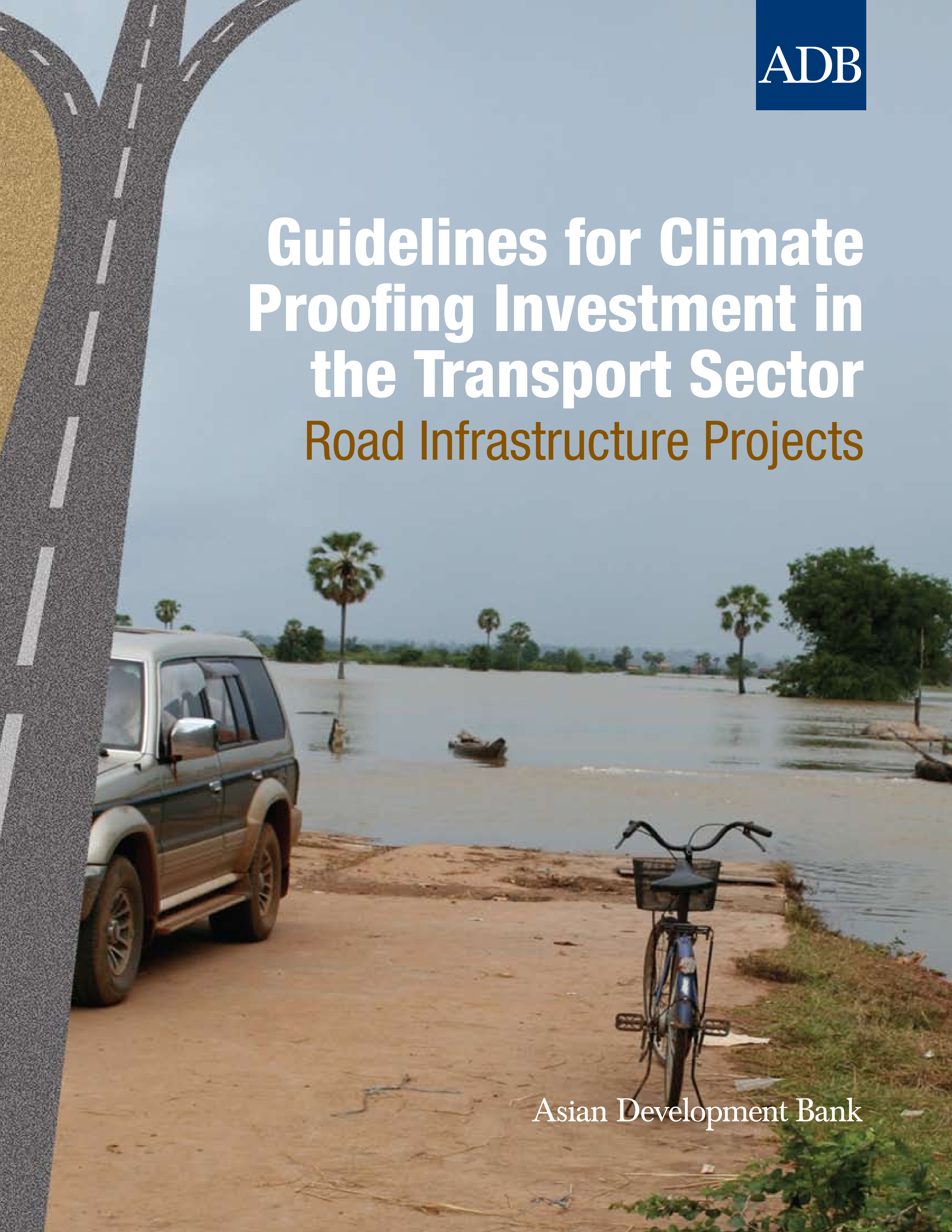
ADB

Guidelines for Climate Proofing Investment in the Transport Sector

Road Infrastructure Projects



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.

The long-term strategic framework of 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 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 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 first in a series of technical notes covering various sectors. It is intended to guide 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 road projects. We hope that it improves—and simplifies—the work of development professionals in their efforts to enhance the climate resilience of transport projects. We welcome comments and feedback, which will improve subsequent versions of this note.

This report was prepared by Liza Leclerc, Benoit Laplante, and David Corderi under RETA 6420: Promoting Climate Change Adaptation in Asia and the Pacific, financed by the Japan Special Fund and the Government of the United Kingdom. The initial preparation of the report was coordinated and supervised by Jay Roop. Charles Rodgers provided overall guidance in the finalization of the report. The report also benefited from valuable inputs from Daniele Ponzi and Xianfu Lu. Comments and suggestions were also received from ADB Climate Change Adaptation and Land Use Working Group, the Transport Community of Practice, and participants of the ADB Climate Change Learning Week 2010. Lorie Rufo provided invaluable technical assistance and overall support.

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Abbreviations

ADB	–	Asian Development Bank
GIS	–	geographic information system
GCM	–	global circulation (climate) model
IPCC	–	Intergovernmental Panel on Climate Change
NPV	–	net present value
OECD	–	Organisation for Economic Co-operation and Development
O&M	–	operations and maintenance
PPTA	–	Project Preparation Technical Assistance
RCM	–	regional climate models
UNFCCC	–	United Nations Framework Convention on Climate Change

Glossary*

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 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.

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.

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

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 (e.g., at seasonal, interannual, or long-term timescales).

Climate projection. The calculated response of the climate system to emissions or concentration scenarios of greenhouse gases, often based on 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 those 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 (10 to 100 kilometers) information from larger-scale models or data analyses. There are two main methods: 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. 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.

General circulation models. 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. Atmospheric and oceanic 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 weather forecasting, understanding the climate, and projecting climate change. More than 20 GCMs currently exist.

Impact assessment. The practice of identifying and evaluating, in monetary and/or nonmonetary terms, the effects of climate change on natural and human systems. Climate projections are used to first identify how the climate is changing, and then the impact of those changes on systems such as river basin dynamics are assessed, through hydrologic modeling, for example.

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).

Special Report on Emissions Scenarios. The *Special Report on Emissions Scenarios* was a report prepared by the Intergovernmental Panel on Climate Change for the Third Assessment Report in 2001 on future emissions scenarios to be used for driving global circulation models to develop climate change scenarios. There exist four broad families of emissions scenarios (A1, A2, B1, and B2) that depend on different assumptions pertaining to economic growth, population growth, the adoption of new technologies, and the degree of integration among nations of the world.

Storm surge. The temporary increase, at a particular locality, of the height of the sea due to extreme meteorological conditions. The storm surge is defined as being the excess above the level expected from the tidal variation alone at that time and place.

Threshold. The level of magnitude of a system process at which sudden or rapid change occurs. A point or level at which new properties emerge in an ecological, economic, or other system, invalidating predictions based on mathematical relationships that apply at lower levels.

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 range of values calculated by various models) 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

This publication, *Guidelines for Climate Proofing Investment in the Transport Sector: Road Infrastructure Projects* (henceforth *Guidelines*), aims to present a step-by-step methodological approach to assist project teams to incorporate climate change adaptation measures into transport sector investment projects. While the focus of the *Guidelines* is on the project level, an improved understanding of climate change impacts should also be used in the design of infrastructure planning and development policies and strategies to ensure appropriate resource allocation. Though the transport sector includes roads, waterways, rails, and airborne transport, this *Guidelines* focuses solely on road infrastructure.

Climate Change Impacts and the Transport Sector

The transport sector is vulnerable to projected changes in climate variables. Increased frequency and intensity of extreme weather events as well as the projected rise in sea level are expected to result in consequences such as the following:

- Changes in temperature—both a gradual increase in temperature and an increase in extreme temperatures—are likely to impact road pavements (for example, heat-induced heaving and buckling of joints).
- Changes in temperature will also impact the behavior of permafrost and thus the infrastructure lying on permafrost.
- Extreme weather events, such as stronger and/or more frequent storms, will affect the capacity of drainage and overflow systems to deal with stronger or faster velocity of water flows.
- Increased salinity levels will reduce the structural strength of pavements and lead to precipitated rusting of the reinforcement in concrete structures.

Adaptation to Climate Change

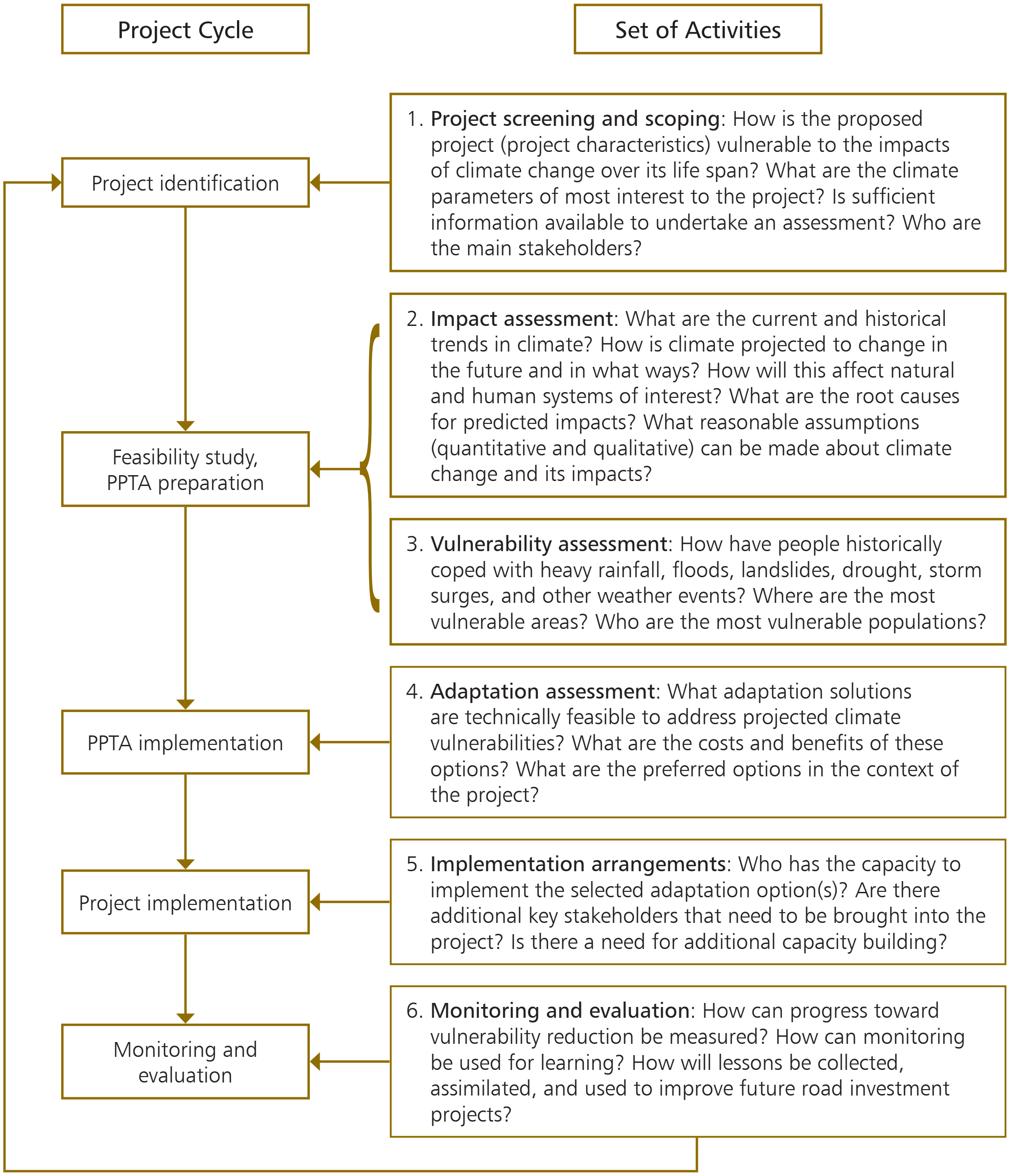
Adaptation options in the sector can generally be divided into engineering (structural) options (subsurface conditions, material specifications, cross section and standard dimensions, drainage and erosion, and protective engineering structures), and non-engineering options (maintenance planning and early warning, alignment, master planning and land use planning, and environmental management). In addition, it is important to recognize that in a number of circumstances, a "do nothing" response to climate change—for example, allowing an infrastructure to deteriorate and be decommissioned instead of climate proofing the infrastructure—may be a preferred course of action.

Developing an Adaptation Methodological Approach

The methodological approach presented in this *Guidelines* for building adaptation into road 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 broken 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.

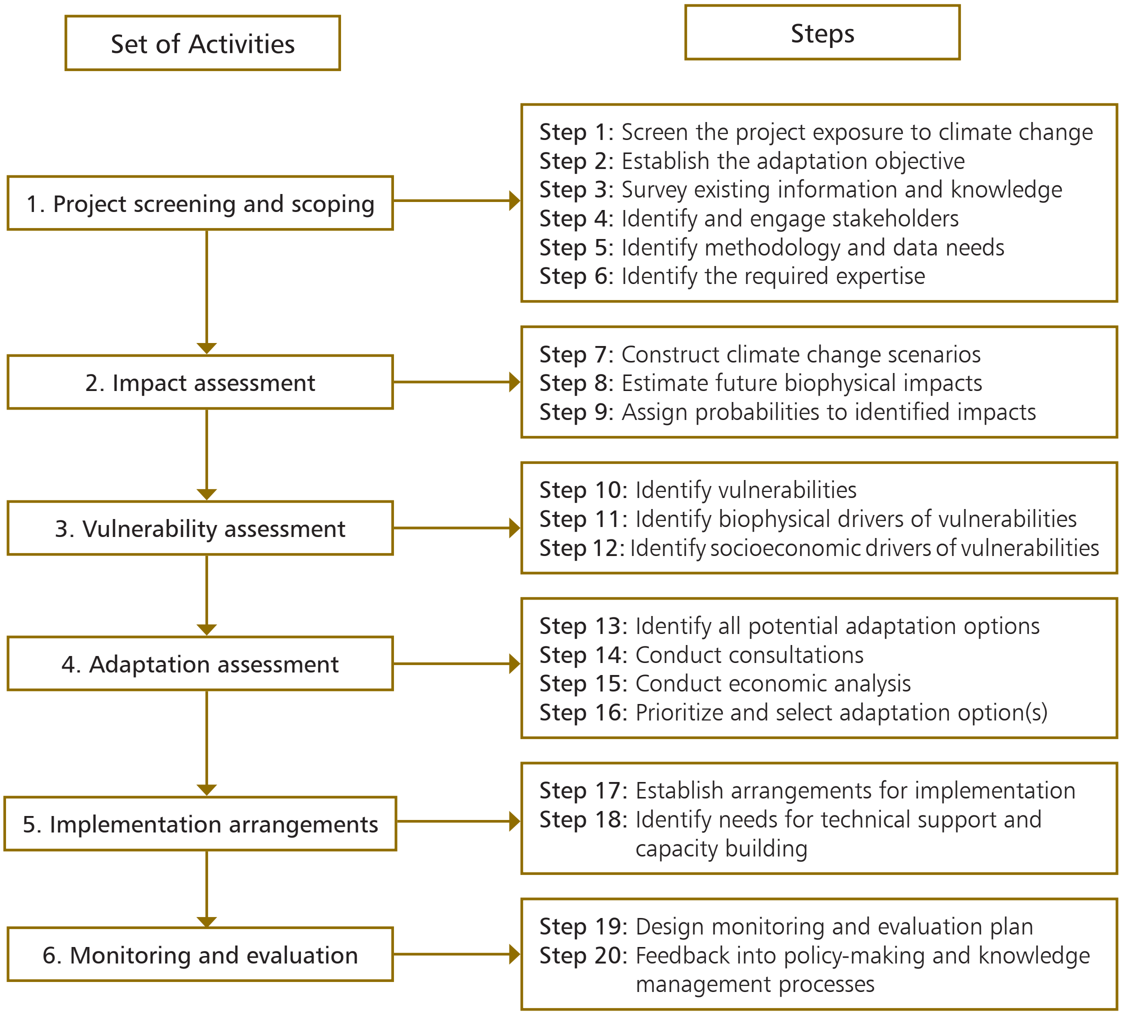
Figure E1 Assessing Adaptation Needs and Options: 6 Sets of Activities



PPTA = project preparation technical assistance.

Source: ADB.

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



Source: ADB.

Introduction

Transport is one of the main sectors that the Asian Development Bank (ADB) supports. Investment in the transport sector has accounted for 21% of ADB's lending portfolio since it was established in 1966, and for 27% of its lending portfolio over the period 2005–2009. For the period 2010–2012, transport sector lending is projected to be approximately $3.4 billion per year. Approximately 70% of ADB transport lending has been, and continues to be, for roads (ADB 2010).

In the years ahead, the demand for freight and passenger transport will continue to grow faster than gross domestic product (GDP). In the next decade, it has been estimated that the countries of Asia and the Pacific will need to invest $8 trillion in infrastructure, much of this being for transport (ADB 2009). ADB thus expects a strong continuing role financing the development of this sector in its developing member countries.

In the context of climate change, discussions about the transport sector most often pertain to its contribution to the overall emissions of greenhouse gases and how investments in the sector could contribute to an overall mitigation strategy (Leather et al. 2009).

However, it must be simultaneously recognized that the transport infrastructure is directly vulnerable to the impacts of climate change. To the extent that structures cannot be divorced from the environment within which they are built, environmental changes—such as a rise in sea level, more frequent and intense storms and storm surges, increased wave heights, floods, droughts, and temperature changes—all have consequences for the design, construction, and location of transport infrastructure. Inadequate attention to these impacts can increase the long-term costs of transport investments and increase the likelihood that such investments will fail to deliver the benefits for which they were intended.

Measures to adapt to climate change in the transport sector range from making adjustments to engineering specifications (design standard strategies) to alignment and master planning, and include environmental measures, such as reforesting a hilly area to prevent a road section from being damaged by a landslide. Climate-proofing investments in the transport sector will be achieved by assessing the potential impacts of climate change and the vulnerability of the transport infrastructure to those impacts, and then evaluating feasible and effective adaptation options.

This publication, *Guidelines on Climate Proofing Investment in the Transport Sector: Road Infrastructure Projects* (henceforth *Guidelines*), presents a step-by-step methodology to help project teams incorporate climate change adaptation into transport sector investment projects.

The information presented in this *Guidelines* draws in part from the existing climate change and transport literature and knowledge. It also draws from a number of projects that the team of consultants supported over the course of a year in Cambodia, Solomon Islands, and

Timor-Leste. This operational support allowed the consultants to test tools for designing the adaptation methodology in real-world operations to ensure its relevance to transport sector practitioners.

Part A presents a detailed discussion of the possible impacts of climate change on the transport 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 transport sector. Part C discusses issues pertaining to mainstreaming adaptation into road sector development policy and planning.

Part A: Climate Change and the Transport Sector

The Case for Action

In early 2007, the Intergovernmental Panel on Climate Change (IPCC) released its Fourth Assessment Report.[1] In that report, the IPCC noted that over the past 150 years, global average surface temperature has 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 anthropogenic (human) greenhouse gas concentrations.[2] 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:[3]

- Even if greenhouse gas concentrations were to stabilize at existing levels, anthropogenic warming and sea level rise will continue for centuries to come due to the timescales associated with climate processes and feedback effects.
- Both past and future anthropogenic carbon dioxide emissions will continue to contribute to warming and sea level rise for more than a millennium.
- World temperatures may rise by between 1.1 °C and 6.4 °C during the 21st century, depending on the emissions scenario that is realized (the “best estimate” range is between 1.8 °C and 4.0 °C).
- Sea levels will rise by 18–59 centimeters by 2100, mostly as a result of thermal expansion of the oceans and only partly as a result of a global reduction in snow cover.
- 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 there will be an increase in droughts, tropical cyclones, extreme high tides, and storm surges.

Changes in the frequency and/or intensity of extreme weather events, as well as gradual changes in climate parameters (such as temperature and precipitation), can be damaging to infrastructure.

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1 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. The Fifth Assessment Report is currently under preparation and expected in 2014.

2 In the language of the IPCC, “very likely” stands for “with a probability greater than 90%.”

3 More specifically, these conclusions were presented by IPCC’s Working Group I, which focused on the physical science of climate change.

Direct impacts include damage to structural integrity; indirect impacts may include changes in average and peak demands, which may result in revisions to the operations and capacity of the infrastructure.

In a recent study, the World Bank (2010) estimated the costs of climate change adaptation in developing countries at $75 billion–$100 billion a year over the period 2010–2050. The infrastructure sector alone represents an estimated $15 billion–$30 billion a year over the same period. Roads and urban infrastructure account for most of this estimated adaptation cost. Geographically, more than 50% of this cost is expected to be incurred in South and East Asia and the Pacific.

Vulnerability of the Transport Sector to Climate Change

The transport sector is vulnerable to changes in climate variables, expected changes in the frequency and intensity of extreme weather events, and increased sea level. The following are a few examples of the potential effects:

- Changes in temperature—both a gradual increase in temperature and an increase in extreme temperatures—are likely to impact road pavements (for example, heat-induced heaving and buckling of joints).
- Changes in temperature will also impact the behavior of permafrost and thus the infrastructure lying on permafrost.
- Changes in precipitation and water levels will impact road foundations.
- Extreme weather events such as stronger and/or more frequent storms will affect the capacity of drainage and overflow systems to deal with stronger or faster velocity of water flows.
- Stronger or faster velocity of water flows will also impact bridge foundations.
- Increased wind loads and storm strengths will impact long span bridges, especially suspension and cable-stayed bridges.
- Increased storm surges will significantly impact all components of the coastal transportation infrastructure.
- Increased salinity levels will reduce the structural strength of pavements and lead to precipitated rusting of the reinforcement in concrete structures.

Additional potential impacts of climate change on the transport infrastructure are presented in Table 1.

A growing (albeit still relatively small) number of national, state, and local governments have undertaken systematic assessments of the potential impacts of climate change on their infrastructure in general, and transportation infrastructure in particular. Given its long coastline, Australia has undertaken significant efforts in this direction.[4] Additional efforts were undertaken in selected locations of Canada,[5] Great Britain,[6] New Zealand,[7] and the United States[8] (Box 1).

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[4] See Australian Academy of Technological Sciences and Engineering (2008) and AUSTROADS (2004) for more details.

[5] McCulloch et al. (2002), Andrey and Mills (2003), and Infrastructure Canada (2006).

[6] London Climate Change Partnership (2002).

[7] Jollands et al. (2007).

[8] See for example Smith and Levasseur (2002), Larsen et al. (2008), and Bipartisan Policy Center (2010).

Table 1 Some Potential Impacts of Climate Change on Road Transport Infrastructure

Potential Climate Change	Impacts on Road Transport Infrastructure
Increases in very hot days and heat waves	Deterioration of pavement integrity, such as softening, traffic-related rutting, and migration of liquid asphalt due to increase in temperature (sustained air temperature over 32 °C is identified as a significant threshold) Thermal expansion of bridge expansion joints and paved surfaces
Increases in very hot days and heat waves and decreased precipitation	Corrosion of steel reinforcements in concrete structures due increase in surface salt levels in some locations
Increases in temperature in very cold areas	Changes in road subsidence and weakening of bridge supports due to thawing of permafrost Reduced ice loading on structures such as bridges*
Later onset of seasonal freeze and earlier onset of seasonal thaw	Deterioration of pavement due to increase in freeze–thaw conditions in some locations Reduced pavement deterioration from less exposure to freezing, snow, and ice*
Sea level rise and storm surges	Damage to highways, roads, underground tunnels, and bridges due to flooding, inundation in coastal areas, and coastal erosion Damage to infrastructure from land subsidence and landslides More frequent flooding of underground tunnels and low-lying infrastructure Erosion of road base and bridge supports Reduced clearance under bridges Decreased expected lifetime of highways exposed to storm surges
Increase in intense precipitation events	Damage to roads, subterranean tunnels, and drainage systems due to flooding Increase in scouring of roads, bridges, and support structures Damage to road infrastructure due to landslides Overloading of drainage systems Deterioration of structural integrity of roads, bridges, and tunnels due to increase in soil moisture levels
Increases in drought conditions for some regions	Damage to infrastructure due to increased susceptibility to wildfires Damage to infrastructure from mudslides in areas deforested by wildfires
Increase of storm intensity	Damage to road infrastructure and increased probability of infrastructure failures Increased threat to stability of bridge decks Increased damage to signs, lighting fixtures, and supports
Increase in wind speed	Suspension bridges, signs, and tall structures at risk from increasing wind speeds

* Positive impacts

Source: Adapted from Committee on Climate Change and US Transportation (2008).

Box 1 Impacts of Climate Change on Road Infrastructure in New York and Seattle

New York and Seattle (among other urban and coastal areas in the United States) have been the subject of climate change studies.

In the city of Seattle, the following components of the road infrastructure system were found to be most vulnerable:

- bridges and culverts (from increased mean annual rainfall, rainfall intensity, and sea level rise),
- causeways and coastal roads (from sea level rise and increased frequency and intensity of storm surges),
- pavement surfaces (from increased mean annual temperature),
- surface drainage (from increased intensity of rainfall), and
- hillside slope stability (from increased mean annual rainfall and rainfall intensity).

In the New York metropolitan area, it was found that the transportation systems would be significantly affected by floods and rising water tables, especially because many of the critical transport facilities are in tunnels.

See Cohen, S., W.K. Soo Hoo, and M. Sumitani. 2005. *Climate Change Will Impact the Seattle Department of Transportation*. Seattle, Washington: Office of City Auditor; and Rosenzweig, C. and W.D. Solecki. 2001. *Climate Change and a Global City: The Potential Consequences of Climate Variability and Change—Metro East Coast*. Report for the US Global Change Research Program, National Assessment of the Potential Consequences of Climate Variability and Change for the United States. New York: Columbia Earth Institute.

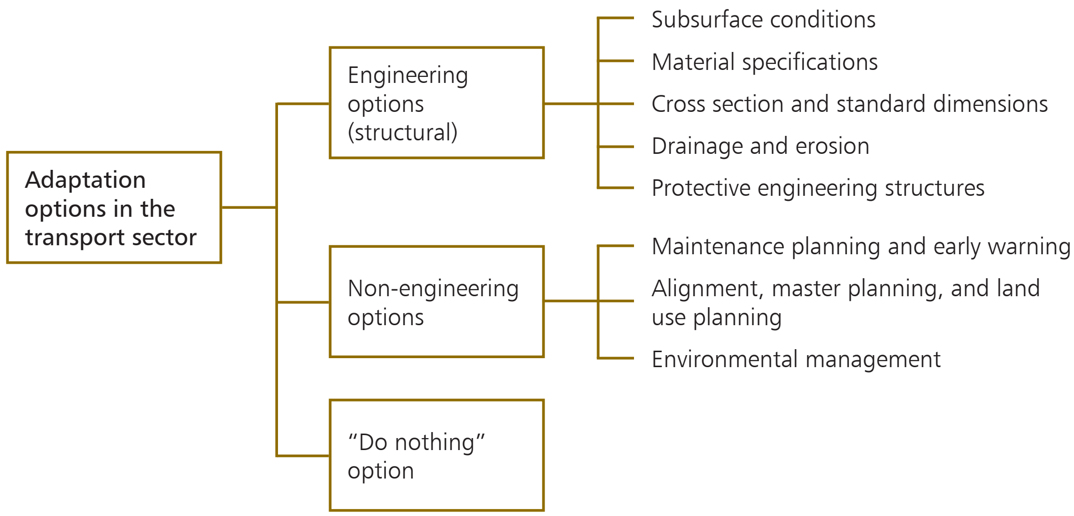
While climate change may have some positive effects on the transport sector, the bulk of the impacts is expected to be detrimental. This thus suggests that impact assessment, vulnerability assessment, and adaptation assessment will increasingly become of crucial importance to guide investments in the sector.

Adaptation Options to Climate Change in the Transport Sector

Adaptation options in the transport sector may generally be grouped into engineering (structural) options and non-engineering options. Each of these options is described in greater detail in Figure 1. Note that a decision not to act, or to maintain a business as usual approach ("do nothing" option) should also be retained as a possible option. In a number of circumstances, findings from the impact, vulnerability, and adaptation assessments may indicate that doing nothing (no climate proofing) is the best course of action.

Adaptation approaches can also be introduced at a number of different entry points. Making site-specific infrastructure adjustments to a road design is often possible within the scope of a given project. However, because projects are often set in terms of location and scope, it can be difficult to introduce less conventional measures such as ecosystem-based measures or alignment review. As such, greater attention needs to be given to the upstream decision-making processes such as transport master planning. This is discussed in further detail in Part C.

Figure 1 Nature of Adaptation Options in the Transport Sector



Source: ADB.

Design Standard Options

Subsurface conditions

The stability of any type of infrastructure crucially depends on the materials on which it is built. In the case of transportation infrastructure, an important factor pertains to the degree of soil saturation and the expected behavior of the soil under saturated conditions. The type, strength, and protection of subsurface conditions and materials may have to be increased to control and prevent soil saturation from damaging transport infrastructure. The composition of the subsurface materials can be adjusted to account for changing climatic conditions. Availability of water for compaction during construction may be an issue in some areas where rainfall is projected to diminish. Melting permafrost may also be a critical factor in some ADB member countries.

Material specifications

All materials have their own set of properties and will exhibit different behavior under different environmental conditions. The strength of these materials may have to be increased to withstand increased or decreased moisture contents. The protection of these materials (for example, against increased moisture and salinity) may have to be enhanced to preserve the expected lifetime of the transport structure, or other materials may need to be used. For example, because of increased salinity, steel reinforcements and culverts may be replaced with less corrosive materials.

Cross section and standard dimensions

The design of each component of the transport infrastructure reflects design standards adopted by the agency that is sponsoring or regulating the infrastructure. Many of these standards are based on field or laboratory studies. These standards tend not to change rapidly and may not be responsive to changes in climate conditions. For example, standards may need to be revised to increase the slope of pavement in areas where one can expect a need to remove more water from the road. Similarly, standards (or guidelines) pertaining to road elevations or the vertical clearance of bridges over waterways may have to be revised upward to withstand more extreme flood conditions (Box 2).

Typical practice is to use historical climate information as a basis for determining engineering specifications. Using forecast data and trends (discussed further in Part B), rather than historical trends, can assist the engineer to design for future climate conditions.

Drainage and erosion

When water represents a key challenge for the design of a given transport infrastructure, then particular attention must be paid to standard designs pertaining to drainage systems, open channels, pipes, and culverts to reflect changes in future expected runoff or water flow. Further, it may be appropriate to include a provision for use of superfluous drainage water for domestic or irrigation purposes.

Protective engineering structures

In the case of coastal roads, protective engineering structures can be used to fend off rising sea levels and storm surges. These may include dikes, seawalls, rocky aprons, breakwater systems, and other structures. However, these systems on their own have often been found to be unstable, as waves hit the walls directly or scour the sandy sea floor and compromise structural integrity (El Banna 2005). For this reason, these measures may yield better results over the long term when combined with softer measures such as mangrove rehabilitation. Further, retaining walls can also be planned for areas where land and mudslides are increasing, with the same caveat that reducing the causes of such events in the first place may be more effective.

Box 2 **Flooding in the Mekong Delta and Rural Road Development in Cambodia**

Many parts of Cambodia already experience regular and severe flooding. Through its *National Communications on Climate Change* published in 2001, the government has produced flood vulnerability maps that identify segments of the ADB transport project area as being priority areas for addressing flood problems.

The transport project aims to rehabilitate and pave 505.4 kilometers of rural roads of 5–6 meters in width to improve rural connectivity to paved national and provincial road networks. The total loan amount is $67 million, of which ADB finances $35 million, with cofinancing from Export-Import Bank of Korea for civil works in the amount of $19.35 million and a $5.4 million grant from the Nordic Development Fund for the climate change adaptation component of the project.

While flooding is a more obvious challenge in the project area due to recent floods, droughts are at the same time getting more intense. A possible adaptation strategy would combine engineering, environmental, and policy-oriented tools to address this increased variability. A combination of measures have been suggested, including (i) elevating vulnerable segments of the road; (ii) using materials that accommodate greater moisture content; (iii) improving flood management through revegetation, using more flood- and heat-tolerant indigenous species; and (iv) developing a vulnerability map and early warning system for the Ministry of Rural Development to use to improve its master planning. Options that conserve and redistribute water from times of excess to times of shortage would complete a package of adaptation measures.

Source: ADB. 2010. *Proposed Loan Kingdom of Cambodia: Rural Roads Improvement Project*. Report and Recommendation of the President to the Board of Directors, Manila.

Non-Engineering Options

Maintenance contracting and early warning

For infrastructure that is already in place, increasing maintenance contingency budgets in areas where climate change impacts are acute will allow more intensive supervision and monitoring of the most vulnerable areas. This can reduce road closures and more serious consequences of disasters. Furthermore, maintenance planning systems can include early warning systems to anticipate extreme events so that crews and contractors can be prepared for an upcoming high rainfall event and possible landslides. On the one hand, this will ensure that forced road closures are kept to a minimum. On the other hand, preemptive road closures may minimize losses of property and life. This suggests the presence of a trade-off between increased capital costs today with less operating expenditures and damages in the future.

Alignment, master planning, and land use planning

Roads influence development patterns. Once a road is built into an area, economic growth and community development are encouraged by this access. It is therefore important to consider whether roads are opening up development in areas that are hazard prone. Melting permafrost areas, for example, are prone to increasing landslides. The location of coastal infrastructure in many cases, including for transportation, needs to be revisited to avoid damages related to sea level rise and increased storm surges.

Where realignment is a plausible adaptation solution to protect transport infrastructure, care must be given to understanding the implications of resettlement of populations and economic activities. Realignment can imply resettling populations in other vulnerable areas, creating another more serious problem.

Such interventions are not easily handled within the scope of a project. Part C discusses entry points for upstream planning issues.

Environmental management

Harnessing the services provided by environmental buffers can moderate the damages from floods, droughts, and landslides. Examples include ensuring increased vegetative land cover and preserving and conserving mangroves, peatlands, and forests, which help to regulate the hydrologic cycle and minimize the severity of floods. Adjustments can also be made to environmental management plans that are usually prepared for road development projects (for example, selecting more drought- and heat-tolerant indigenous species during post-construction rehabilitation works).

Furthermore, it is important to assess and reduce the impact that a road development may have on the region's vulnerability. Environmental impact assessments often focus on the environmental impact of a given road. However this can result in inadvertent maladaptation, such as exacerbating existing floods or droughts, or causing urban heat island effects. This should be assessed at both the project and policy levels.

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, a best course of action may to be 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 presents and discusses a step-by-step approach to assessing the impacts, vulnerability, and adaptation to climate change.

Part B: Climate Proofing Road Investment Projects

Overview

A significant part of climate proofing will take place at the project level to ensure that a project's design is appropriate for changing climate conditions. The development of the adaptation strategy itself is therefore best integrated into the activities of the project preparation technical assistance team, after potential risks to the project due to climate change are identified during the concept stage. This is because the assessment will require specific expertise and budget and may result in revisions to the project design, detailed design activities, and implementation structures.

The methodological approach for assessing adaptation to climate change presented in this *Guidelines* is divided into six different sets of activities and 20 steps as illustrated in Figure E2. The process begins with a rapid screening of the concept note to determine whether a project may be at risk from climate change and ends with defining implementation arrangements and monitoring frameworks. The core activities fall under the categories of impact assessment, vulnerability assessment, or adaptation assessment.

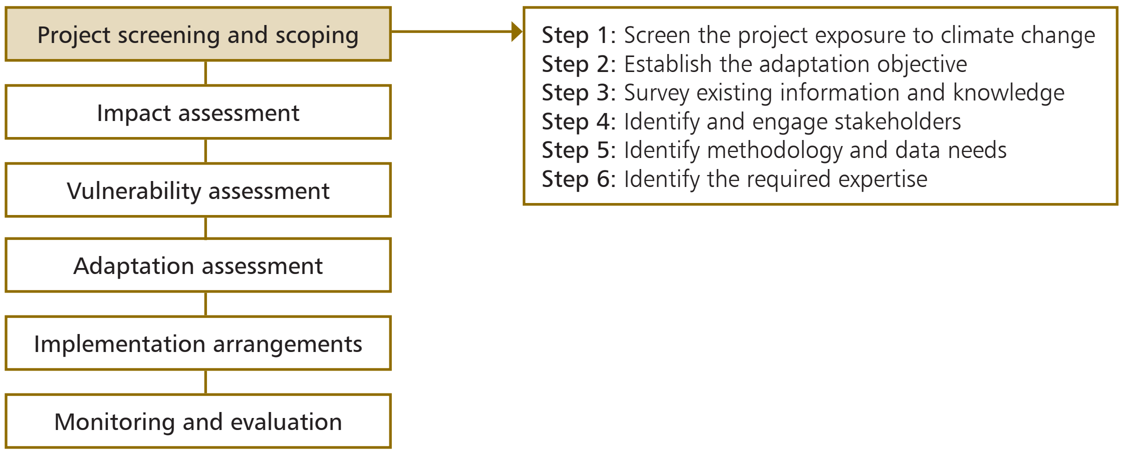
These activities and steps, described in further detail below, are not meant to be prescriptive; they must be tailored to local and sector needs. However, they do present a general framework to organize the information needed to make sound decisions regarding adaptation needs and investments.

Project Screening and Scoping

The goal of project screening in this context refers to determining a project's risk level as a result of climate change.

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

Figure 2 **Project Screening and Scoping**



Source: ADB.

Step 1: Screen the Project Exposure to Climate Change

Risk screening tools have been developed by a number of organizations to rapidly assess the risk 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 exploration is warranted. While different risk screening tools use slightly different approaches, it has been recognized that expert opinion and judgment, based on awareness and knowledge of climate change and hazards, remain essential for all (Box 3).

ADB has developed a project risk screening tool that is being tested by a number of member countries. This tool screens for risks from both climate change and natural hazards. After it is tested, climate change and natural hazards may become a component of the safeguards screening.

Box 3 **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

Dutch Ministry of Foreign Affairs: Climate quick scans, www.nlcap.net

German International Cooperation: Climate check, www.gtz.de/climate-check

World Bank: Climate change 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

Step 2: Establish the Adaptation Objective

A project's needs for adaptation should be considered from two perspectives:

1. The risk that climate change poses to the achievement of the project objective and outcomes; for example,
   - reduced road safety and security due to increased landslides and increased wave height,
   - reduced access and mobility of rural communities to markets due to road closures,
   - unsustainable and costly rehabilitation works as drainage is insufficient for peak rainfall events, and
   - increased maintenance costs due to increases in landslides.

2. The risks the project may pose to increasing the vulnerability of the surrounding area and population, such as
   - increased flooding in surrounding areas due to reduction in permeable surfaces (e.g., caused by newly paved roads);
   - reduced environmental buffers against floods and droughts due to increased access into ecologically sensitive areas;
   - additional strain on already decreasing water resources due to increased population along roads; and
   - increasing urban heat island effect caused by local microclimate influences by paved surfaces.

The adaptation-related objectives should be chosen to minimize these potential effects. Establishing as a starting point how climate change may affect the project objective and outcomes will help ensure that the right data are collected throughout, that the right expertise is recruited from the outset, and that the most appropriate national or local partners are brought into the project.

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 and ensure that coordination efforts within countries and between donors are being supported. Each country has a climate change focal point[9] 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.[10] Least developed countries have also prepared national adaptation programs of action to identify their most urgent adaptation needs.[11] While some of these documents may benefit from being revised and updated, they provide a good basis for identifying country needs and a focal point around which to coordinate the multiple climate change initiatives underway.

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

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

[11] 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

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.[12]

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 all the climate change parameters of most interest to the project should be initiated at the concept stage and can be further developed at later stages. Climate change parameters of interest to road infrastructure include, among others,

- sea level and wave action (for coastal roads),
- precipitation intensity and slope (for mountainous regions),
- peak rainfall events (for designing drainage),
- profiles of past extreme weather events,
- changes to the onset of rainy seasons (for road maintenance and construction scheduling),
- wind speed (for bridge design), and
- changes to snowfall events (for decisions on the need for snow removal equipment).

Specifying these concerns at the outset is important as it will guide the nature 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 and ensure that the needed data are collected during project preparation.

Step 6: Identify the Required Expertise

The assessment of adaptation options requires interaction between different experts (Figure 3). Many of the activities required to develop a climate change adaptation assessment within 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 1 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 only meant to indicate the general nature of the tasks and deliverables that may be required, not to provide a comprehensive list of such tasks and deliverables.

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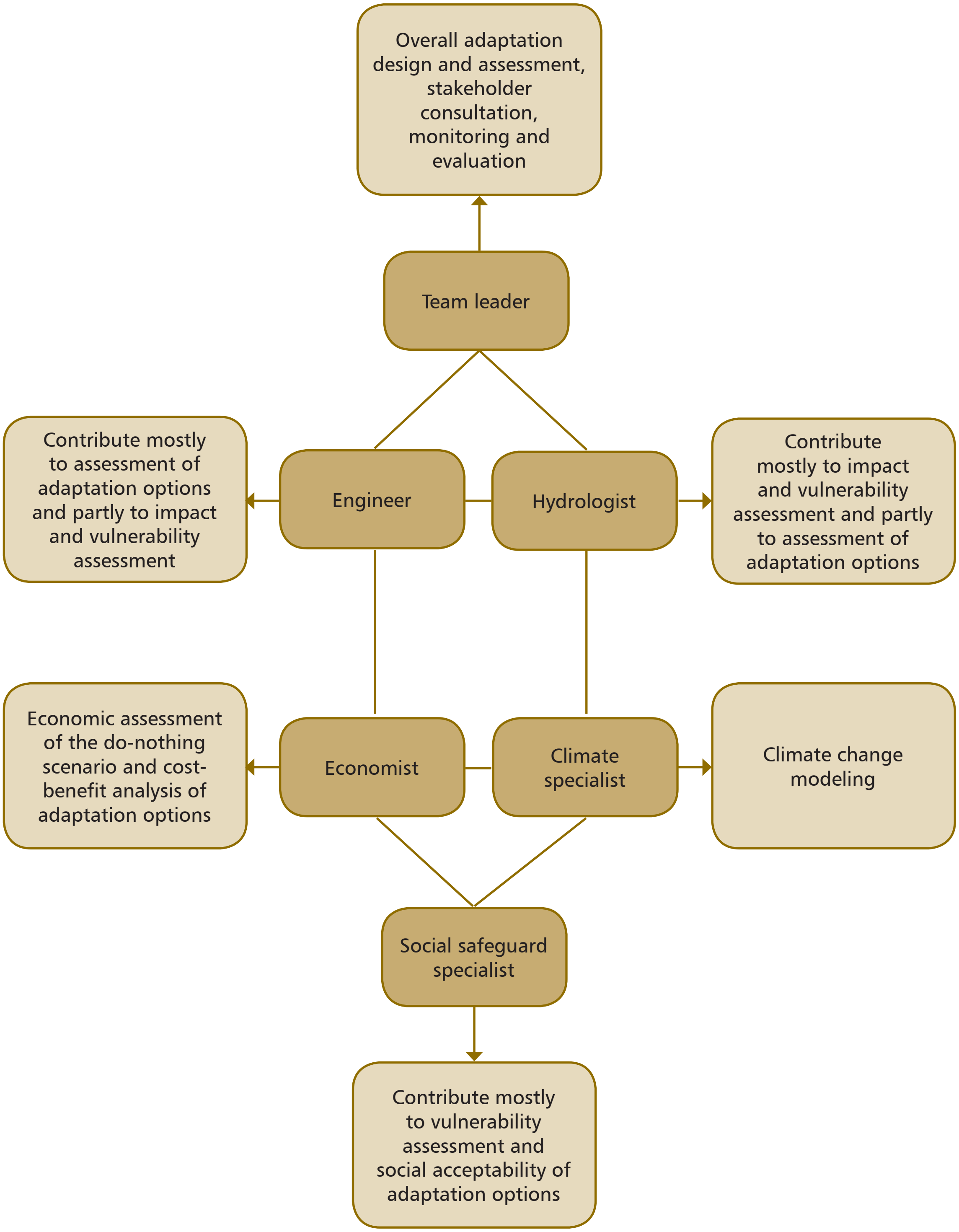
12 These country profiles can be accessed at www.adaptationlearning.net/country-profiles

Figure 3 Assessing Adaptation Needs and Options: A Web of Interaction

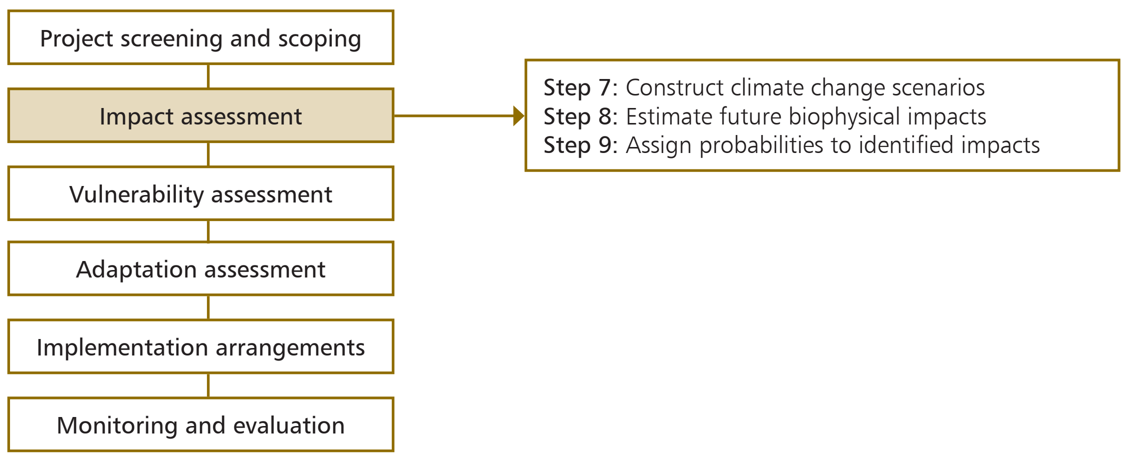


Source: ADB.

Impact Assessment

The goal of the impact assessment is to identify and evaluate, in monetary and/or nonmonetary terms, the effects of climate change on natural and human systems. First, climate projections are used to identify how the climate has changed and is projected to change. Second, the impacts of those changes on systems such as river basin dynamics are assessed.

Figure 4 **Impact Assessment**



Source: ADB.

For any given project, the decision of what types of climate scenarios and projections to develop is based on a number of factors, including the need to account for a wide range of uncertainty, time frames, budget sizes, and data availability. In an increasing number of cases, climate change scenarios have already been developed through national and regional climate change initiatives, such as the national communications to the UNFCCC, and can simply be adapted for use by the project. It is important to begin by identifying whether climate projections are already available, as developing such projections can be costly and time consuming. Also, in some cases, topographical variability is so great that even the most up-to-date climate model experiments would not be able to provide the desired precision or accuracy at the project level (Box 4). 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 projections represent the response of the climate system to emissions or concentration of greenhouse gases. They are 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 greenhouse gas emissions.. Therefore, climate projections are not forecasts or predictions, but provide alternative characterizations of possible future climate conditions. They are helpful in exploring "what-if" questions; they do not aim to provide accurate predictions of how climate will be in the future.

Box 4 Solomon Islands Pilot Project

The Solomon Islands are made up of 6 large islands and 997 smaller islands. The topography is highly variable and mostly mountainous. In an ADB project, design engineers were concerned with ongoing damage to existing infrastructure and wanted to know how floods might be changing for a particular stream crossing along an area in West Guadalcanal. They wanted to determine what engineering changes might be required to adapt a stream crossing for climate change, and how much it would cost.

An assessment by the Ministry of Environment of climate trends from the 1960s to present show that while temperature records show a general warming trend, rainfall records show a downward trend in seven locations where meteorological data had been collected. Satellite records also show a net sea level rise of 7.6 millimeters per year from 1994 up to June 2008 (Solomon Islands National Adaptation Programme of Action 2008).

However, engineers needed to know about projected changes in peak and extreme events, which determine the risk level to build into the project design. No meteorological station exists near the project site and the regional climate models that exist could not capture the topographical complexity of the small islands. Further, little was known about the hydrology of the water basin in question. Hence, impacts of climate change on river flow would also be difficult to capture through modeling. The project team decided to forego detailed climate change projections and impact assessments for this project because the level of detail required could not be met with enough accuracy through existing models. The project team assumed instead a doubling of the annual flood probability. The resulting increase in the height of the stream crossing increased the project cost by 6%, which decision makers felt was acceptable given the current road closures already taking place. It is expected that future maintenance costs can also be kept in check with fewer damages to the stream crossing. Future work through a new project will assess alignment of transport systems across the islands based on vulnerability maps that will be produced.

Source: Solomon Islands Government. 2010. *West Guadalcanal Road Flood Damage Restoration Subproject, Guadalcanal Province. Economic Assessment*. Solomons Island Road (Sector) Improvement Project Feasibility Study, Ministry of Infrastructure Development, Solomon Islands.

The IPCC's Task Group on Data and Scenario Support for Impact and Climate Assessment provides general guidance on the use of data and scenarios in impact and adaptation assessments.[13] The following points provide further information on guiding the development of climate change scenarios.

Identifying the relevant climate variables needed for the impact assessment

The construction of climate change scenarios begins with an understanding of which climate variables are likely to affect the transport project. Individuals creating climate change scenarios need to discuss data needs with the team of experts assessing impacts for the transport 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 change expert then will be in position to determine how to meet the expressed needs for information

Learning from the past: Establishing the climate baseline

Past climate data are generally needed to develop climate projections, given that biases are often found in climate model simulations. Observed meteorological data are also more reliable than climate models when it comes to representing weather variability on the project site. The analysis of historical data not only helps identify trends in the main climatic variables but also allows for the ground-truthing of the simulation results from climate models. Historical climatic data can be used

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

to assess the ability of a given climate model to reproduce local climate conditions (skill score)[14] by verifying 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 measured.

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 transportation projects.

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 of the project site. In many countries, it is common for weather data 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 area needed—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 climate projections from general circulation models: Model selection and downscaling techniques[15]

Climate change scenarios are normally constructed using climate projections from general circulation models (GCMs). 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 the projections 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 a geographic and temporal scale fine enough for many impact assessments at the project level. GCMs typically provide projections at a horizontal resolution of hundreds of kilometers.

Downscaling: From global to local climate projections

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

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14 See for example Tebaldi et al. 2006.

15 See Trenberth et al. 2007 for an in-depth discussion on general circulation models.

There are two main approaches[16] for downscaling: dynamical downscaling (using regional climate models) and statistical downscaling (using empirical relationships). Each downscaling method has its strengths and limitations and the appropriate method 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.

Appendix 2 provides further details on the different downscaling approaches that can be used to construct 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. The most common approach has been to use existing GCMs or regional climate models (RCMs) and apply a simple spatial downscaling technique using local historical climate data. This is a cost-effective option to obtain climate projections for the project site. Given the time, technical expertise, and resources required, building new RCMs or even running new simulations with existing RCMs is generally not advisable within the context of a single project.

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 apparent 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 rise, whereas uplift of the land leads to a relative rise that is less than the global average. Impact assessments in coastal zones normally apply the predicted estimates of sea level rise on coastal areas.

Accurately estimating sea level rise on 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 patterns, (iv) hydrological and meteorological characteristics, and (v) oceanographic characteristics. Using this data, hydrodynamic and/or hydraulic models can estimate the area inundated given a specific assumption about the amount of sea level rise. When available, a detailed assessment on inundation areas with and without flood protection infrastructure can be done. 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.

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

Step 8: Estimate Future Biophysical Impacts

Once climate change scenarios have been constructed, there must be an attempt to quantify the key relationships between changes in climate parameters—such as average temperature, average

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[16] See Wilby and Wigley 1997; Wilby et al. 1998; Wood et al. 2004; and Wilby and Fowler 2011.

precipitation, temperature and precipitation extremes, sea level rise, and storm surges—and impacts on the transport sector. 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 road 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 2). The use of return periods and of changes in return periods aims to attach probabilities or changes in probabilities to extreme weather events.

Additional sources of information for scenario development and impact assessments are presented in Box 5.

Table 2 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

Source: IPCC, 2007.

Box 5 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/orchid

Climate Change Explorer Tool (weADAPT):
http://wikiadapt.org/index.php?title=The_Climate_Change_Explorer_Tool

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

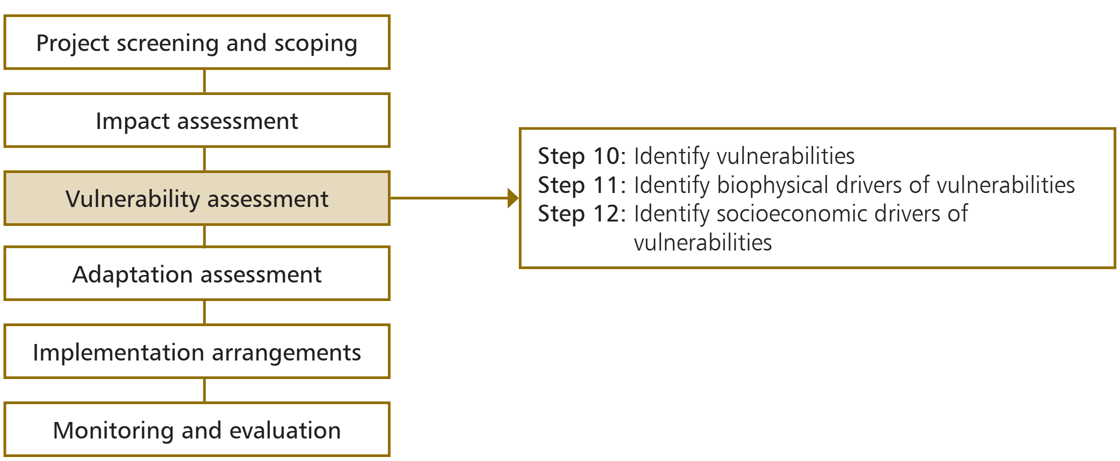
World Bank Climate Change Knowledge Portal: http://sdwebx.worldbank.org/climateportal/

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

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.

Figure 5 Vulnerability Assessment



Source: ADB.

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 adaptive capacity also manifest themselves locally. Indeed, the specific nature and degree of the vulnerability are very much site specific and must be assessed at the specific location of the project site.

As such, identification and assessment of vulnerability at the local level will increase the likelihood that the proposed adaptation measures are relevant. Vulnerability and adaptive capacity are also a result of the interaction between socio-ecological factors and processes such as income level, 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 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, permafrost areas, and desert margins.

Biophysical drivers that may exacerbate damages to roads and stream crossings are potentially numerous and may include

- deforestation and loss of land cover;
- anthropogenic coastal and riverbank erosion;
- overextraction of groundwater for domestic, agriculture, and/or industrial use; and
- ecological degradation caused by unsustainable development.

Using GIS, it is useful 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 a road transport 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); and
- areas in the watershed that are exposed to climate-related hazards, including floods, landslides, and droughts

Maps of the above areas can be overlaid with areas reflecting climate change projections. 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 of sensitive areas due to topography can be overlaid with climate hazard maps to determine the levels of exposure of sensitive areas to climate hazards.

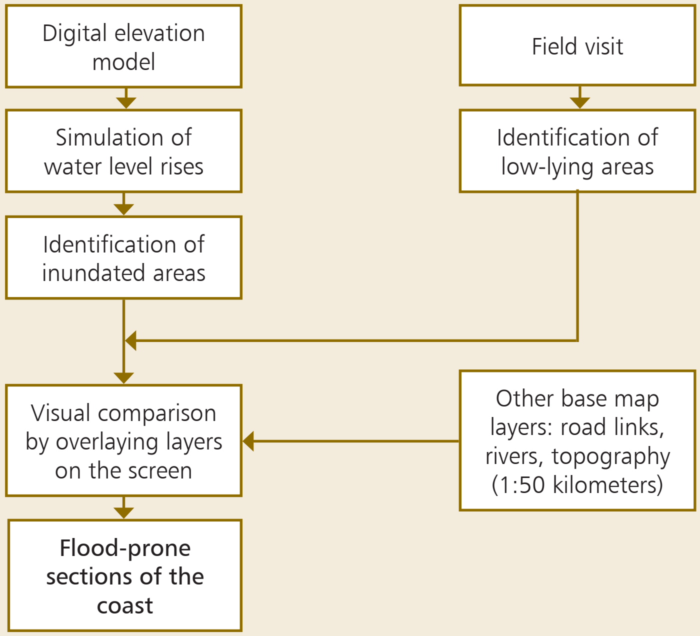
From this type of assessment, it is then possible to develop a significant understanding of the areas and populations most exposed and most vulnerable to climate change. For example,

- land use and land cover maps can be overlaid with vulnerability maps to determine which of the key land use and land cover (i.e., natural forests, cultivated areas, residential areas, others) are vulnerable to climate change; and
- maps of population distribution and vegetation use (e.g., agricultural production) can be overlaid with vulnerability maps to determine which of the current ADB program and project areas in the area are vulnerable to climate change.

Box 6 presents an example of the approach described above.

Box 6 **Assessment of Biophysical Vulnerability in Timor-Leste**

In Timor-Leste, the environmental specialist and the geographic information systems expert produced a map of a road where sea level rise was a concern. This was done using simple digital elevation models and ground-truthing (field visits), overlaid with information on the road in question along with hydrological and topographic information.



Source: ADB.

Step 12: Identify Socioeconomic Drivers of Vulnerability

In addition to biophysical drivers of vulnerability, socioeconomic drivers should be included in the overall vulnerability assessment so as 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 coping capacities. Common indicators of adaptive capacity include human development indices, population density, low levels of economic diversification, and dependence on agriculture for livelihoods. Education levels and literacy rates have also been associated with a population's ability to respond to changes.

While it is important to recognize that climate hazards may change over the lifetime of an investment project, it is equally important to recognize that vulnerability can change. This particularly may be the case in developing countries where socioeconomic conditions are often

Box 7 Consultation in Cavite City, Philippines

Cavite City is surrounded by three bays and is at risk from rising sea levels and tropical cyclones. Other threats linked to climate change include erosion, sedimentation, flooding, and saltwater intrusion into groundwater.

Poor people are most at risk due to their vulnerability to climatic events and social, economic, technological, and institutional disadvantages. Many autonomous adaptation tactics have positive outcomes, but they are inadequate and not effectively integrated into local development plans. They include accommodating sea level rise by building houses on stilts, reinforcing the physical structure of houses, moving to safer places during crises, placing sandbags along the shorelines, and engaging in alternative income-generating activities.

Some government strategies (relief assistance, resettlement, shoreline protection, etc.) have reduced the vulnerability of coastal households, but the measures are considered to be insufficient at best, inadequate at worse, and costly. Consultations revealed that communities feel they only have poor to fair human, physical, and financial capacities to face the threat of climate change. People expressed significant concerns over climate risks and proposed several adaptation strategies, many of which were nonstructural, capacity-building measures, that include the following:

Improved knowledge management, such as community-based monitoring of changes in coastal areas for input into vulnerability and adaptation assessments; creation of community early warning systems; and documentation, sharing, and promotion of traditional knowledge, skills, and practices that enhance adaptation.

Policy and institutional reforms, such as developing an integrated coastal zone management plan that includes land and sea use zoning, alternative livelihood development and eco-waste management, and providing secure property rights and microfinance schemes that enhance the adaptive capacity of vulnerable groups.

Capacity development through raising awareness; participatory risk and adaptation assessment and planning; alternative livelihood development, and creating a multisector integrated coastal zone management body.

Source: International Institute for Environment and Development. 2007. *Community-Based Adaptation–IIED Briefing*.

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 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 7). As indicated earlier, the involvement and awareness of local communities in identifying vulnerability and adaptation options contribute to the community acceptance of project activities.[17]

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 can contribute to decision making in terms of selecting adaptation strategies, which are not always easily quantifiable.

Box 8 **Additional Resources on Community Participation**

ADB Consultation and Participation Toolkit. www.adb.org/participation/toolkit.asp

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. These are specifically developed to assist community-based programs and provide adaptation options to farming practices and sustainable livelihoods. www.cristaltool.org

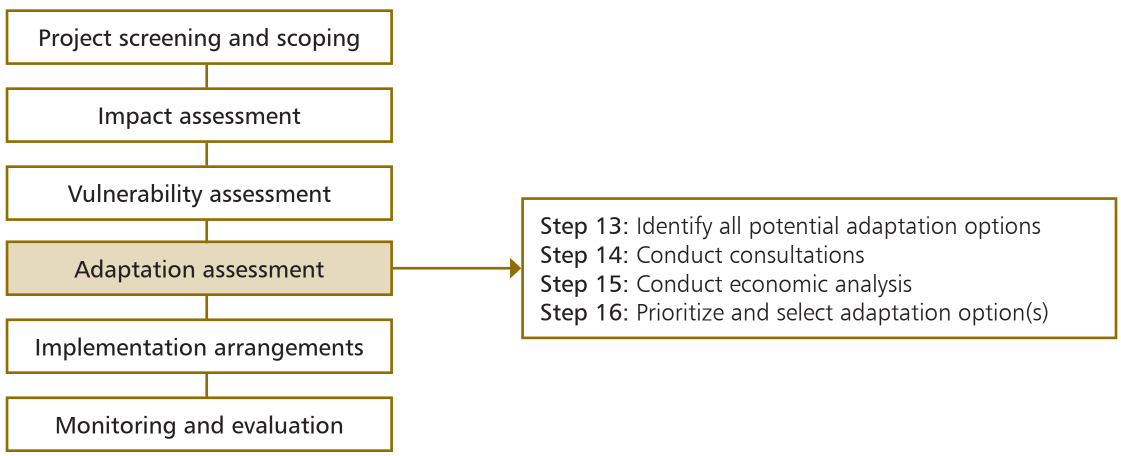
International Institute for Environment and Development website. www.iied.org

[17] The ADB manual on consultation and participation tools, techniques, and templates offers further specialized information on this subject and can be found at www.adb.org/participation/toolkit.asp. 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.

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.

Figure 6 **Adaptation Assessment**



Source: ADB.

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 3 contains some examples.

It is also important to recognize that in some cases, the best adaptation option(s) may be beyond the scope of an existing project or beyond the authority of a given line ministry such as a transport ministry. For example, realigning roads away from floodplains may be the most appropriate option in some situations, but may be difficult to address at the project stage. Similarly, watershed reforestation may be the most appropriate option in some situations, but may fall outside the scope of authority of a ministry of transport. These should be taken up as part of an upstream planning process and can be flagged for such higher-level discussions. This is discussed in greater detail in Section C.

Step 14: Conduct Consultations

As may be understood from the partial list of adaptation options presented in Table 3, 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.

Table 3 A Range of Adaptation Options

Climate Issues	Potential Adaptation Options
Sea level rise and storm surges	• Monitoring of certain roads that may be submerged • Using suitable materials and providing lateral protections • Raising the level of the road • Constructing levy bank with drainage/seawall • Road realignment • Increasing maintenance budget • Including additional longitudinal and transverse drainage systems • Protecting levy bank with suitable mangroves • Planting artificial reefs • Replacing metal culverts with reinforced concrete
Reduction in rainfall or increased erosion	• Using flexible pavement structures • Increasing maintenance budgets to clear dust and landslides • Increasing water retention capacity and slow infiltration through environmental measures and bioretention systems to recharge aquifers and reduce surface flow runoff • Revegetating with drought-tolerant species • Mulching • Using matting/erosion control blankets • Applying granular protection • Moistening of construction materials • Obtaining the optimum level of compaction (to avoid any subsequent settlement) • Ensuring the selection of materials with high resistance to dry conditions
Increase in precipitation	• Applying a safety factor to design assumptions • Reducing the gradients of slopes • Increasing size and number of engineering structures (hydraulic structures, high river crossings) • Increasing water retention capacity and slow infiltration through natural or bioengineered systems • Raising pavement and adding additional drainage capacity • Increasing monitoring of vulnerable roads in order to prevent disasters • Using water capture and storage systems • Realigning natural water courses (river training) • Enclosing materials to protect from flood water (i.e., impermeable linings) • Using materials that are less affected by water • Allowing for alternative routes in the event of a road closure
Increased wind strength	• Modifying the design of supports and anchorages • Installing protection systems such as windbreaks • Planting coastal forests and mangroves

Source: ADB.

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.[18]

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 (arguably more so than any other exogenous factors impacting a project's costs and benefits) requires paying particular attention to the treatment of risk and uncertainty.

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.[19] 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 3 earlier, 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 transport infrastructure if no adaptation measures were in place?
- **Scenario 2**: What are the *expected* impacts of future climate change on the transport infrastructure 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. The cost-benefit analysis of alternative adaptation options should account at least for the following three important factors:

- While all adaptation options shall aim to climate proof the transport infrastructure, 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 the transport infrastructure from landslides may also deliver fruit crops, or the planting of mangroves to protect a road from storm surges 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 shall aim to climate proof the transport infrastructure, some adaptation options may do so at the expense of other sectors of the economy. For example, a floodwater diversion option may keep the transport infrastructure functional but increase flooding in another area. These impacts, whether intentional or not, need to be accounted for in the cost-benefit analysis.

[18] See Boardman et al. (2005) for a description of the stepwise process.

[19] See for example Mechler (2005).

- 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.[20]

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 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 when recommending the adoption or rejection of an adaptation option.

A key advantage of sensitivity testing is that it is extremely easy to conduct.[21] 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 by 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

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

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

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. 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.[22] 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.

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 transport infrastructure 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.[23]

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:

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

[23] 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.

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. Box 9 presents an example of economic analysis of adaptation options applied in Timor-Leste.

Box 9 Economic Analysis of Road Upgrade Project in Timor-Leste

In a road upgrade project where the sole identified benefit of an adaptation measure was a reduction in future road expenditures for both operations and maintenance and rehabilitation (O&M/REHAB), the economic analysis proceeded along the following steps:

Step 1: Looking into the future, specify the expected annual O&M/REHAB regime and expenditures that will be needed to maintain the road to a given desired standard for each year of its useful life (for example, "the drainage works and surface materials are specified to withstand a maximum extreme precipitation event of 5 inches [12.5 cm] per hour") *without climate change*. In the absence of climate change, past O&M/REHAB regime and expenditures may provide a reasonable basis for assessing future O&M/REHAB regime and expenditures.

Step 2: Looking into the future, estimate the expected annual O&M/REHAB expenditures for each year of the useful life of the road *with* climate change, but assuming *no* adaptation. In circumstances where climate change is expected to increase the need for road maintenance, O&M/REHAB expenditures would generally be expected to increase.

Step 3: Compute the cost of climate change as the difference between the present value of the O&M/REHAB expenditures without climate change and the present value with climate change.

Cost of climate change =
present value of O&M/REHAB expenditures with climate change –
present value of O&M/REHAB expenditures without climate change

Step 4: Identify all sets of adaptation measures that may prevent or avoid some or all of the projected cost of climate change, as identified, quantified, and monetized above. While these adaptation measures may be structural (e.g., wider drainage work, elevated roads and bridges, sea dykes, etc.), also consider the possibility of bioengineering options (e.g., reforestation of a denuded hill or watershed).

Step 5: Quantify and monetize the impact of the identified adaptation measures on the "cost of climate change." This monetized impact (avoided cost of climate change) will represent the present value of the expected benefits of the adaptation measures.

Step 6: Assess the present value of the cost of the adaptation measure itself.

Step 7: Calculate the net present value of the adaptation measure. Recommend adoption if the NPV of the adaptation measure is positive; reject the measure otherwise. If more than one adaptation measure delivers a positive NVP, recommend the adaptation measure with the highest NPV.

Source: ADB.

Step 16: Prioritize and Select Adaptation Option(s)

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

Box 10 Additional Resources on Adaptation Learning

Adaptation Learning Mechanism. www.adaptationlearning.net

weAdapt Knowledge Base. www.weadapt.org/knowledge-base/guidance/knowledge-base

United Nations Framework Convention on Climate Change (UNFCCC) compendium of methods and tools to assess impacts, vulnerability and adaptation to climate change. http://unfccc.int/adaptation/nairobi_workprogramme/knowledge_resources_and_publications/items/5457.php

UNFCCC database of local coping (adaptation) strategies. http://maindb.unfccc.int/public/adaptation

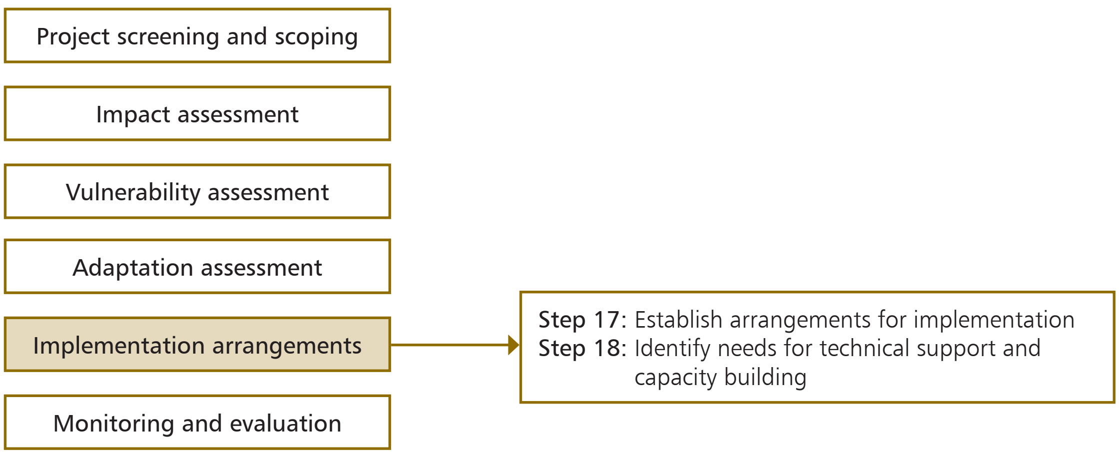
Implementation Arrangements

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

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 transport sector project (such as the Ministry of Transport, Ministry of Rural Development, or Ministry of Construction), 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. As flooding is often a key impact on roads, national disaster preparedness committees may have a role to play. Likewise, many of the “low-risk” adaptation strategies, such as improved watershed management or mangrove rehabilitation to protect coastal roads, will require engagement of land management and forestry experts and organizations.

Figure 7 **Implementation Arrangements**



Source: ADB.

In all cases, introducing a climate change lens to a project 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.

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 the Ministry of Transport. This adds further reasons for addressing adaptation at the earliest stages of policy and strategy development, as will be discussed in Section C.

Step 18: Identify Needs for Technical Support and Capacity Building

Experience indicates that the capacity and awareness required to manage 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.

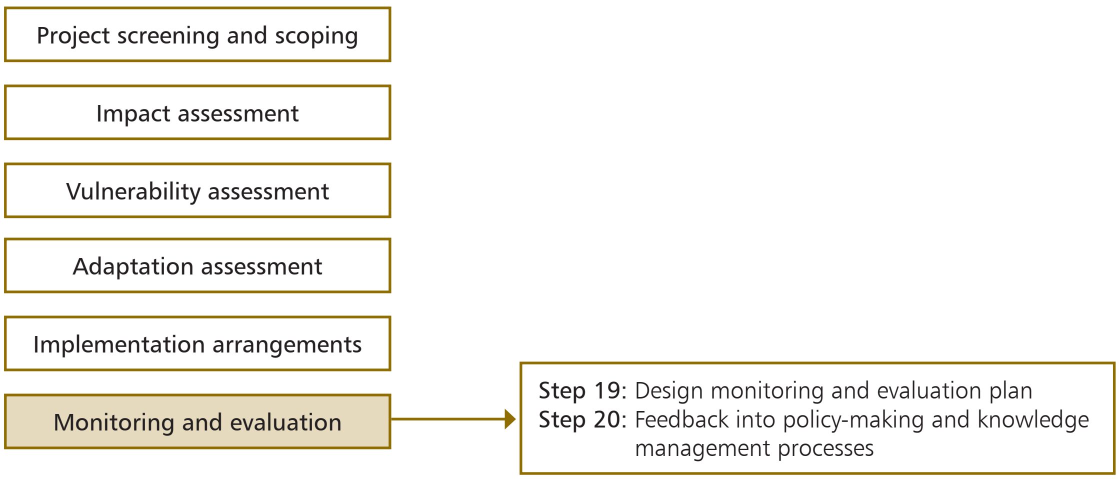
Monitoring and Evaluation

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

Step 19: Design Monitoring and Evaluation Plan

There is little experience worldwide in understanding how effective the different options to reduce vulnerability to climate change actually are, making monitoring and evaluation all the more

Figure 8 **Monitoring and Evaluation**



Source: ADB.

important to develop this knowledge. There are a number of challenges in doing so, 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.[24]

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.[25] Table 4 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 robust.

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 in Part C.

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

[25] www.adb.org/Documents/guidelines/guidelines-preparing-dmf/guidelines-preparing-dmf.pdf

Table 4 Example of Indicators for Measuring Adaptation Results in Transport Projects

Indicator Type	Indicator
Impacts (long-term effect)	• Increased robustness of infrastructure design and long-term investment development • Increased resilience of vulnerable natural and managed systems, such as flood management
Outcomes (process indicators)	• Percent reduction in road closures due to landslides or flooding • Percent reduction in flooding where drainage capacity has been increased • Improved decision making and sector planning based on climate change considerations
Outputs	• Transport sector planning documents include adaptation strategies • Length of road constructed to withstand climate change impacts • Area of mangrove planted to protect coastal roads

Source: ADB.

Part C: Building Adaptation Strategies 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 (such as between meteorological focal points and transport focal points), 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.[26] 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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[26] For example, see the following guidelines:

1. 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
2. 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
3. Adaptation Fund: http://adaptation-fund.org/policies_guidelines

Also see UNFCCC Decision 5/CP.7, http://unfccc.int/files/cooperation_and_support/ldc/application/pdf/13a01p32.pdf

National and Sector 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 transport 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 transport, and for infrastructure development generally, guidance intended to strengthen cross-sector cooperation between ministries can be very helpful. For instance, flood management around critical transport infrastructure can be better managed between ministries of water and hydrology, meteorology, and transport. 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; their effects require regional coordination, such as that seen 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. For the transport sector, this may have implications on the modes of transport selected, the resources available for additional climate-proofing activities, and the tools available for screening climate risks in project selection (Box 11).

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 transport sector. There is, however, little detailed experience at the policy level to draw from, with few transport ministries going beyond awareness raising and research (Gallivan et al. 2009).

Transport planning sets out the goals and priorities for transport infrastructure development, maintenance, and decommissioning. A number of planning factors, or objectives, are often established, such as to increase the transportation system's safety for motorized and non-motorized users; increase the accessibility and mobility of people and freight; protect and enhance the environment; promote energy conservation; improve the quality of life; promote consistency

Box 11 **Applying a Climate Lens**

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

- the extent to which the policy, strategy, regulation, or plan under consideration could be vulnerable to risks arising from climate variability and change;
- the extent to which climate change risks have been taken into consideration in the course of program formulation;
- 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
- 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 downsteam actions.

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

between transportation improvements; and promote efficient system management and operation (Gallivan et al. 2009).

Incorporating adaptation considerations into, for example, transport master plans will further secure the likelihood of meeting the given transport-related objectives and may also identify new priorities. The simplest way for a transport plan to incorporate climate change adaptation is to acknowledge the relationship between climate change impacts and the plan's goals, such as safe and effective road networks. The structure of this incorporation will vary from case to case. It may include stand-alone components within the transport strategy, such as conducting a climate change risk assessment for each project identified, or involve incorporating climate change adaptation within other sub-goals of the transport plan, such as increasing the height of stream crossings along vulnerable coastal areas.

Challenges faced by 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 inefficiency—will provide only a temporary and superficial fix. Transport sector ministries will need to coordinate more effectively with other line ministries in dealing with climate change these issues. There are a number of options for doing this:

- Establish or enhance cross-ministerial committees for managing adaptation to climate change, including for transport.
- Strengthen departments of disaster risk management and meteorology to improve information on which to make decisions.
- Introduce early warning and response systems for transport ministries to improve maintenance schedules and to respond quickly to post-disaster recovery needs.
- Promote low-risk 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 transport sector or, preferably, as part of the national standards. Transport ministries can test tools and adaptation approaches by applying strategic environmental assessments with climate change to their sector policies and plans.

Further, transport 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 transport infrastructure (for example, to avoid flood or permafrost zones).
- Design flexible transport infrastructure that can accommodate incremental changes over time.
- Incorporate climate change indicators into transport planning budgeting frameworks to ensure accountability.

A useful summary of policy options for adapting the transport sector to climate change was developed by the Bipartisan Policy Center (2010). It is summarized in Table 5.

Table 5 Policy Options for Adapting the Transport Sector to Climate Change

Research/Policy Overview	Policy Description
Develop appropriate model outputs	Integrate climate data and projections, and more information about the likelihood and extent of extreme events, into transport planning.
Inventory assets	Inventory transport infrastructure and locations that are vulnerable to climate impacts.
Identify secondary impacts	Conduct research on demographic responses to climate change and land use interactions, and how these responses impact the transport sector.
Support decision making	Provide modeling and adaptation planning tools to local governments to help identify vulnerabilities.
Coordination and collaboration	Facilitate and support cross-disciplinary coordination and collaboration among the public sector, private sector, and local stakeholders to assess impacts, vulnerabilities, and adaptation options.
Emergency preparedness planning	Develop climate change strategies to integrate emergency response into transport infrastructure design and operations.
Expand planning timeframes	Transport agencies need to incorporate the effects of longer-term climate change into their planning processes.
Refine risk analysis tools	Planners/engineers require support to develop and use probabilistic techniques in risk analysis tools to address uncertainties that are inherent in projections of climate phenomena.
Land use	Work with appropriate agencies to influence land use decisions and avoid inappropriate development in high-risk areas.
Develop risk assessment and adaptive management approach	Adopt an iterative risk management approach to provide transport decision makers a more robust picture of the risks to various components of the transport network.
Develop new design standards	Develop new design standards and codes to incorporate projected changes in climate conditions.
Update regulations	Require climate change adaptation screening in environmental impact assessments.
Institutional changes	Make institutional changes to facilitate integration of climate change impacts into the decision-making process for transportation planning and investment.
Assessment of costs and benefits	Provide guidance to identify opportunities for adaptation and to assess cost estimates and benefits for adaptation initiatives and programs.
Performance measures	Develop performance measures to inform prioritization and decision making on adaptation approaches and projects.

Source: Bipartisan Policy Center. 2010. Transportation Adaptation to Global Climate Change. Washington, DC.

Conclusions

This publication has presented a step-by-step approach to help project teams incorporate climate change adaptation into transport sector investment projects. The steps are based on ADB's experience to date on climate proofing transport projects, and these guidelines may change as experience evolves. Though it is premature to offer conclusions, the points below should help guide ADB and its partners toward developing and implementing climate-proofed projects.

- **Additional and predictable financing** is needed to support approaches that seek 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. Proposals by the Adaptation Fund Board[27] to support projects and programs, as well as budget support pilots underway by some donors, will be important models to monitor and assess how these approaches might influence future financing architecture for adaptation. Fully integrating adaptation assessment activities into the project development cycle, such as is proposed in this publication, will often require the project officer to raise additional cofinancing for transport projects, preferably in the form of grants.

- **Holistic adaptation solutions are cross-sector.** Sector-based approaches have their limits, and regional ecosystem-based assessments and analysis are needed to influence integrated planning for infrastructure such as roads. Given that 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. When working with line and sector ministries, support should also be extended to strengthen the ability of often-weaker environment ministries to participate within their given mandates. This strengthens climate change adaptation efforts throughout the whole government rather than single ministries.

- **Adaptation is characterized by decision making under uncertainty**. Uncertainties associated with climate science and socioeconomic trends requires a pragmatic, participatory, and flexible approach to constructing scenarios and assessing impacts, vulnerability, and adaptation. Adaptation policies, strategies, and options would be more robust with a certain level of flexibility to take advantage of new developments in climate science and technology.

[27] The Kyoto Protocol Adaptation Fund has been established by the parties to the Kyoto Protocol to fund concrete adaptation projects and programs. http://afboard.org/index.html

- **Mainstreaming adaptation into the transport sector should take place at the national, sector, and project levels.** Each level has a specific role to play in addressing planning, budgeting, and community-level vulnerability issues. There is value in conducting sector-specific assessments, as each sector will have its own challenges under a climate change lens. There is a need for sector experts themselves to develop practical climate proofing experience.

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Appendix 1
Draft Terms of Reference

Sample Additional Activities for Project Preparation Team Members

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 ADB technical note, *Climate Proofing Investments in the Transport Sector: Road Infrastructure*, may serve as a useful guide.

The results of the assessment should be fully incorporated into the project design including the detailed engineering design, environmental management plan, social safeguard measures, monitoring and evaluation framework, and budget. 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)

- Oversee and coordinate the implementation of the draft strategy for vulnerability, impact, and adaptation assessments.
- Identify and discuss the adaptation objective with all relevant stakeholders
- Synthesize vulnerability and impact information collected by other members of the team into the decision matrix provided by ADB.
- 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).
- Recommend adaptation options in a presentation to the government, ADB, and other relevant stakeholders.
- Ensure integration of adaptation components into the project design.
- Identify additional training needs, indicators for monitoring, and budget for adaptation components as needed.

Civil Engineer (International, 1.0 person-month)

- Identify adaptation engineering options and those costs for the project.
- Assist other team members in identifying all benefits of the adaptation options from an engineering perspective.

- Prepare revisions to engineering designs, taking climate change into account.
- Recommend to ADB adjustments and improvements to support development of a replicable model to be used in the project and in the future.
- Contribute specialist advice including preliminary designs and cost estimates.
- Prepare technical documentation, including engineering design and specifications that include adaptation considerations.

Economist (International, 1.0 person-month)

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

Environmental and Social and Poverty Specialist (International, 1.0 person-month)

- Identify the climate parameters of concern for the project, including but not limited to changes of precipitation, temperature regimes, and elevation of coastline.
- Conduct a vulnerability assessment in the project area to identify vulnerability of the planned infrastructure as well as the project's potential effects on the vulnerability of the area and people.
- Coordinate the climate impact assessment with assistance from a climate modeler and in coordination with the team hydrologist.
- Facilitate participation of government counterparts in ongoing capacity-building activities to ensure skills transfer for improved sustainability of designs.
- Conduct community and expert consultations to verify and refine selected adaptation options.
- Revise the environmental management plan in line with findings.
- Assist the economist in estimating the life-cycle project costs and benefits of climate change adaptation options, including socioeconomic and environmental benefits.
- Assist the project manager in adjusting the project design to incorporate climate change adaptation.
- Provide recommendations and suggestions for environmental or nonstructural adaptation interventions.

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

- Facilitate participation of government counterparts in ongoing capacity-building activities to ensure skills transfer for improved sustainability of designs, and identify additional training needs.
- Undertake initial poverty and social assessment, including field assessment of vulnerability to climate change.
- Collect existing impact assessments and reports and prepare a summary of existing information and potential gaps.

- Collect all relevant climate change data from government ministries and international and community organizations.
- Identify potential adaptation options.

Hydrologist (National, 1.0 person-months)

- Undertake hydrological assessments under various climate change scenarios.
- Produce flood and drought maps and hot spots for current and future scenarios.

Terms of Reference for Impact Assessment Specialist

Objective/Purpose of the Assignment

Based on available and relevant information, conduct a desktop assessment of anticipated climate change impacts on a selected transportation project, using various and integrated impact assessment techniques.

Skills Required

It is preferable that this contract is implemented by a team of consultants with expertise in climate change modeling (including downscaling techniques) and hydrological modeling, and who have the engineering/economic knowledge to prepare impact assessments in the relevant sector.

Scope of the Work

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

- change in onset and intensity of seasonal rains;
- increase in very hot days and heat waves;
- sea level rise;
- increase in intensity and frequency of extreme weather events;
- changes in seasonal precipitation and flooding patterns; and
- increase in cyclone intensity, frequency, and duration, and associated storm surge and wave action.

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

Detailed Tasks

- Review the project preparation technical assistance and of the climate change adaptation methodology prepared for the project.
- 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.

- Survey the existing information, such as relevant climate change projections and local historical climate data. 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 those that would be representative of this entire range. Identify any need for further modeling, or where existing modeling is sufficient for the project, prepare a short synthesis report.
- Identify the probabilities of specific climate change occurrences and the level of certainty. Identify assumptions and limitations of using the projections for influencing project design.
- Formulate downscaled climate change scenarios for the time horizon of the project, specifying the technique used for downscaling.
- Identify possible technical gaps that limit the development of climate change projections for the country.
- Submit for review and approval a draft outline of the analysis to be undertaken, including recommended methodology for impact assessment (e.g., hydrological modeling, stating clearly the climate scenarios and impact models to be used in the analysis and a justification for their choice).
- Provide an expert opinion on the probability of further climate change research altering the project design protocols or operations requirements, including master planning.
- Submit a draft report for review.
- 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 of a system's vulnerability to climate changes and existing trends in climate.

Skills Required

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

Scope of the Work

The goal of the vulnerability assessment is to identify existing vulnerabilities and coping strategies. A vulnerability assessment attempts to identify the root causes of a system's vulnerability to climate changes. This includes collecting and analyzing raw and observational data of current practices to compensate for vulnerability. (Note: Local nongovernment organizations may be appropriate partners for conducting local consultations.)

Detailed Tasks

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

Final Outputs

- A vulnerability and risk map based on geographic information systems.
- Report containing a summary of key observable vulnerabilities, sensitivities, coping strategies, and needs.

Size of Contract

- 1.0 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 climate adaptation options related to the project and to highlight findings to ADB for future work (optional).

Skills Required

The consultant is expected to have a multidisciplinary environmental or natural resource management background and a good understanding of the social and economic aspects of vulnerability. (Note: This work can often be led by the environmental specialist with inputs from other technical assistance 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 for the purpose of moderating harm or exploiting 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

- Identify all potential adaptation solutions, including soft and hard measures.
- Conduct multistakeholder consultations to identify and confirm all options, including their costs, benefits, and risks.

- Based on tasks 1–3, evaluate adaptation measures and options for the proposed road rehabilitation project in conjunction with the executing agency, technical assistance team economist, road engineer, and poverty reduction expert to provide an economic assessment of adaptation options and to define co-benefits for other aspects of development.
- Organize a second consultation meeting with the project executing agency and other stakeholders to seek agreement on prioritized adaptation measures to undertake during project implementation.
- Incorporate selected adaptation priorities into the project design, including institutional arrangements and budget.
- Identify any additional capacity building required for the project implementation unit.
- Identify indicators to monitor reductions in vulnerability and sustainability of adaptation measures in the context of the project implementation.

Final Output

- Synthesis of the results from the impact assessment, vulnerability assessment, and economic analysis. Recommendations should be included in this report.
- 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 transport infrastructure under consideration. This study aims to inform project officers and policy makers with respect to the desirability (from an economic point of view) of investing into adaptation, and to assess and rank adaptation options with respect to their economic outcomes (using net present value as the preferred criterion to undertake this ranking).

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

- Prepare a detailed review of the relevant historical records and data, especially those pertaining to direct damages to road infrastructure, indirect impacts resulting from the damaged road infrastructure, and repair costs.

- Provide a list of alternative adaptation measures that 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.
- Identify data sets that can be used to implement the objectives of the study.
- Prepare a detailed framework (tasks, activities, responsibilities, timelines) for the successful implementation of the study.
- Prepare a report early in the study to identify possible means by which the expected impacts of adaptation measures may be modeled, along with their possible costs and benefits, 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

- 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.
- Based on historical data and the study information, provide an estimate of the benefits and costs of adaptation for each possible adaptation measure.
- Based on the outcome of the analysis, make recommendations pertaining to the adoption of adaptation measures in the context of the project.

Final Output

Analysis and report on the costs and benefits of potential adaptation measures to climate proof the road infrastructure of interest, along with recommendations for prioritizing the adaptation measures.

Size of Contract

- 1.0 person-month

Appendix 2

Climate Downscaling and Projection Methods and Requirements

Dynamical downscaling or **regional climate models** (RCMs) simulate climate using processes similar to global climate models (GCMs) but at much finer scales (10–50 kilometers). GCM outputs are used as boundary conditions for regional climate models (RCMs). The primary contribution of RCMs is the inclusion of more realistic topographic and land cover features, which is not included in great detail in GCMs. These models are computationally intensive and costly. They are not recommended at the project level due to their expense 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. It relies on determining statistical relationships between large-scale atmospheric variables and local response variables, such as daily precipitation measured at weather stations. Changes in the large-scale variables projected under climate change (as simulated by GCMs) can be translated into changes in the local variables through the statistical relationships. 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, and depends on the statistical relationships established under current climate conditions, which may be invalid under a future changing climate. There are two types of statistical downscaling, *spatial* and *temporal*.

- *Spatial downscaling* is possible through a variety of empirical/statistical methods (linear interpolation, krigging, 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 used for climate change downscaling include weather generators, among others.
- *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. Other techniques are also used, such as stochastic weather generators.

Guidelines for Climate Proofing Investment in the Transport Sector
Road Infrastructure Projects

This publication, Guidelines for Climate Proofing Investment in the Transport Sector: Road Infrastructure Projects, aims to present a step-by-step methodological approach to assist project teams to incorporate climate change adaptation measures into transport sector investment projects. While the focus of the publication is on the project level, an improved understanding of climate change impacts should also be used in the design of infrastructure planning and development policies and strategies to ensure appropriate resource allocation. Though the transport sector includes roads, waterways, rails, and airborne transport, this publication focuses solely on road infrastructure.

About the Asian Development Bank

ADB's vision is an Asia and Pacific region free of poverty. Its mission is to help its developing member countries reduce poverty and improve the quality of life of their people. Despite the region's many successes, it remains home to two-thirds of the world's poor: 1.8 billion people who live on less than $2 a day, with 903 million struggling on less than $1.25 a day. ADB is committed to reducing poverty through inclusive economic growth, environmentally sustainable growth, and regional integration.

Based in Manila, ADB is owned by 67 members, including 48 from the region. Its main instruments for helping its developing member countries are policy dialogue, loans, equity investments, guarantees, grants, and technical assistance.

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