by ADB.
(iv) Organize and lead multi-stakeholder consultations to identify and prioritize adaptation options, based on economics assessment in addition to any other prioritization conditions identified (i.e., through multi-criteria analysis).

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[46] As commented under Step 6, existing project preparation technical assistance team members (including energy specialist, design engineers, economist, environmental and social specialists) could take on all the assessments. The additional tasks essentially entail analyzing the potential impacts of projected climate change and sea level rise (if the project involves coastal zone) on key project components/aspects, and identify and assess possible options for managing the adverse impacts to the design, operation, and maintenance of the relevant project components. Therefore, a set of additional tasks with relation to impacts, vulnerability, and adaptation assessments could be distributed to the relevant technical assistance team members.

(v) Recommend adaptation options in a presentation to the government, ADB and other relevant stakeholders.
(vi) Ensure integration of adaptation components into the project design.
(vii) Identify additional training needs, indicators for monitoring and budget for adaptation components as needed.

Civil (Power) Engineer (International, 1.0 person-months)

(i) Identify adaptation options and their costs for the project.
(ii) Assist other team members in identifying all benefits of the adaptation options from the power sector perspective.
(iii) Prepare revisions to project design taking climate change into account.
(iv) Recommend to ADB adjustments and improvements toward development of a replicable model to be used in the project and in the future.
(v) Contribute to specialists' advice including preliminary designs and cost estimates.
(vi) Prepare technical documentation, including project design and specifications with adaptation considerations.

Economist (International, 1.0 person-months)

(i) Identify and estimate all costs and benefits of the various adaptation options taking into account power, engineering, environmental, and socioeconomic perspectives including the economic assessments.
(ii) Apply a cost-benefit/cost-effectiveness analysis for the adaptation options identified above.
(iii) Make recommendations on improvements based on the cost-benefit/cost-effectiveness analysis with a view to developing a replicable model for future projects.

Environmental and Social Specialist (International, 1.0 person-months)

(i) Identify the climate parameters of concern for the project, including but not limited to changes of precipitation, temperature regimes, and extreme events.
(ii) Conduct a vulnerability assessment in the project area to identify vulnerability of the planned infrastructure as well as of the local area and people.
(iii) Coordinate the climate impact assessment with assistance from a climate modeler and in coordination with the team hydrologist.
(iv) Facilitate participation of government counterparts in ongoing capacity building activities to ensure skills transfer for improved sustainability of designs.
(v) Conduct community and expert consultations to verify and refine selected adaptation options.
(vi) Revise the Environmental Management Plan in line with findings.
(vii) Assist the economist in estimating the life cycle project costs and benefits of climate change adaptation options, including socioeconomic and environmental benefits.
(viii) Assist the project manager in adjusting the design of the project by incorporating climate change adaptation measures.
(ix) Provide recommendations and suggestions for environmental or nonstructural adaptation interventions.

Environmental and Social Specialist (National, 4.0 person-months)

(i) Facilitate participation of government counterparts in ongoing capacity building activities to ensure skills transfer for improved sustainability of designs and identify additional training needs.

(ii) Undertake initial poverty and social assessment, including field assessment of vulnerability to climate change.
(iii) Collect and summarize existing impact assessments and reports and prepare a summary of existing information and potential gaps.
(iv) Collect all relevant climate change data from government ministries and international and community organizations.
(v) Identify potential adaptation options.

Hydrologist (National, 1.0 person-months)

(i) Undertake hydrological assessment under various climate change scenarios.
(ii) Produce flood and drought maps and hot spots for current and future scenarios.
(iii) Provide recommendations for adaptation interventions.

Terms of Reference for Impact Assessment Specialist[47]

Objective/Purpose of the Assignment

Based on available and relevant information, conduct a desktop assessment of anticipated climate change impacts on a selected energy project, using downscaling techniques of global circulation models and integrated impact assessments.

Skills Required

It is preferable that this contract is implemented by a team of consultants with the following expertise: climate change modeling (including downscaling techniques), hydrological/irrigation modeling, and the engineering/economic knowledge for impact assessment in the relevant sector.

Scope of the Work

The purpose of this contract is to conduct a detailed climate change impact analysis as input to project design. The assessment will in part be led by the identified climate parameters of relevance to the project design, such as

- changes in maximum and minimum temperatures,
- increase in very hot days and heat waves,
- sea level rise, and
- increase in intensity of and frequency of droughts and floods and extreme events.

The consultant will also provide an expert opinion as to the probability and reliability of climate change modeling scenarios.

Detailed Tasks

1. Review the project preparation technical assistance and the climate change adaptation methodology prepared for the project.
2. Identify with the project team the climate change parameters to be assessed and the modeling scale (temporal and spatial) to be used in the impact assessment. Identify the goal of the climate change impact assessment in the context of the overall project objectives.
3. Survey the existing information such as relevant climate change projections and local historical climate data available. Prepare an assessment on the reliability of existing climate change projections based on the model's ability to represent past climate conditions. Evaluate the range of climate projections and select projections that would be

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[47] As commented under Step 6, there does not need to be a range of new consultants to perform the various assessments. The only additional expert required to carry out the analyses is a climate/sea level scenario specialist (or climate/coastal specialist). All other tasks could be performed by existing members of the PPTA team. An example set of terms of reference for climate and coastal/sea level specialists are provided for consideration.

representative of this entire range (i.e., dry, average, and wet scenarios). Identify any need for further modeling, or where existing modeling is sufficient for the project, prepare a short synthesis report.

4. Identify the probabilities of occurrence of specific climate changes from taking place and the level of certainty. Identify assumptions and limitations in terms of the use of the projections for influencing project design.
5. Formulate downscaled climate change scenarios for the relevant time horizon of the project, specifying the technique used for downscaling.
6. Identify possible technical gaps, in country and generally, for improving capabilities for climate change projections in the country.
7. Submit for review and approval a draft outline of the analysis to be undertaken, including recommended methodology for impact assessment (i.e., hydrological modeling, agronomic assessment, the climate scenarios to be used in the analysis, the impact models, and a justification for their choice.)
8. Provide an expert opinion on the probability of further climate change research potentially altering project design protocols or operations requirements, including master planning.
9. Submit a draft report for review.
10. Finalize the report based on comments received by ADB.

Output/Report Requirements

Final report containing estimated projections for key climate parameters, probability analysis, impact assessment, risks, and assumptions.

Draft Terms of Reference for Vulnerability Assessment Specialist

Objective/Purpose of the Assignment

To identify the root causes for a system's vulnerability to climate changes and existing trends in climate.

Skills Required

The consultant is expected to have a background in multidisciplinary environmental or natural resource management as well as in the power sector, and have a good understanding of the social and economic aspect of vulnerability. (Note: This work can often be led by the environmental specialist with inputs from other team members.)

Scope of the Work

The goal of the vulnerability assessment is to identify existing vulnerabilities, coping strategies, and social and poverty dimensions, and to confirm and calibrate the climate modeling undertaken by the climate change modeler. This includes collecting and analyzing raw and observational data of current practices to compensate for vulnerability.(Note: Local nongovernment organizations may be an appropriate partner for conducting local consultations.)

Detailed Tasks

1. Collect data and identify observed trends in climate.
2. Work with impact modeler to verify and ground-truth climate change predictions.
3. Conduct field consultation with local community groups on existing vulnerabilities and coping strategies.
4. Prepare climate vulnerability maps based on existing environmental and climate data, including land cover/vegetation cover, slopes, geological hazards, and precipitation distribution.
5. Identify priority areas with high vulnerability, to be verified also during ground-truthing along the proposed investments to assess current observed changes and coping practices.

Final Outputs

1. The final vulnerability and risk map based on geographic information systems data.
2. Report containing summary of key observable vulnerabilities, sensitivities, coping strategies, and needs.

Size of Contract: 1 person-month

Draft Terms of Reference for Adaptation Specialist

Objective/Purpose of the Assignment
The consultant's objective is to lead the identification and prioritization of adaptation options in the context of the project, and to highlight findings to ADB for future work (optional).

Skills Required
The consultant is expected to have a multidisciplinary energy and environment background and have a good understanding of the social and economic aspect of adaptation. (Note: This work can often be lead by the environment specialist with inputs from other team members).

Scope of the Work
Adaptation is defined as adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects that moderates harm or exploits beneficial opportunities. The objective of the adaptation assessment is to identify all potential adaptation options, identify their costs and benefits, and prioritize their implementation in the context of the project goals.

Detailed Tasks:
1. Identify all potential adaptation solutions, including soft and hard measures.
2. The expected co-benefits can be identified at this time.
3. Conduct multi-stakeholder consultations to identify and confirm all options, including their costs, benefits and risks.
4. Based on tasks 1 to 3, adaptation measures and options for the proposed project will be evaluated jointly with the executing agency, technical assistance team economist, engineer, and poverty reduction expert to provide an economic assessment of adaptation options and to define co-benefit for other aspects of development.
5. A second consultation meeting will be organized with the project executing agency and other stakeholders' agreement on prioritized adaptation measures to undertake during project implementation.
6. Incorporate selected adaptation priorities into the project design, including institutional arrangements and budget.
7. Identify any additional capacity building needs required for the project implementation unit.
8. Identify indicators to monitor vulnerability reductions and sustainability of adaptation measures in the context of the project implementation.

Final Outputs
1. Synthesis of the results from the impact assessment, vulnerability assessment, and economic analysis. Recommendations should be included as part of this report.
2. Adaptation strategy including prioritized adaptation options, implementation arrangements, implementation risks, training and capacity building plan, budget, and input into the project design and monitoring framework

Size of Contract: 1–2 person-months

Draft Terms of Reference for Economic Analysis

Objective/Purpose of the Assignment
The overall objective of this study is to conduct a cost-benefit analysis or a cost-effectiveness analysis of the various technically feasible adaptation measures which may be implemented to climate proof the different components under consideration in the energy project. This study aims to inform project officers and policy makers with respect to the desirability (from an economic point of view) of investing in adaptation, and to assess and rank

adaptation options with respect to their economic outcomes.

Detailed Tasks and Outputs

Specific tasks and deliverables may be divided into two phases:

Phase 1: Assessment of historical records and data, and design of methodology

Tasks

1. A detailed review of the historical records and data of relevance, especially those pertaining to direct damages to power production and infrastructure, and to indirect impacts resulting from the damage to power infrastructure.
2. Provide a list of alternative adaptation measures, which may have already been undertaken and implemented for similar situations in the country or are in the process of being designed and implemented, along with their expected impacts and costs. For this purpose, all available information from primary and from secondary data should be used.
3. Identification of data sets which may be used to implement the objectives of the study.
4. Detailed framework (tasks, activities, responsibilities, time lines) for the successful implementation of the study.
5. A report early on in the study to identify possible means by which the expected impacts of adaptation measures may be modeled, and their possible costs and benefits estimated, and validate the proposed methodological approach and framework.

Final Output

A report covering in detail all of the above tasks.

Phase 2: Cost-benefit analysis of adaptation measures

Tasks

1. Evaluate the effectiveness of the past and present adaptation initiatives with quantitative estimates (to the extent data allows) with notes on circumstances/conditions/reasons behind successes or failures of the initiatives.
2. Based on historical data and the study information, provide an estimate of the benefits and costs of adaptation for each possible adaptation measure.
3. Based on the outcome of the analysis, make recommendations pertaining to the adoption of adaptation measures in the context of the project.

Final Output

Report on analysis of the costs and benefits of potential adaptation measures to climate proof the components of interest in the project, along with recommendations pertaining to the nature of the adaptation measures to receive priority based on the outcome of the economic analysis.

Size of Contract: 0.5 person-month

Appendix 3: Common Climate Downscaling Methods and Requirements

Dynamical downscaling or regional climate models (RCMs) simulate climate using similar processes as general circulation models (GCMs) but at much finer scales (10–50 kilometers). GCM outputs provide inputs as boundary conditions for the RCM. The primary contribution of RCMs is the inclusion of more realistic topographic and land cover features, which are not comprehensively included in GCMs. These models are computationally intensive and costly. They are not recommended for downscaling at the project level due to their cost unless there is already an existing model for the region.

Empirical or statistical downscaling is one technique for projecting climate change on a much smaller scale and relies on determining statistical relationships between large-scale atmospheric variables with local response variables, such as daily precipitation as measured at weather stations. Changes in those large-scale variables projected under climate change (as simulated by GCMs) can be translated into changes in the local variables. Statistical downscaling has the advantage of being less expensive and less computationally onerous compared with RCMs. However, statistical downscaling does not simulate climate; it is just a technique to project results from GCMs. There are two types of statistical downscaling: spatial and temporal downscaling.

Spatial downscaling is possible through a variety of empirical/statistical methods (linear interpolation, kriging, spline fitting, and intelligent interpolation). Straight linear interpolation may be the simplest statistical technique for downscaling large-scale GCM projections to finer grids or points. Uncertainty estimates can be obtained by applying Monte Carlo or other stochastic tools. Additional statistical or empirical methods utilized for climate change downscaling include weather generators among others.[48]

Temporal downscaling is often needed to generate realistic series of daily rainfall given that GCMs do not produce reliable climate data in a resolution that is less than months or seasons. A simple method for downscaling temporally (e.g., monthly to daily) is to use the changes in monthly means of variables from GCM projections to adjust a daily baseline period obtained from meteorological stations. There are also other techniques used such as stochastic weather generators.

Table A1 summarizes the key features, including the skill, time, and resource requirements, for different approaches to downscaling.

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[48] See Wilby et al. 1998.

Table A1. Summary of Key Features of Different Climate Downscaling Approaches to Climate Scenario Development

Method	Assumptions	Type of Result	Limitations	Required Data	Cost	Time Demand	Computing Demand	Required Analyst Skill
General Circulation Models (GCMs)[a]	The model simulates the important climate process well	200–400 kilometers (km) resolution; monthly and daily data; means and time series	Grid boxes have low resolution	Some data for validation purposes; combine with 30 years of observed data	Low/medium	Medium	PC or workstation	Modest
Regional Climate Models (RCMs)[b] ----- existing	The models have higher spatial resolution and they simulate important climate processes well	25–100 km resolution; monthly and daily data; means and time series	RCMs use boundary conditions from GCMs so they may not correct for errors	Maybe some data for validation purposes; may need to combine with 30 years of observed data	Low/medium	Medium	PC or workstation (maybe some large data storage requirement)	Modest
Regional Climate Models (RCMs)[b] ------ new	The models have higher spatial resolution and they simulate important climate processes well	25–100 km resolution; monthly and daily data; means and time series	RCMs use boundary conditions from GCMs so they may not correct for errors	Extensive data for initialization and validation purposes; may need to combine with 30 years of observed data	Very high	Very high	Workstation or mainframe computer	Extensive knowledge of climate modeling
Empirical Downscaling[b]	Use existing relations to calculate small-scale climate	Site-specific time series; monthly or daily data	Scale relations are constant over time	Extensive daily or monthly series of climate variables	High if data to be purchased	High	PC or workstation	Some understanding of climate dynamics
Weather Generators (WGs)[b]	Weather can be described as a stochastic process	Site-specific time series; daily data		Extensive daily weather series for sites or grids	High if data to be purchased	Medium/ High	PC	Some understanding of statistical properties of weather series

GCM = general circulation model, RCM = regional climate model

[a] It is assumed that people will use existing GCM results, and not run their own. [b] These methods must all be used in conjunction with GCM results.

Guidelines for Climate Proofing Investment in the Energy Sector

This publication provides a step-by-step methodological approach to help project teams assess and incorporate climate change adaptation measures into energy investment projects. While the focus of the Guidelines is at the project level, an improved understanding of climate change impacts should also be used to incorporate climate change considerations into energy planning and policy at the country level.

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