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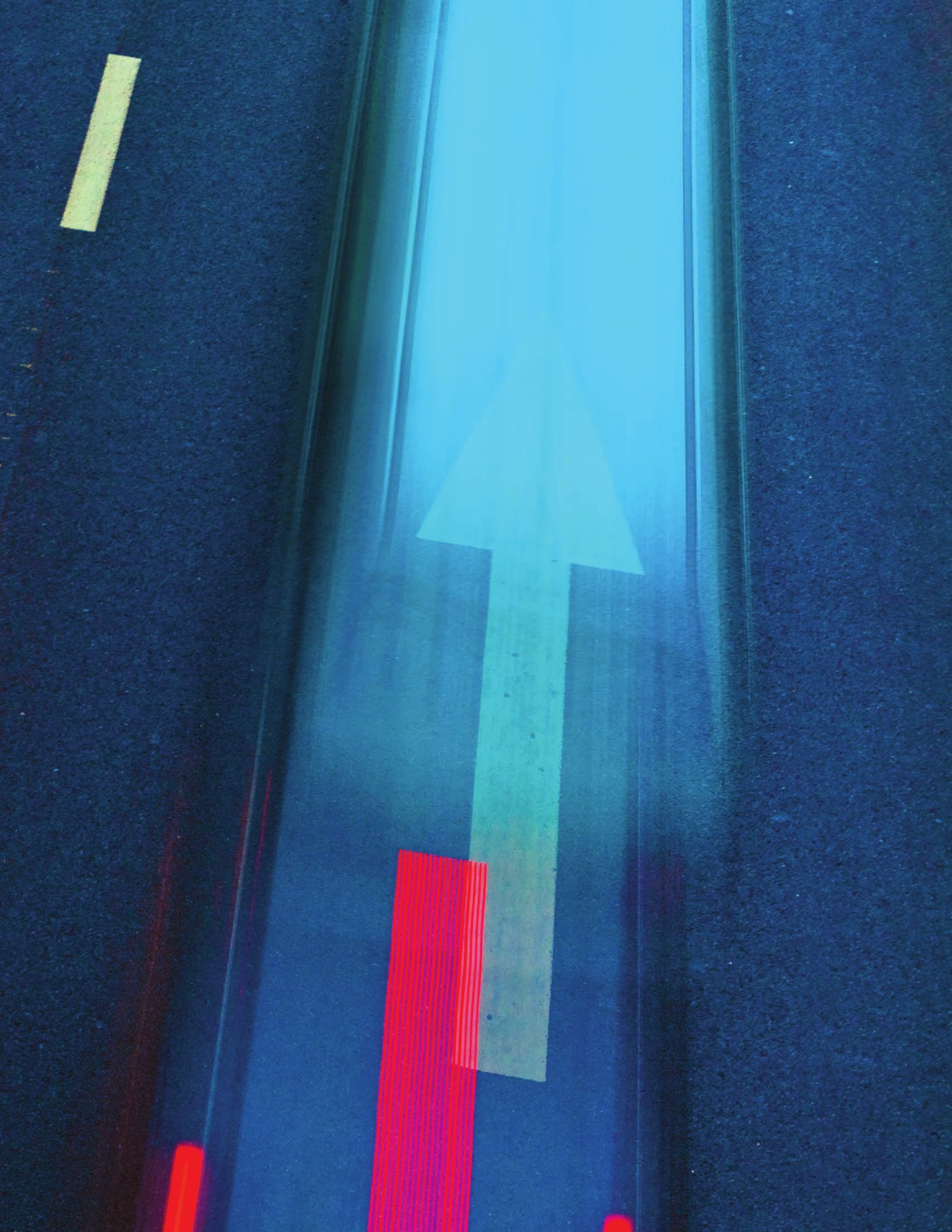
Moving Toward Climate-Resilient Transport

The World Bank's Experience from Building Adaptation into Programs

Jane Olga Ebinger and Nancy Vandycke

WORLD BANK GROUP



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FOREWORD

The economic, social, and environmental benefits of transport infrastructure and services are well recognized. A road can make a difference between surviving and thriving. In South Sudan, the World Bank helped build rural roads—before they were built, farmers could not think beyond subsistence farming because they had no means to bring their crops to market. New routes and development corridors can make a difference between isolation and connectivity to global economics and social development.

Less well understood is the role of transport in minimizing effects of disasters, enabling recovery, and improving preparedness. As the climate changes and countries suffer more frequent extreme weather events, that role of transport is becoming crucial. Flooding of the Kosi River in Nepal in 2008 cut off the East-West Highway, interrupting the flow of goods and services and affecting medical referrals to the main hospital. It took a full year for the highway to be fully restored.

Countries are investing massively in transport infrastructure—estimated globally at $1.4 trillion to $2.1 trillion per year[1]—and such spending is likely to rise to meet aspirations for greater mobility and connectivity. Growing climate risks will impact the entire transport value chain, from its location, design, and construction standards to the services it provides. These risks raise the question of whether, and by how much, new or existing transport infrastructure, whose lifetime spans decades, should be adapted to new climatic conditions. If the design of these assets is based on historical records, they may underperform on several levels under new climatic stresses.

Countries clearly need to invest in resiliency. In the run-up to the Twenty-First Conference of the Parties to the UN Framework Convention on Climate Change (COP21), 84 percent of the Intended Nationally Determined Contributions submitted by 147 Parties to the convention address economy-wide adaptation. However, only 16 Parties identify transport as a priority area for adaptation.[2] This highlights the need for more awareness of transport in managing climate change so it can continue to deliver social and economic benefits.

At the World Bank, we recognize that countries' needs for ending extreme poverty, boosting shared prosperity, and addressing climate change are enormous. Today, more than one-fourth of the Bank's transport commitments support mitigation and adaptation to climate change, and we are working with clients to find ways to respond to the expected rising demand for climate action. In October 2015, the World Bank Group pledged to increase its climate finance by one-third, to 28 percent of annual commitments, by 2020. Supporting the transition to low-carbon, resilient transport networks and services will be an important part of this engagement.

Pierre Guislain
Senior Director, Transport & ICT
World Bank

[1] Lefevre, Leipziger, and Raifman (2014).

[2] UNFCCC (2015b).

Making Transport Climate-friendly

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ACRONYMS

°C	Degrees Centigrade
°F	Degrees Fahrenheit
AAA/ESW	Analytic and Advisory Activities including Economic and Sector Work
AASHTO	The American Association of State Highway and Transportation
ADB	Asian Development Bank
AR5	Fifth Assessment Report of the IPCC
CAPEX	Capital Expenses
CBA	Cost/Benefit Analysis
CEO	Chief Executive Officer
CO_2	Carbon Dioxide
COP	United Nations Framework Convention on Climate Change Conference of the Parties
CPF	Country Partnership Framework
CRU	Climate Research Unit
DMU	Decision-Making Under Uncertainty
DRC	Democratic Republic of Congo
FHWA	The US Federal Highway Administration
GCCDR	The World Bank's Climate Change Crosscutting Solutions Area
GCM	General (worldwide) Circulation Model
GDP	Gross Domestic Product
GEF	Global Environment Facility
GFDRR	Global Facility for Disaster Recovery and Reconstruction
GHG	Greenhouse Gas Emissions
GIS	Geographic Information System
Gt	Gigatons (thousand million tons)
GTIDR	Transport & ICT Global Practice of the World Bank
HGV	Heavy Goods Vehicles
IBRD	International Bank for Reconstruction and Development
ICT	Internet Communications Technology
IDA	International Development Association
IFC	International Finance Corporation
INDC	Intended Nationally Determined Contributions
IPCC	Intergovernmental Panel on Climate Change
LDC	Least Developed Countries
LULUCF	Land Use and Land-Use Change
MCE	Multi Criteria Evaluation
MDB	Multilateral Development Bank
NAPA	National Adaptation Programmes of Action
NGO	Nongovernmental Organization
ND-GAIN	University of Notre Dame Global Adaptation Index
O-D	Origen-Destination

OECD	Organization for Economic Co-operation and Development
O&M	Operations and Maintenance
OPEX	Operational Expenses
PAD	Project Approval Documents
PICs	Pacific Island Countries
PPCR	Pilot Program for Climate Resilience
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
RDM	Robust-Decision Making
Rio+20	United Nations Conference on Sustainable Development held in Brazil on 20–22 June 2012
SAR	South Asia Region
SCD	Systematic Country Diagnostic
SIDS	Small Island Developing States
T&I	World Bank Transport & ICT Global Practice
TTL	Task Team Leader
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
USD, US$	United States Dollars
V20	Vulnerable Twenty Group of Ministers of Finance
WBG	World Bank Group

EXECUTIVE SUMMARY

Transport infrastructure and services are critical for development. They enable the distribution of goods and services within and between countries. They facilitate access to jobs, markets, schools, and hospitals. They support communities and countries' efforts to rebound from disasters and high-impact climate events.

In developing countries, the volume of transported passenger and freight has exploded, along with the demand for greater interconnectedness and better mobility. But the heavily debated question is how these aspirations for greater interconnectedness and mobility can be met in a sustainable way.

Climate change is a defining challenge of our time. Actions to reduce greenhouse gas (GHG) emissions and stabilize warming at 2 degrees Celsius will fall short if they do not include the transport sector. Transport contributes to GHG emissions; but it is also vulnerable to the impacts of climate change, and action is needed to adapt transport systems to better withstand those impacts. Climate change is putting at risk the lives of millions of people worldwide, many coastal cities, and trillions of dollars of investment in transport infrastructure and services.

Access to transport services has become so woven into the fabric of communities and economic development that service disruptions can have far-reaching implications for entire communities, countries, and regions—in developed and developing countries. A transport system that cannot withstand the emerging impacts of climate change will prove burdensome. It will impose high costs for maintenance and repair; limit community access to jobs, schools, and hospitals; and cause large economic losses. Ensuring the climate resilience of transport investments is also critical in allowing other sectors to quickly rebound after natural disasters and climate-related shocks.

The demand from client countries for adaptation action is growing. The 20 countries most vulnerable to climate change have come together to plan economic and financial measures to build resilience. And 100 of the 147 Parties participating in the November–December 2015 UN conference on climate change have adaptation among their priorities. Under a commitment made at Rio+20, the multilateral development banks (MDBs) have been scaling up finance for sustainable transport, with average annual lending of $25 billion per year. They are ready to do more for climate change. At the World Bank, we are ready to respond to client needs. In October 2015, the World Bank Group pledged to increase its climate work by one-third within five years, to 28 percent of its annual commitment, and the increase will include enhanced support for transport.

Building resilience in transport will require tools and approaches to allow climate and disaster risks to be systematically identified, prioritized, and built into investment planning and decision-making processes. This report takes stock of the World Bank's efforts and experience in building resilient transport systems. The tools and approaches discussed here—from upstream sectoral and spatial planning to postdisaster risk and recovery support, from infrastructure system solutions and support to building an enabling environment—have all been piloted, and all contribute to reducing climate risks and increasing the resilience of transport systems. However, most of these efforts are new and evolving, and large gaps in knowledge and capacity remain.

The World Bank will leverage its expertise, convening power, and global engagement to aid policy makers and practitioners in an environment rendered deeply uncertain by climate change. In doing so, the World Bank will join forces with the rest of the transport community to raise the dual awareness that transport is vulnerable to climate change and that it is critical to building the climate resilience of communities and countries. We will build this into our dialogue with client countries to ensure that potential climate change and disaster risks and opportunities are identified and robust solutions are developed.

1

"We are committed to scaling up our support for developing countries to battle climate change. As we move closer to Paris, countries have identified trillions of dollars of climate-related needs. The Bank, with the support of our members, will respond ambitiously to this great challenge."

—Jim Yong Kim, President, The World Bank Group

Introduction

Transport plays a critical role in economic development. Infrastructure and services are critical to development and form the backbone of economic and community activities at the local, regional, national, and international levels. They enable the distribution of goods and services within and between countries and ease access to schools, markets, and health services. Food security and vaccination programs, for example, require functioning roads and railways and access to ports and airports to move critical supplies to people.

While there is agreement on the need for greater connectivity, there is much debate on how to deliver it given the challenges from climate change. The contribution of the transport sector to increasing greenhouse gas emissions (GHG) and fossil fuel consumption have been at the center of global discussions on climate change. Transport is among the fastest growing sectors for CO_2 emissions from fuel combustion, and it is estimated to contribute approximately 23 percent of total energy-related CO_2 emissions in 2010. Transport enables development, but causes traffic congestion, pollution, noise, and road accidents, that together bring about 2 percent to 10 percent reduction in country-level GDP. Reversing this trend in emissions growth will require action to decouple emissions growth from GDP growth—driven by passenger and freight activity. This includes policies to encourage investment in low-carbon transport modes; programs to curb energy and emissions growth; and action to transform the way countries manage transport services.

It will also require action to adapt to the current impacts of climate change, as well as those that are likely to occur due to past and projected GHG emissions. Failing to substantially cut GHG emissions will have increasingly severe consequences: extreme heat will become more frequent and impact a larger area of land, precipitation and water resources will change, and diseases will move into new ranges. As sea levels rise, the risks from storm surges and tropical cyclones will rise, particularly for highly exposed small island states and low-lying coastal zones. Glacial melt poses an increasing risk of flooding, and impacts on seasonal water resources will affect agriculture and energy supplies.

These changes will have serious implications for transport infrastructure, operations, and maintenance and the communities they serve. Direct impacts include temporary or permanent flooding of roads, damage to bridges and ports, increased maintenance costs due to damage, and service disruption. Severe disruptions can isolate communities for long periods, restrict access to key markets and economic hubs, and lead to economic losses and loss of lives. Access to reliable transportation services has become so ingrained in the fabric of strong communities and economies that disruptions can have far-reaching implications on entire regions—in both the developing and developed worlds.

A fully defined adaptation program for the transport sector would factor climate change into investment planning and decision making and new approaches to deal with uncertainty (see Box 1).[3] A community's resilience certainly requires robust transport. But properly planned and used, transport can itself powerfully advance the resilience of the community: First, used strategically, transport can serve as a tool to steer population growth and settlement patterns over time to reduce vulnerability. Second, transport has a critical role to play before and after climate-related events in helping facilitate regenerative responses from other sectors, including energy, water, and trade.

[3] Models based on historical climate information can no longer be used to prioritize and make investment decisions. Similarly, climate models can project at best broad climate trends over large temporal and geographical scales and are not meant to provide detailed location specific outcomes for shorter time periods of a decade or less. Even with finer-scale data or new observations from the next few decades, much uncertainty remains because of development pathways, the associated emissions, and the likely changes to the climate system.

BOX 1 Terms and Concepts

Adaptation constitutes "The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects." (IPCC AR5 Glossary)

Resilience is the "capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential functioning, identity and structure, while also maintaining the capacity for adaptation, learning and transformation." (IPCC AR5 Glossary)

Deep uncertainty is defined as uncertainty that occurs when parties to a decision do not know or cannot agree on (1) models that relate the key forces that shape the future, (2) probability distributions of key variables and parameters in these models, and/or (3) the value of alternative outcomes. In general, most of future socio-economic conditions (population, prices) are deeply uncertain, and so is climate change. (Lempert et al. 2003)

Decision making under uncertainty methodologies are state-of-the-arts methods that help plan for robust projects, despite these deep uncertainties about the future. They move away from relying on predictions of the future in project design and place the decision back into the center by asking the question "what are the future conditions that make my system (e.g. road network) fail?". The systems or projects are stress-tested under hundreds of combinations of plausible future conditions—that include changing climate conditions. Once the main risks and the specific vulnerability thresholds of the system are identified, planners can evaluate them and explore options that may reduce these risks.

Recognizing the need to build resilience into transport infrastructure and systems and the potential for using transport to help communities adapt to climate change, this report takes stock of emerging efforts and experience of the World Bank. It makes the case for a more systematic approach in responding to communities and governments that ask, "How can we reach development, poverty, and shared-prosperity goals while considering current and future climate change?"[4]

[4] Economics of Climate Adaptation Working Group (2013).

2

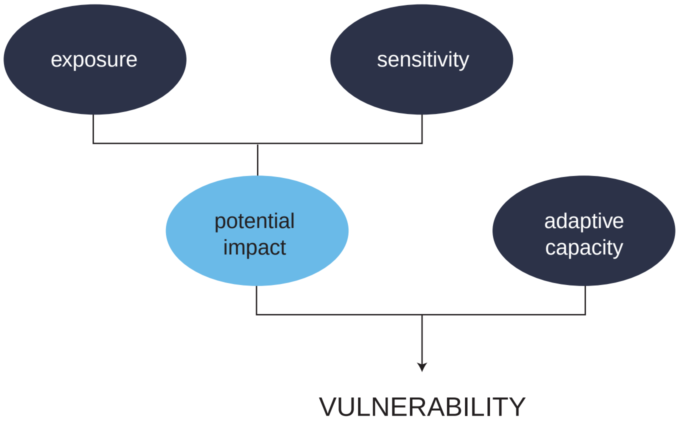
“Countries are investing massively in transport infrastructure and such spending is likely to rise to meet aspirations from greater mobility and connectivity. Growing climate risks will impact the entire transport value chain. These risks raise the question of whether, and by how much, new or existing transport infrastructure, should be adapted to them.”

Vulnerability of Transport Systems to Climate Risks

Some of the effects of climate change on transport systems are visible today (see Figure 2). In Russia, warmer temperatures are softening permafrost areas and beginning to destabilize the ground under a number of facilities, including a power station, an airport runway, and residential buildings. In addition, extreme temperatures are contributing to the loss of about 200 kilometers of road every year in the Kyrgyz Republic, which also reports other contributing factors, including difficult terrain, excessive loads, and a lack of road maintenance funding (Vandycke 2013).

The vulnerability of a transport system is a function of the *potential impact* of climate change—based on location and thus its *exposure* and *sensitivity* to climate change—and its *adaptive capacity*, broadly defined to include both providers and users (Figure 1).[5]

FIGURE 1 Framework for Defining Vulnerability



Source: Australian Government, 2005 (graphic reproduced from Fay, Ebinger, and Block, 2010).

[5] Kopp, Block, and Iimi (2013, pp. 49–52).

The concept of *exposure* is straightforward: "it is determined by the type, magnitude, timing, and speed of climate events and variation to which a system is exposed (for example, changing onset of the rainy season, higher minimum winter temperatures, floods, storms, and heat waves)" (Fay, Ebinger, and Block, 2010). It can be difficult to characterize the exposure of a locality or a transport network, quantitatively or qualitatively, in a way that is useful to decision makers. But a qualitative understanding of current changes and projected trends, however uncertain, is an important first step.

The *sensitivity* of a system depends on its structural characteristics—for example, engineered dirt or gravel roads are more likely to become impassable than paved roads during heavy rains, and poorly maintained assets of any type are more sensitive than better maintained assets. Location also matters: settlements and hence transport assets are often concentrated in coastal zones, where climate hazards are particularly challenging. For example a paved coastal road in the tropics could be exposed to sea-level rise and higher storm surges; hotter, longer, and more frequent heat waves; more frequent or more intense storms; or alternating periods of dry weather and more intense rainfall.

The potential impacts of climate change on transport systems are well known (Table 1). Although many impacts will be felt in the long term, they can also lead to damage and disruption in the short term and increase the frequency, impact, and risk of high-cost climate-related events.

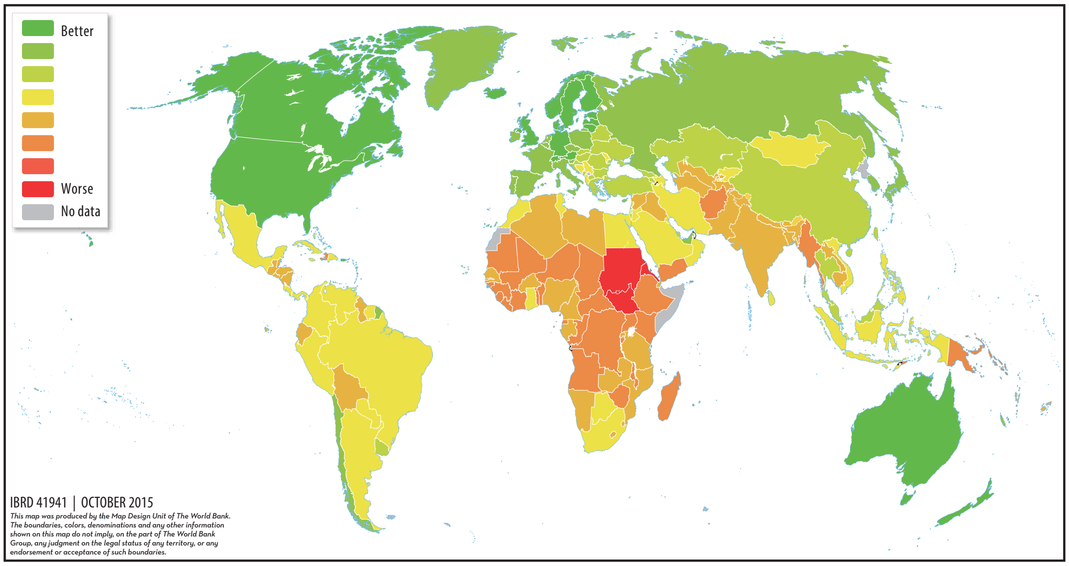
How potential impacts translate into actual impacts depends not only on the exposure and sensitivity of the transport system to such events, but also on its *adaptive capacity*—its resources for coping with impacts and minimizing damage. In the coastal road example, adaptive capacity could include the ability to close the road and reroute traffic with minimal delay; mobilization of resources to proactively maintain drainage and pavement; and planning to ensure that new infrastructure is not sited in exposed areas.

TABLE 1 Examples of Potential Impacts of Climate Change on Transport Systems

Climate Hazard	Potential Impact
Sea Level Rise, Storm Surge, and Flooding	• Damage to port infrastructure and disruptions in port operations and shipping traffic. • Loss of coastal waterway systems and/or disappearance of barrier islands. • Damage to, or inaccessibility of, low-lying coastal infrastructure such as roads and railway beds, tunnels, and underground rail/subway corridors (Titus 2002). • Aggravated coastal flooding as storm surges build on a higher base and reach further inland leading to road, rail, and airport closures, for example (U.S. Climate Change Science Program 2008).
Strong Wind and Storms	• Greater likelihood of infrastructure failure and disruptions of transport operations for all modes of traffic. • Increased threats to bridges. The structural integrity of long span bridges is vulnerable to strong winds as are auxiliary infrastructure such as road signs, traffic signals, overpasses, train stations, and toll collection stations. • Damage to overhead lines for railways, power supply, signs, lighting features, and increased tree fall leading to the closure of railway tracks and roads. • Delays and cancelation of flights and unreliable air travel services. • Damage to cranes and terminal facilities. • Safety hazards for vehicles.
Increasing Precipitation Intensity	• Flooding of roads, railways, and tunnels causing traffic disruptions and road/rail closure. • Slope failures and landslides (road/rail). • Washout of gravel and earth roads and railway tracks. • Erosion and scouring or washout of bridges or other works for waterway crossings. • Increased sediment loading of drainage works leading to increased maintenance requirements and costs. • Potential increases in sudden snow loading on bridges and overhead or suspended works. • Potential for sudden icing of drainage works causing flooding.
Changes in Precipitation (Averages)	• Increased drought, reducing the navigability of inland waterways. • Settlement of infrastructure and road beds due to increased aridity or lower water table affecting the base stability.
Extreme Heat	• Increased pavement deterioration, softening, and cracking, rutting, and bleeding. • Rail track deformation and buckling. • Thermal expansion of bridge joints. • Increased energy consumption due to refrigeration of transported goods and use of air conditioning. • Increased forest fires resulting in land infrastructure closure and failure.
Rising (Average) Temperatures	• Longer shipping seasons in the Arctic, opening of new shipping routes. • Reduced winter maintenance costs. • Longer construction season. • Decreased viability of ice roads.
Extreme Cold	• Increased thermal cracking of pavements and runways. • Brittle failures of railways tracks.
Increased Freeze Thaw Cycles	• Increased fatigue failure for most infrastructure, particularly roads. • Weathering of the vehicle fleet.
Permafrost Degradation	• Base stability of most infrastructure is affected resulting in substantial failures.

Source: Adapted from Ziad Nakat, 2010, "Climate change adaptation in the transport sector," background paper for Marianne Fay, Rachel I. Block, Jane Ebinger (eds), *Adapting to Climate Change in Europe and Central Asia,* World Bank Group.

FIGURE 2 Vulnerability to the Risks of Climate Change and Other Global Challenges



The ND-GAIN index summarizes a country's vulnerability to climate change and other global challenges. It uses six measures describing exposure, sensitivity and capacity in each of six major sectors; food, water, health, ecosystems, human habitat and infrastructure. These 36 measures are combined to give a vulnerability score for each country. The ND-GAIN index also includes an estimate of a country's readiness to absorb and apply resources to actions to adapt to reduce its vulnerability. Readiness is based on 9 measures that indicate its economic, governance and social capacities. The figure shows the overall vulnerability score based on 2013 data.

Source: University of Notre Dame Global Adaptation Index (ND-GAIN).

A transport system that has low resilience to actual and expected climate change can impose high costs for maintenance and repair. For example, with more intense and frequent precipitation, roads may deteriorate faster or bridges may collapse. And such vulnerability can have far-reaching social, fiscal and economic consequences, impairing people's ability to access jobs, markets, schools, and hospitals.

Quantifying the costs of climate change for transport systems and the benefits of increasing resilience are critical for the dialogue with countries and investors about long-term plans. Global estimates suggest that the cost to adapt to climate change in a 2ºC-warmer world is in the range of $70 billion to $100 billion per year by 2050 (World Bank 2010b). Infrastructure, which is particularly sensitive to changes in annual and maximum monthly rainfall, accounts for a large share of the adaptation costs. Urban infrastructure—drainage, public buildings, and similar assets—account for about 54 percent of the infrastructure adaptation costs, followed by railways at 18 percent, and roads (mainly paved) at 16 percent. Not estimated is the cost of inaction on adaptation.

Studies looking at the economics of local adaptation often focus on a developed-country context, with gaps for a number of sectors, including infrastructure (Chambwera et al. 2014). Further, the convergence between global and local costs is generally limited. Costs for strengthening infrastructure against wind, rain, and floods were 10–20 percent higher at the local level, due to the inclusion of social impacts, than disaggregated costs based on global estimates.

The IPCC finds shortcomings in data, methods, and coverage for available studies of global adaptation costs, funding, and investment (Chambwera et al. 2014). But it also highlights some agreement on core considerations when conducting economic analysis of adaptation: broad coverage of climate stressors; multiple alternatives or conditional groupings of adaptation options; rigorous economic analysis of costs and benefits; and a strong focus on practical decision making that considers drivers of uncertainty.

As the climate changes, the costs to transport networks of retaining the original infrastructure can be seen by disaggregating them into maintenance, repair, and construction; disruption; social; and economic. The case of Can Tho City in Vietnam provides an example (Table 2).

Maintenance, repair, and construction costs are expected to increase with climate change. For example, costs include the rehabilitation of road networks where drainage systems cannot cope with peak rainfall events, or rising maintenance needs due to increasing landslides or saltwater intrusion from

TABLE 2 Vietnam, Can Tho City: Costs to Transport from Flooding

Vulnerability Seasonal flooding of the city increases from 30% to 50%. Serious floods occurred annually from 2011 to 2014.	**Maintenance, repair, construction:** New bridges and ring roads bypass the city center, efforts guide growth to lower risk areas.
	Disruption: Loss of connectivity due to flooded roads, dependence on road networks, urban sprawl.
	Social: Poor sanitation due to flooding, health impacts, prolonged travel times.
	Economic: Negative economic effects on 42% of businesses, 54% of grocers, 3% of workers. Indirect effects due to missed work, revenue loss, and additional health costs.

Road Project Coverage from The Ministry of South Sudan

PLAY VIDEO

sea level rise and storm surges. All roads deteriorate with time, but potholes or ruts accelerate deterioration by allowing water to infiltrate, and periodic maintenance is needed to keep roads smooth. This deterioration is expected to accelerate as systems are exposed to more severe weather and climate risks. In Ecuador, for example, poor maintenance of roads and bridges, exacerbated by noncompliance with regulations, contributed to damages during an El Niño period (Kopp, Block, and Iimi 2013). In sub-Saharan Africa, projected climate risks are expected to generate $5.2 billion in maintenance costs for 11 corridors covering about 20,000 kilometers of paved primary roads through 2050—*in addition to* the expected $6.3 billion for a scenario without climate impacts. Using a proactive adaptation policy, the additional cost would decrease to $2.64 billion (Cervigni 2015).

Poor maintenance, often due to lack of funds, undermines road safety because of the resulting rutting and potholes. Slick pavement and adverse weather contribute to about one-fourth of all highway crashes in the United States.[6] Rain increases pavement-related road accidents by about 30 percent.

Railways, air traffic facilities, waterways, and maritime ports must also be properly maintained. To take only the case of maritime transport, the Philippines consists of more than 7,100 islands, and maritime transport is the second most important mode after roads. Although the number of vessels entering the country's ports increased by about 10 percent between 1999 and 2005, maintenance of the country's navigational facilities had long been neglected. Physical damage or poor maintenance caused 112 of 419 lighthouses and lighted buoys to be shut down before a corrective project was launched (JICA 2007).

Disruption costs arise as direct and indirect effects of an initial asset failure. Climate events can have a direct impact on interconnectedness, reducing transportation speed, trade, and local development. Failure of one component in the transportation system may undermine the performance of many other networks, such as energy, with economic implications beyond the direct impact of the initial market failure. Transport delivers critical interdependencies; their breakdown could dramatically disrupt a regional economy (Meyer 2007).

The 2008 flooding of the Kosi River, which crosses from Nepal into the Indian state of Bihar, caused an embankment to breach even though the flow of water was just one seventh of the system's design flow. The breach damaged 79 percent of roads in Bihar, and, in cutting off Nepal's East-West Highway, it interrupted the country's flow of goods and services, including to the main hospital at Dharan. It took the Nepal Department of Roads a full year to fully restore the East-West Highway.[7]

In Mozambique, the economy-wide effects of road traffic disruptions due to changes in rainfall patterns have been forecasted at approximately $2.5 billion per year between 2010 and 2050 (Cervigni 2015). Mozambique's high vulnerability to extreme weather was demonstrated by the floods of 2000, 2001, 2012, and 2013, which together carried a restoration cost of approximately $400 million.

Social costs to communities from weather-related disruptions of transport include reduced access to education, health, and government services for specific populations or vulnerable groups; a greater incidence of road accidents due to more hazardous conditions; and reduced access of rural communities to markets.

Structural and economic costs to communities arise if transport cannot help other sectors to quickly rebound after climate-related events. The largest share of economic loss from seasonal flooding in Can Tho City in Vietnam (Table 2) is incurred through indirect costs, such as missed work, revenue loss and additional health costs. Climate change can also have effects on the structure of the economy, and the relevance of

6 National Research Council Committee on Climate Change and US Transportation (2008).

7 Dixit A. (2009).

existing transport network. For example, if corn cultivation shifts northward in response to rising temperatures, agricultural products may flow to markets from different origins and by different routes.[8]

Some approaches to estimating the costs of adaptation have been piloted at the World Bank and will be explored in Section 4.

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8 Schwartz, H. G., M. Meyer, C. J. Burbank, M. Kuby, C. Oster, J. Posey, E. J. Russo, and A. Rypinski (2014).

3

"The financing of climate action is a collective challenge. We all know that country needs for ending extreme poverty and boosting sharing prosperity and combatting climate change are enormous. Together, all of us here will have to find ways to respond to the expected rising demand."

—Jim Yong Kim, President, The World Bank Group

Responding to Demand for Adaptation Action

Over the past 50 years, major weather-related disasters have caused some 800,000 fatalities and more than $1 trillion in economic loss. In the past decade, the damage caused by such disasters has reached record levels.[9]

In response to these challenges, the Finance Ministers of the Vulnerable Twenty (V-20) agreed in October 2015 to join forces.[10] The group will focus on economic and financial measures, particularly to foster low-emissions development and a significant increase in investment in climate resiliency. For V-20 countries, climate impacts already exceed regional and national capabilities: typhoons with wind speeds that are about 10 percent stronger and 30 percent more destructive than they were in the 1970s, and rising sea levels that will partially or completely submerge some island nations and displace at least 500,000 people. These countries have suffered an average of more than 50,000 deaths per year since 2010 and escalating annual losses of at least 2.5 percent of GDP potential per year.

Globally, 147 Parties to the U.N. Framework Convention on Climate Change (UNFCCC) have submitted Intended Nationally Determined Contributions (INDCs) to climate action in advance of COP21.[11] INDCs from 100 of those Parties underscored the importance of economy-wide actions to address climate change mitigation and adaptation in the period to 2030.[12] However, among the 100 Parties, only 16 highlighted the importance of transport among their priorities for adaptation, and even fewer included transport-specific adaptation measures (Table 3), highlighting the need to do more to position transport as a core part of the adaptation agenda.

[9] Economics of Climate Adaptation Working Group (2013).

[10] V-20 Draft Outcome Document/Communique of the Inaugural V20 Ministerial Meeting, final adopted October 8, 2015, at Lima.

[11] Twenty-First Conference of the Parties to the UNFCCC (COP21), Paris, from November 30 to December 11, 2015.

[12] These INDCs, including submissions from 38 least-developed countries, constitute 84 percent of the INDCs submitted by all 147 Parties as of October 1, 2015 (UNFCCC 2015b).

The MDBs have been working globally to direct financial resources toward the sustainable development and expansion of transport infrastructure services. At the 2012 U.N. Conference on Sustainable Development (Rio+20), the MDBs pledged to increase their financing for more sustainable transport to $175 billion by 2022.[13] The World Bank Group with the

TABLE 3 Transport-Specific Adaptation Action in Intended Nationally Determined Contributions (INDCs)

Country	Adaptation
Belize	Vulnerability assessment of transport infrastructure, particularly in urban areas and areas critical to sustaining the country's productive sectors (tourism, agriculture, and ports).
Gambia	Improved resilience of road networks under changing climate conditions.
Madagascar	Effective application of existing or newly established sectoral policies, including flood-resistant infrastructure standards for terrestrial transport.
Maldives	Coastal protection measures to protect the shoreline of the island with the country's main airport as well as measures for its other air and sea ports.
Republic of Moldova	Analyzing adaptation options, including altering assumptions about infrastructure design and operations and incorporating uncertainty into long-range decision making.

Source: Partnership on Sustainable Low-Carbon Transport (2015b).

[13] See *Progress Report (2014–15) of the MDB Working Group on Sustainable Transport* (draft). http://www.adb.org/documents/progress-report-2013-2014-mdb-working-group-sustainable-transport.

BOX 2 Risk Management and Climate Change Adaptation for the Transport Sector in the Republic of Moldova's INDC

The INDC submitted to the UNFCCC by the republic of Moldova includes an objective to "Assure the development of climate resilience by reducing at least by 50 percent the climate change vulnerability and facilitate climate change adaptation in six priority sectors (agriculture, water resources, forestry, human health, energy and transport) by 2020."

Adaptation measure are identified for the transport sector to reduce losses and risks in the event of significant changes in temperature and extreme rainfall:

- **For significant variations of temperatures, including heat waves:** developing new, heat-resilient paving materials; making more use of heat-tolerant streets and landscape protection for highways; properly designing, constructing and milling out ruts; shifting construction schedules to cooler parts of day; designing replacement or new infrastructure for higher maximum temperatures; adapting cooling systems.
- **For increases in extreme precipitation events:** developing new, adverse climate conditions-resilient paving materials; overlaying roads with more rut-resilient asphalt; using the most efficient technologies to assure sealing and renewal of asphalt concrete; broader use of efficient road maintenance methods; conducting risk assessments for all new roads; improving flood protection; making more use of sensors to monitor water flows; upgrading road drainage systems; grooving and sloping pavements; increasing the drainage capacity standard for new transportation infrastructure and major rehabilitation projects; engineering solutions; and increasing warnings and providing updates to dispatch centers, crews and stations.

Given the long planning horizons for transport infrastructure the INDC highlights the need determine whether, when, and where the long term impacts of climate change could be consequential.

Source: http://www4.unfccc.int/submissions/INDC/Published%20Documents/Republic%20of%20Moldova/1/INDC_Republic_of_Moldova_25.09.2015.pdf

seven other leading MDBs[14] provide about $25 billion a year, or about 20 to 30 percent of overall lending commitments, for sustainable transport solutions—putting them on track to deliver on the Rio+20 commitment by 2022.

The MDBs have also responded to client demand for adaptation finance. Over the 2012–14 period, the MDBs committed $4.7 billion for finance with adaptation co-benefits (Annex 1) through energy, transport, and other built environment and infrastructure projects (Table 4).

At the World Bank, transport has been the second-largest sector after energy for project commitments with climate mitigation and adaptation co-benefits. Over fiscal years 2011–15, the World Bank committed $30.3 billion to transport investments in 330 projects. More than one-fourth of these commitments delivered climate mitigation and adaptation co-benefits to projects around the world (Figure 3), largely focused on modal shifts to lower-carbon railways and urban transportation systems. For example, of the $5.3 billion committed by the World Bank in fiscal year 2015, $1 billion supported mitigation solutions, and $200 million supported adaptation to climate change. The high and growing demand for greater mobility and connectivity and the rise in urbanization taking place in the context of a changing climate will only increase the demand for climate action financing in transport.

In October 2015, the World Bank Group announced, with the support of shareholders, that by 2020 it will expand its climate work by one-third, to 28 percent of annual commitments. The commitment covers expanded support for transport. Among other features, it will embrace a plan for sub-Saharan Africa over 2015–18, to be launched at COP21, that includes strengthening the resilience of coastal zones and cities—areas where transport infrastructure plays a critical role.

[14] The eight leading Multilateral Development Banks include: African Development Bank, Asian Development Bank, European Bank for Reconstruction and Development, European Investment Bank, Inter-American Development Bank, Islamic Development Bank, and the World Bank Group.

TABLE 4 MDBs Adaptation Finance

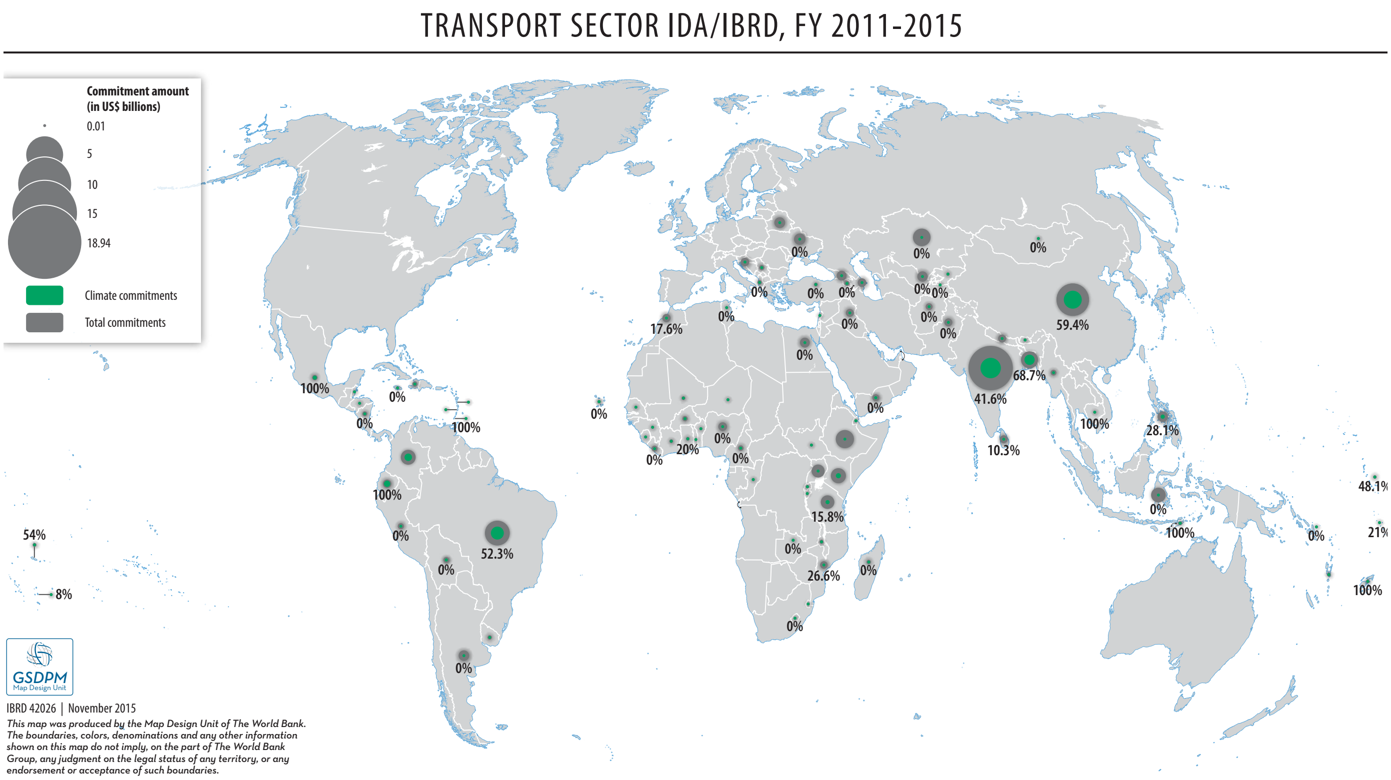
millions of dollars

Year	Energy, Transport, and Other Built Environment and Infrastructure	Other Sectors	Total	Memo: Percent for Built Environment and Infrastructure
2012	2,150	3,806	5,956	36
2013	1,422	3,404	4,826	29
2014	1,148	3,921	5,069	23
Total	4,720	11,131	15,851	30

Source: Joint Report on Multilateral Development Banks' Climate Finance (2014).

FIGURE 3 World Bank Transport Commitments with Climate Co-Benefits, Fiscal Years 2011–15

billions of dollars



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"Economic thinking on adaptation has evolved from a focus on cost-benefit analysis and identification of "best economic" adaptations to the development of multi-metric evaluations including the risk and uncertainty dimensions in order to provide support to decision makers."

—Muyeye Chambwera, United Nations Development Programme

Toward Climate-Resilient Transport Systems

How can decision makers navigate the options for improving the climate resilience of transport systems? In principle, they should be able to assess a range of interventions by taking into account climate risks, the economic and social costs and benefits of the interventions, and the risk-weighted damage that each action could help avert. But tools and approaches for such assessments are still emerging, being pilot tested largely on an ad hoc basis. With or without these methods, the task of adaptation is inherently complex.

Incomplete information and deep uncertainty. The climate is changing, but little is known with certainty about future climate risks. Traditional decision-making models have typically been calibrated with historical statistics for climate variables, such as precipitation, wind speed, and temperature. However, past records are no longer reliable indicators for the future. "Stationarity" can no longer be used to guide decisions (Milly et al. 2008). Moreover climate impacts are specific to location and context, requiring an analysis of vulnerabilities and adaptation options tailored to the situation. Methodologies that take into account deep uncertainties are therefore required to help decision-makers select the most robust options.

Transport assets tend to be long lived. Integrating climate risks into the decision-making process is made even more complex by the fact that the useful lifetime of transport infrastructure is generally long and spans several decades from design to the end of its operational life. During that period, the climate may go through considerable change. Dealing with these (deeply uncertain) changes in climate requires to build flexibility in transport systems in order to avoid underperforming assets as the years go by (Figure 4).

Adaptation to new norms takes time. Adaptation often requires technological changes (such as innovative materials for asphalt that can withstand long periods of flooding) and involves transitional phases (such as ensuring redundancy in the connectivity of rural and urban areas). During transition periods, parts of the transport system may be maladapted to prevailing climatic conditions and require heightened risk management and maintenance.

Adequate adaptation may not always be possible. Especially in many tropical areas, climate change will expose infrastructure and transport services to extreme weather conditions and events that may exceed design thresholds. For example, temperatures that exceed the threshold for the stability of asphalt make roads paved with it unusable. Adaptive management measures that include monitoring infrastructure responses to changing climate extremes will need to be part of the transport's response. Maintenance regimes can then be adjusted and codes revised as needed for new transport infrastructure.

FIGURE 4 Climate Change in the Context of the Useful Life of Transport Infrastructure

Source: Stenek and Skromne (2011).

4.1 Framework to Integrate Climate Resilience into Transport Systems

The World Bank has applied a range of tools and approaches to its engagement in building resilient transport systems, including upstream sectoral and spatial planning, post-disaster risk and recovery support, the enabling environment, and the supporting resilient infrastructure solutions. All of these tools and approaches address different types of vulnerability and phases in the life cycle of a transport system.

Figure 5 presents a four-pillar framework for the World Bank's approach to integrating climate resilience in transport systems:

1. Sectoral and strategic spatial planning that is informed by assessments of risk and vulnerability
2. Resilient infrastructure solutions, which comprise investments in physical infrastructure, new technologies, and community-based adaptation, all designed to ensure that the transport system is robust, redundant, and resilient
3. Enabling environment: institutional and capacity support, awareness raising, and finance to enhance the capabilities of the relevant stakeholders at the policy and regulatory level
4. Post-disaster risk and recovery support to ensure that short- and long-term climate change risk and resilience is integrated into rebuilding efforts

Figure 5 provides some examples of how these objectives have been delivered at the operational level and the tools and approaches that have been piloted by the World Bank. In some cases, tools and approaches address more than one part of the framework. The following sections explore each part of the framework and give examples of tools and approaches applied at the country level.

More work is needed, however, to fill the large gaps in our knowledge and capacity. Such work is needed to clarify, for example, how to sequence, prioritize, and combine approaches and select them with a carefully crafted decision-making approach under deep uncertainty. Finding ways to systematically integrate climate change into transport decisions will help decision makers prioritize policy actions and investments that best mitigate damages and reduce the costs of system disruption on development.

4.2 Sectoral and Spatial Planning

In some sectors, such as agriculture, stakeholders have long engaged with climate scientists to build a mutual understanding of risks, impacts, and adaptation approaches. Transport and climate specialists would likewise benefit from greater communication on how climate change might evolve, how it will affect the design of transport systems, and what actions to take as a result. For example, by mapping critical infrastructure links and identifying those that are vulnerable to projected climate impacts, a decision can be taken on how to proactively manage those vulnerabilities and maintain necessary services.

The same concept applies to decisions surrounding physical assets and institutional arrangements that can help answer key questions. For example, What is the landscape surrounding the asset? Who has jurisdiction over operations, maintenance, and design—both the original design and future retrofits? Are drainage systems integral to the road? Are they managed by the roads authority or by the urban water and sanitation authority? What standards and manuals provide technical specifications for design under future climate change? What is the intended design life of the assets? Have design thresholds already been, or are they likely to be, exceeded?

Countries are integrating climate risk considerations into transport system plans, design, construction, and operation. Mexico and Samoa, for example, are building this into transport plans, conducting feasibility studies on specific investments, adopting climate resilient designs that can also inform new standards and codes, and providing an adequate maintenance budget. However, this approach is at an early stage of development and is not being widely applied in other countries. At the World Bank Group, climate and disaster risk considerations are being integrated in Country Partnership Frameworks that guide our support to client countries (Box 3).

At the most basic level, a country-based assessment of a transport system's ability to withstand climate change is based on an inventory of transport facilities; an analysis of climate-related risk factors; enumeration of adaptation responses (Table 5); and an economic assessment of response packages.

Typically, these methodologies construct response packages based on a set of standardized proactive and reactive adaptation strategies related to damages from potential climate impacts such as high temperatures, changing precipitation patterns, increased flooding or flash-flooding, permafrost melting, and sea-level rise. The damages on road networks include pavement deterioration, weakened bridge joints, bridge scouring, erosion, and changes in frequency and intensity of snow and ice removal.

The following sections provide four examples of tools and approaches for sectoral and spatial planning piloted by the World Bank.

FIGURE 5 Framework to Integrate Climate Resilience in Transport Systems[15]

	Sectoral and Spatial Planning	Resilient Infrastructure Solutions	Enabling Environment	Post-disaster Risk and Recovery Support
Objective	Upstream vulnerability assessment for climate change and other challenges	Investments in physical infrastructure or new technologies designed to reduce the impacts of current and future climate risks and ensure robustness, redundancy and resilience. This can include community based adaptation.	• Policies, plans, codes and reforms designed to reduce the impact of current and future climate risks, or enable future adaptation. • Investments in human, institutional, and technical capacity to raise awareness, analyze, and cope with current and future climate risks. • Investments in systems that collect, organize, store and analyze climate data, and capture and share lessons. • Funding and resources allocated to deliver and maintain resilient infrastructure systems	Ensuring short and long term climate change risk and resilience is integrated into rebuilding efforts
Delivery	Examples: • Urban planning • Transport master plan • Road network plans	Examples: • Non engineering and engineering solutions • Maintenance	Examples: • Codes and standards • Institutional coordination • Awareness programs • Budget planning • Contingency planning • Improved hydro met information • Monitoring for resilience	Examples: • Post disaster needs assessment • Building back better • Strengthened codes and standards • Across government & donor coordination
Bank Piloted Tools and Approaches	• Economics approach to vulnerability assessment • Engineering approach to vulnerability assessment and resilience planning • A systematic condition assessment of infrastructure through vulnerability and risk assessment • Vulnerabilities assessment using socio-economic criticality and flood susceptibility in the transport network	• Screening tools for climate and disaster risk for use in early stages of investments • Decision-support systems for evaluating and including impacts on economic and social continuity of alternative transport network investments • Cost-risk assessment framework under a given climate scenario • Decision-making under uncertainty (DMU)	• Infrastructure planning and maintenance through a vulnerability lens • Tracking climate mitigation and adaptation co-benefits • Socio-economic resilience indicator	• Building resilience in the transport sector after disaster • A systematic condition assessment of infrastructure through vulnerability and risk assessment

[15] Some tools and approaches can be applied across several pillars of this framework.

BOX 3 Integrating Climate and Disaster Risk Considerations into Systematic Country Diagnostics

At the World Bank Group, the Country Partnership Framework (CPF) guides support to a client country. It is informed by a Systematic Country Diagnostic (SCD) that identifies the most important challenges and opportunities at a country level for reaching the goals of ending extreme poverty and increasing shared prosperity in a sustainable manner. Climate and disaster risk considerations are integrated into this process under a policy commitment under the seventeenth replenishment of IDA; the Bank's fund for the poorest countries.

A recent review of experience, shows that SCDs/CPFs for regional programs in Cambodia, Lao PDR and Myanmar are including disaster response measures and should consider transport systems and mobility across and within countries.

In Honduras the SCD notes its high vulnerability to natural hazards and disaster risks and related socio-economic impacts. It identifies the need to further develop knowledge and disaster risk assessments to reduce existing high levels of structural vulnerability in public assets as well as integrating disaster risk reduction criteria in territorial and sector planning processes.

In the Pacific Region the SCD notes the high vulnerability of Pacific Island countiesto climate and disaster events. It highlights the importance of integrating climate change adaptation and disaster risk management into policy, planning and investment decisions. It also notes that investments in improved disaster risk management and early adaptation show unambiguously high rates of return, particularly for people and assets in coastal areas.

TABLE 5 Categories of Adaptation Actions

Typology	Description
OECD	Bear Losses, Share Losses, Modify the Threat, Prevent Effects, Change Use, Change Location, Research, and Encourage Behavioral Change
USAID	Sustain Losses, Cope (with stressors), Share Losses, Adjust (behavior), Reduce Impact, Defend/Armor/Protect, Relocate, and Research
Asian Development Bank	Engineering Options, Non-Engineering Options, Biophysical Options, and Do Nothing Option
Pilot Program for Climate Resilience (Climate Investment Funds)	Policy Reform/Development/Enabling Environment, Implementation, Capacity Building, Knowledge Management

Source: Adapted from Strategic Framework & Typology for Climate Resilience Measures, World Bank, 2015.

BOX 4 Integrating Climate Risk and Resilience in Development Planning

The Pilot Program for Climate Resilience (PPCR), operated by the multidonor Climate Investment Funds (CIF), is demonstrating ways to integrate climate risk and resilience into developing countries' core development planning. To date, 18 countries, plus the Caribbean and Pacific regional programs of the PPCR have endorsed multisector investment plans that have been developed on a consultative basis across government, the private sector, donors, and civil society. Some plans, such as Mozambique's include a transport focus.

Through its "IDA 17 replenishment" (fiscal years 2015–17), the World Bank will support the development and implementation of at least 25 additional multisector plans and investments for managing climate and disaster risk in development.

A further example of integrating climate risk and resilience are postdisaster needs assessments, which help countries develop long-term strategies for resilient recovery and reconstruction.

BOX 5 Accessibility and Resilience of Road Networks

In a study of "Road Networks, Accessibility, and Resilience," the World Bank developed a methodology for testing the resilience of the national road networks in Colombia, Ecuador, and Peru to climate-related shocks (Briceño-Garmendia et. al. 2015). The resilience of the road network is its ability to remain operational as a system, even though particular links in the system are substantially degraded or out of service entirely.

Faced with the challenge of having to allocate resources efficiently and prioritize the most urgent investments on the road networks, decision-makers struggle to identify the most critical links and evaluate their vulnerability, in face of uncertain future events and uncertainties about their impact. In this study, the World Bank sought to answer three key questions: (1) How can we identify the most critical roads in the national network? (2) Given the existing uncertainties, what are the expected annual losses linked to flood disruptions of critical group of links? (3) How can we best reduce these losses and choose between available ex-ante options and ex post interventions?

To help answer these questions, the study illustrates how to effectively combine traditional transport models, like HDM-4, with innovative network analysis and state-of-the-arts methods for managing uncertainties about the future.

By using the interdiction technique on thousands of links, this study shows how to select the most critical links. It then demonstrates how to select the most exposed and vulnerable of these links to floods and landslides. It also shows that the analyst can easily take into account additional qualitative information on the strategic or economic relevance of some links, to improve the decisions. Finally, by running hundreds of scenarios of possible events and their impacts, it applies a robust decision-making approach to guide a cost-effectiveness analysis of policy options available when a road network is exposed to unpredictable climate events.

4.2.1 Economics Approach to Vulnerability Assessment

An economics approach is being used to assess the vulnerability of critical links in a road network as part of road sector and network risk planning. It measures and assesses the accessibility of road networks, identifies and assesses critical corridors of the network as well as cost-efficient options to reduce vulnerability. The result is identification of specific links whose failure during weather or other climate-related events would produce the greatest damage to the economy. Options and plans to reduce those risks are considered. Such an approach was taken in a World Bank study of the economic resilience of the national road networks in Colombia, Ecuador, and Peru (Box 5).

4.2.2 Engineering Approach to Vulnerability Assessment and Resilience Planning

An engineering approach integrates socioeconomic and technical factors into a decision tool to help road managers prioritize investments to improve the resilience of the road network under current climate conditions. This approach, which has been piloted in Morocco (Box 6), provides a detailed, prioritized list of engineering improvements to the climate resilience of roads and contributes to sectoral planning.

4.2.3 A Systematic Condition Assessment of Infrastructure through Vulnerability and Risk Assessment

Underinvestment in infrastructure maintenance makes it vulnerable to unexpected failures and may undermine the ability of many other networks to perform. Therefore, the indirect economic impact of the initial failure can be much greater than the direct loss. For example the interruption of energy supplies due to a natural disaster will affect water supplies, which will have consequences extending far beyond the direct failure of the energy supply system. The same is true for other networks, such as transport and critical public buildings.

The combination of aging infrastructure, low funding for rehabilitation or renewal, and an increase in the frequency of natural disasters calls for a proactive approach to managing

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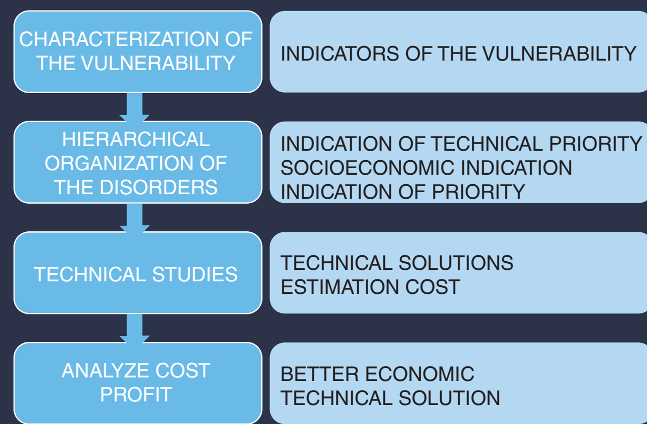
BOX 6 Vulnerability Assessment and Risk Planning for Roads in Morocco

Morocco is subject to extreme climate events whose frequency and intensity are likely to increase because of climate change. These climatic events have serious adverse effects on economic activity and cause large direct and indirect losses. Between 2009 and 2015, repairs of weather-related damage to the road network cost a total of 4 billion Moroccan dirhams ($408 million), of which about 3 billion ($306 million) was drawn from the road maintenance budget. Today intense rainfall can lead to large-scale mudslides, flooding, and roadway erosion, sometimes severing main roads such as the Rabat-Casablanca highway.

In 2010, the World Bank conducted a study on the adaptation of the Moroccan transport sector to climate change and evaluated the vulnerability of the road sections (World Bank 2015a). The method classified road sections according to four types of vulnerability and a set of characteristic indicators of the observed risk. It integrated socioeconomic and technical factors into a decision tool that helps road managers prioritize investments to improve the resilience of the road network under current conditions (Figure B3.1).

The outcome is a prioritized list of vulnerabilities—a kind of "shopping list"—and ranked engineering improvements that will enhance the climate resilience of the road network. This ground-based work can be integrated into other network analyses of vulnerabilities and form part of a comprehensive toolkit for assessing and improving the climate resilience of their road networks.

FIGURE B3.1 Steps to Establish the Most Favorable Solution



The study concluded that the climate data and modeling efforts cannot provide sufficient detail for road planning and design. However, the study also concluded that current road design and construction practice had shortcomings even for current climatic conditions. For example, in Morocco's arid or semi-arid climate, sudden precipitation events would often cause substantial erosion damage to roads and bridges and their associated works.

infrastructure. The biggest challenge is the difficulty of assessing the failure risk for components of an infrastructure network. It requires a systematic assessment of the infrastructure's condition that incorporates vulnerability and risk analysis. A focus on strategic planning can minimize the risk of failure and improve response when failures do occur.

The effects of disruptions can be minimized by integrating disaster risk management at every stage of the life cycle of the infrastructure and combining it with sufficient preparation for emergency response and business continuity. This in turn becomes part of the infrastructure asset management plan. Improving the condition of infrastructure assets improves financial efficiency, increases resilience, improves services, strengthens government agencies and accountability systems, and promotes more sustainable decision making.

This approach has been applied in South Asia. The identification of critical links and disaster risk management strategies are being built into the regular functions of the transport asset management system (Box 7). This pilot approach enables transport maintenance institutions to adjust to the potential for climate-related disasters and integrate them into their operating strategies. Section 4.5 provides guidance on the various methodologies used and shows how to effectively incorporate disaster risk management into asset management.

4.2.4 Vulnerabilities Assessment Using Socioeconomic Criticality and Flood Susceptibility in Transport Networks

Where the road network is located along coastal fronts, it can be vulnerable to disruption from storm surges, inland and coastal flooding, and extreme events like hurricanes. Belize faces such challenges and has developed a participatory approach to assess road network vulnerabilities and identify priority investments.

BOX 7 Integrating Disaster Risk into the Lifecycle Management of Transport Infrastructure in South Asia

The asset management system can be used as a decision-making framework for incorporating adaptation concerns into a transportation agency's management approach (Meyer, Amekudzi, and O'Har 2009). Given that all transportation agencies have some form of an asset management system, it provides a convenient and targeted way to integrate climate-induced change into transport decisions.

In the case of roads, asset management relies on monitoring the performance of systems and analyzing the discounted costs of different investment and maintenance strategies. For existing infrastructure, the key issue is making efficient choices about maintenance and replacement. When building new infrastructure, asset management involves evaluating total life-cycle costs—both the initial capital costs and the subsequent costs for operation, maintenance, and disposal. The aim is to ensure that projects are prioritized appropriately and are built cost effectively. This could include, for example, making a larger initial investment in a thicker pavement to provide a greater-than-proportional increase in pavement life; or shortening the period between pavement overlays, which could reduce fuel and maintenance costs for road users. Climate change monitoring techniques and adaptation strategies can be factored into an asset management system in several ways. Table B4.1 describes the experience with such approaches in the United Kingdom and New Zealand.

TABLE B4.1 Climate-Resilient Asset Management System

Asset Management System Component	Monitoring Techniques and Adaptation Strategies
Goals and Policies	Incorporate climate change considerations into asset management goals and policies. These could be general statements concerning adequate attention of potential issues, or targeted statements at specific types of vulnerabilities (e.g., sea level rise).
Asset Inventory	Mapping of infrastructure assets in vulnerable areas, potentially using GIS. Inventory critical assets that are susceptible to climate change impacts.
Condition Assessment and Performance Modelling	Monitor asset conditions with environmental conditions (e.g., temperature, precipitation, winds) to determine if climate change affects performance. Incorporate risk appraisal into performance modelling and assessment. Identify high risk areas and highly vulnerable assets. Use "smart" technologies to monitor the health of infrastructure assets.
Alternatives Evaluation and Program Optimization	Include alternatives that use probabilistic design procedures to account for the uncertainties of climate change. Possible application of climate change-related evaluation criteria, smart materials, mitigation strategies, and hazard avoidance approaches.
Short- and Long-Range Plans	Incorporate climate change considerations into activities outlined in short and long range plans. Incorporate climate change into design guidelines. Establish appropriate mitigation strategies and agency responsibilities.
Program Implementation	Include appropriate climate change strategies into program implementation. Determine if agency is actually achieving its climate change adaptation/ monitoring goals.
Performance Monitoring	Monitor the asset management system to ensure that it is effectively responding to climate change. Possible use of climate change-related performance measures. Use "triggering" measures to identify when an asset or asset category has reached some critical level.

Source: Meyer, Amekudzi, and O'Har (2009).

In South Asia, the World Bank piloted the integration of disaster risk into the life-cycle management of transport infrastructure. A transport asset management system was developed in Bhutan that incorporated appropriate vulnerability attributes. The database helps monitor assets to plan operations and maintenance activities but also helps identify critical and weak links in the transport network that are vulnerable to disasters. Additional pilots of the approach are being prepared in Sri Lanka, Nepal, and Belize. The objective of these engagements is to raise awareness beyond the ministries of transport, particularly with ministries of finance, on the importance of understanding current risks, reducing transport infrastructure vulnerability, and ensuring future risks are fully taken into account in new transport infrastructure investments and plans.

Belize has most of its population and key economic assets located near the coast and is one of the countries most vulnerable to climate change . A lack of redundancy in the road network makes it particularly vulnerable: 70 percent of the population lives near primary and secondary roads, and flooding of just one section of roadway can sever access and severely disrupt economic and social movement.

The government of Belize, with assistance from the World Bank, developed a multisector National Climate Resilient Investment Plan that identified key vulnerabilities to climate change and laid out a set of strategic investment priorities. A participatory and information-based process was used to develop the plan, with the transport network at its center given its socioeconomic importance.[16] The project included the development of a comprehensive methodology based on the socioeconomic criticality and flood susceptibility of the primary and secondary road networks to identify priority areas of intervention. The assessment of flood susceptibility used a data-driven analysis. The participatory, multicriteria evaluation process involved representatives from ministries, municipalities, the private sector, civil society, NGOs, academic institutions, and international financial institutions (Annex 3).

The analysis informed investments under the Climate Resilient Infrastructure Project, financed by the World Bank, which supports targeted retrofitting, rehabilitation, and reconstruction activities to strengthen the resilience of critical transportation infrastructure to natural hazards and climate change. The government has also used the plan to inform investments by international donors.

4.3 Resilient Infrastructure Solutions

Resilient solutions are designed to reduce the impacts of current and future climate risks. They span a broad range of investments, from physical infrastructure and new technologies to community-based adaptation and approaches that focus on maintenance planning.

Most road projects in the World Bank's transport adaptation portfolio have been focused on "engineering" (or structural) approaches designed to address issues such as subsurface conditions, material specifications, cross-section and standard dimensions, drainage and erosion, and protective engineering structures. Many of the projects addressed expected climate impacts such as changes in rainfall, flooding, and sea-level rise that could impact a section of a road or bridge.

In all cases they have been designed to ensure that transport infrastructure and systems are *robust*, have *redundancy*, and are *resilient*. Robustness considers the ability of the transport system to absorb and withstand disturbances. Redundancy considers the extent to which transport services, as a component of a system, can remain functional in the face of spot failures in its network. Resilience is the ability of the whole transport network to support or facilitate community and national efforts to adapt to climate change.

For example, the Burundi Infrastructure Resilience Emergency Project includes measures to protect slopes, stabilizing embankments, rehabilitating drainage systems, and redirecting groundwater. In the Pacific islands, the Kiribati Road Rehabilitation Project adjusted the final design of the road rehabilitation program to ensure it integrated robust coastal protection measures that minimized erosion. Similarly, the Belize Climate Resilience Infrastructure Project involves retrofitting and rehabilitating existing primary and secondary roads. In India, the Bihar Kosi Flood Recovery Project is financing the reconstruction of roads and bridges following flooding to build resilience through enhanced drainage to limit damage caused by future floods.

The World Bank has been applying such approaches to strengthening the climate resilience of airports as well, such as in the aviation investment projects for Tuvalu and Vanuatu.

The following section will look at the tools and methodologies used by World Bank in addressing resilience of infrastructure.

4.3.1 Screening Tools for Climate and Disaster Risk for Use in Early Stages of Investments

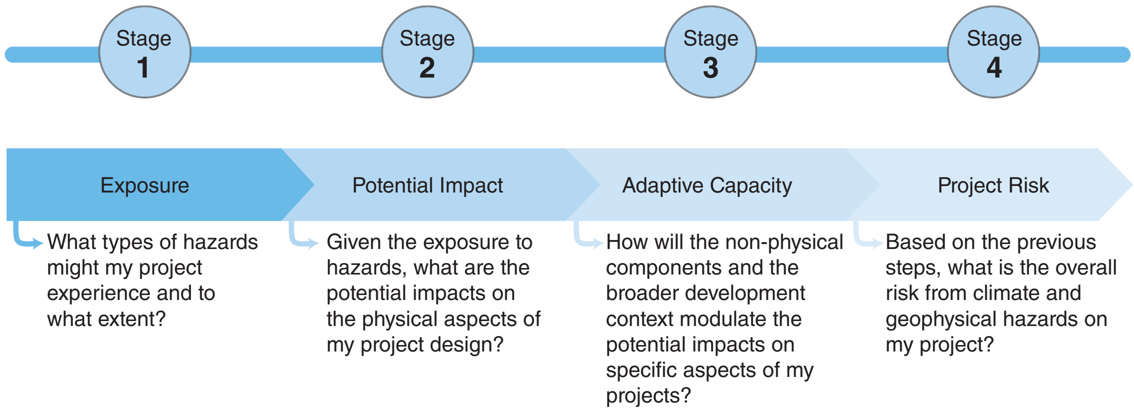
Risk screening is designed to identify at an early stage the climate and geophysical hazards that could impact the design of a strategy or project; it thus allows for proactive management of those impacts. Risk screening typically brings together local expertise and climate information to conduct the assessment. The World Bank has developed a suite of climate and disaster risk screening tools, including those relevant to transport systems.[17] The quality of output produced by the tools depends on expert knowledge and judgment and the quality of the available climate change and hazards information.

The tools—which classify risks as negligible, low, medium, or high—consider exposure, potential impact, and adaptive capacity to determine the risk to the development project (Figure 6). Initial observations from applying the tools for transport systems in IDA project countries suggests that considering the impacts of changes in temperature, rainfall, and extreme events on road surface materials, bridges, and ramps can help determine the risk from climate change (Box 8). In all cases, both short- and long-term risks from climate change should be considered.

[16] The work was conducted through financial support from the Africa Caribbean Pacific (ACP) European Union (EU) Natural Disaster Risk Reduction Program, received through the Global Facility for Disaster Recovery and Reconstruction.

[17] See the World Bank's Climate Change Knowledge Portal, http://climateknowledgeportal.worldbank.org.

FIGURE 6 Climate and Disaster Risk Screening Methodology



BOX 8 Emerging Lessons from Screening Transport Projects for Climate Risk in IDA Projects

A recent portfolio-level review looked at the experience with using the World Bank's climate and disaster risk screening tools for transport projects financed by the World Bank's International Development Association (IDA). The review yielded a number of conclusions and insights.

- Exposure to climate hazards, particularly extreme precipitation and flooding, but also coastal hazards, sea level rise, and storm surge, is rising.
- A project's overall sensitivity to climate change drives potential impacts on physical infrastructure, such as road-surfacing materials, bridges, and ramps. This includes increases in the variability of temperature and precipitation and increases in the intensity of extreme events like flooding and heat waves. Extreme precipitation and flooding are especially highlighted.
- Considering climate risks early in project design matters. For instance, coastal hazards such as sea-level rise and storm surge were not prevalent in many projects analyzed, but where they are present they are expected to present high risks to the location and physical investments. Designing projects in a way that accounts for the current and future risks can help to reduce the sensitivity of transport investments in the medium and long term.
- "Soft" measures such as capacity building, data gathering, policy development, and strategic planning are important for improving the adaptive capacity of the institutions and people that manage and rely on transport networks and should be enhanced.
- The broader development context, including the nationwide transport sector and socioeconomic and political factors, present challenges and opportunities for managing climate risks. This highlights the need to address systemic problems at the country level and integrate the principles of climate resilience where possible.

4.3.2 Decision-support Systems for Evaluating and Including Impacts on Economic and Social Continuity of Alternative Transport Network Investments

Decision-support systems are needed during the investment planning process to help countries and cities understand and evaluate the impacts on economic and social continuity of transport network investments. Such investments might cover the incremental costs of maintenance regimes and assure the provision of spare capacity, back-up systems, and alternative services during spot failures of portions of the transport network. Decision-support systems could be used.

Through its Resilient Cities program, the World Bank has developed a "City Strength" diagnostic using a holistic approach to identify priority actions and investments to strengthen urban

CLICK BOX TO READ MORE...

BOX 9 Building Resilience in Can Tho City, Vietnam

Can Tho City is the 4th largest city in Vietnam and the economic engine of the Mekong Delta Region. In 2014 the city reported annual GDP growth of 12 percent.[a] As one of the 13 Mekong Delta provinces, and being located along the Bassac River (Hau River), Can Tho City shares the hazards of the larger Mekong Delta. The city is susceptible to flooding caused by Mekong alluvial overflow, high tides, and extreme rainfall events. Seasonal flooding typically impacts 30 percent of the city area, but has recently increased to 50 percent (Huong and Pathirana 2013), and the city was seriously flooded every year from 2011 to 2014.

Transport infrastructure in Can Tho is predominantly dependent on roads, rendering the transport sector vulnerable to disruptions caused by seasonal flooding. While the city has assessed transport investments based on flood risks, the link between transport and urban land-use planning is not fully considered. In general, road investments in Can Tho have tended to focus on improving access to existing communities or providing access to large-scale economic development sites. The scale and nature of land use along the roadways has not been sufficiently monitored or planned, and the result has been sprawling growth into low-lying areas.

The city authorities had plans to upgrade the road network to the North of the city in order to improve freight delivery from the industrial zones lying in the Mekong Delta. They also counted on that upgrade to help them with disaster recovery. A World Bank diagnostic revealed however, that pursuing a program of road upgrades outside the city center would actually attract settlement in the plains, around the new roads. The plains being susceptible to flooding, this would only increase the vulnerability of the population.

The diagnostic showed also that if more provisions were not made to encourage more settlement in and immediately adjacent to the historic center—which is not only the main generator of jobs of the region, but also the highest elevation within Can Tho city limits—urban sprawl would probably take place on the other side of the Mekong River, to the Southeast of the city center, where the national government had just constructed a bridge across the river.

Based on this diagnostic, the city of Can Tho reprioritized its investments, choosing instead to strengthen the city center with a bridge connecting the new city bus terminal with the traditional city center, and a ring road providing better connection to other provinces, while allowing traffic to avoid the city center.

[a] "Can Tho Overview," http://cantho.gov.vn/wps/portal/.

Flooding in Can Tho Vietnam

PLAY VIDEO

systems.[18] It also uses a consensus-based approach bringing together a multisector team of experts to engage with city partners for an intensive week of workshops and one-on-one meetings. During these meetings climate impacts and stresses are identified, the city's resilience characteristics (overall and for each sector) are assessed, resilience-enhancing actions are developed and prioritized, and a program of actions and investments recommended.

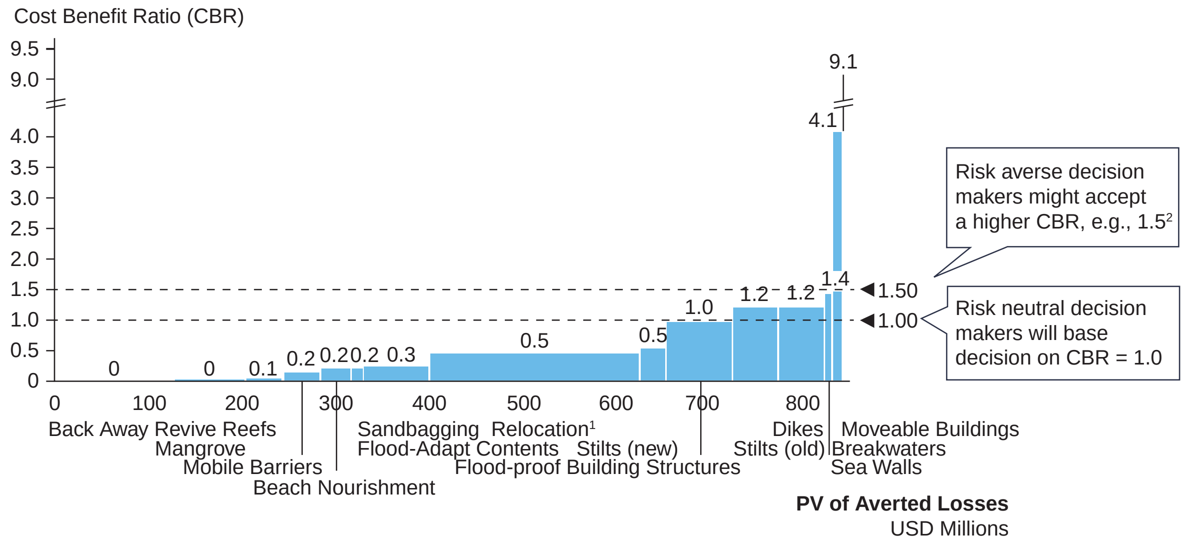
Two innovations in the City Strength methodology are the *simultaneity of the evaluations*–experts from different sectors are carrying out their evaluation at the same time, and comparing notes in real time—and the *commonality of approach across sectors*. Resilience in each sector is evaluated against six dimensions: robustness, reflectiveness, redundancy, inclusiveness, diversity, and coordination. To date, the City Strength diagnostic has been piloted in Can Tho City, Vietnam (Box 9), and Addis Ababa.

4.3.3 Cost-Risk Assessment Framework under a Given Climate Change Scenario

Cost-risk assessment provides a decision-making framework for systematically evaluating the merits of investments that enhance resilience and prioritizing them. The assessment

[18] http://www.worldbank.org/en/topic/urbandevelopment/brief/citystrength.

FIGURE 7 Cost-Benefit Assessment of Options for Samoa to Reduce Annual Expected Losses from Coastal Flooding



[1]Relocation only includes residential and commercial buildings outside of Apia
[2]For example, a cost benefit ratio of –1.5 is implicity accepted by customer's purchasing an insurance contract with a loss ratio betwen 60 and 70%

framework estimates how much each option could reduce risk-weighted economic and social costs and compares that result with the cost of implementing the measure. The framework takes climate change as given. The options are evaluated against a known probable distribution of climate phenomena and the likely loss of benefits associated with each of them. This approach differs from the "robust decision-making" approach (discussed in the next section), which evaluates options under uncertainty about climate risks at a specific location.

In Samoa, high-value assets such as buildings and roads are located in coastal areas that are exposed to increasingly severe storm surges, cyclones, and coastal flooding. For instance, a category 5 storm hit Samoa in 2008, when it was considered to be a 50-year event; by 2030 it may become a 20-year event. In 2008, the annual expected loss from coastal flooding amounted to $25 million, or 5 percent of the country's GDP. In a scenario with a high degree of climate change, the annual expected losses from such flooding could reach $80 million, or 9 percent of (larger) GDP.

Figure 7 shows the cost-benefit assessment for Samoa with a variety of options to reduce the annual expected loss from coastal flooding.[19] The government of Samoa is conducting a risk-based assessment of vulnerability and hazards for its road network that will include resilient infrastructure solutions that are technically feasible and appropriate for the Samoan context (see Box 10).

In some cases, risk and vulnerability assessments have been combined with net-present-value analysis to determine when adaptation options can be financed on commercial terms. For example, a climate risk study of the port in Cartagena, Colombia, identified the effects of climate risks on financial returns and environmental and social performance (International Finance Corporation 2011). The effects included the impact of sea-level rise on the port infrastructure; the consequences for internal and external operations of changes in storm surge, temperature, and precipitation; and climatic impacts that can damage the goods transported through the port or disrupt the transportation chain.

The risks were then quantified and incorporated in the company's financial model, which clearly showed the materiality of various risks over time. Lastly, adaptation solutions and quantified investments were incorporated into the model, demonstrating priority initiatives that could be financed on commercial terms. Following the publication of the study, the port company announced investments of $10 million in the recommended adaptation actions.

4.3.4 Decision Making under Uncertainty

Coping with a less predictable climate requires new decision-making tools designed to reduce risks under conditions of deep uncertainty. The DMU framework is a formalized approach to evaluating options given uncertainties about long-term climate at a specific location. This approach contrasts with traditional decision-making tools that rely on knowing the probability distribution of climate phenomena and the likely loss of benefits associated with each of them.

Deep uncertainty is the condition under which the probability distribution of outcomes from low-probability, high-impact

[19] Economics of Climate Adaptation Working Group (2013).

BOX 10 Toward Climate-Resilient Infrastructure Systems in Pacific Island Countries

Pacific island countries are highly vulnerable to climate change and severe weather events.[a] Roads are typically located adjacent to the coast, often less than a meter above sea level. Severe damage to road networks can block access to other services and critical infrastructure, such as hospitals, schools, port facilities, power plants, and airports. Between 2012 and 2015, tropical cyclones caused physical damage and economic losses in Samoa, Tonga, and Vanuatu ranging from 11 percent to 60 of the respective islands' GDP. The World Bank has been assisting Pacific island governments in the following ways to meet their severe transport challenges.

- Spatial planning and risk-based tools to more effectively prepare for climate change and severe weather. Samoa and Tonga, for example, are making effective use of Light Detection and Ranging (LiDAR) technology, which provides high-resolution aerial photographs to generate elevation data and strengthen spatial hazard mapping analysis. Samoa integrates LiDAR with an existing a citizen-engagement planning tool that assesses the resilience of coastal infrastructure for extreme weather events.
- Fit-for-purpose infrastructure solutions for elevating low-lying main roads, installing drainage, using geocell paving technology for low-volume roads and strengthening coastal infrastructure.
- Strengthening the enabling environment by building the capacity of government and supporting legal and regulatory reforms that improve the delivery of government resources.
- Post-disaster recovery support.

Early lessons from Kiribati, Samoa, and Tonga point to (1) the importance of resilient roads to ensure economic growth and intra-island connectivity, (2) the need for financial sustainability and long-term donor engagement, and (3) the need to raise awareness among road authorities on these issues. Achieving positive project outcomes depends on keeping design and implementation arrangements simple and ensuring that local communities are engaged in projects from start to finish.

[a]The World Bank Group has active engagements in 10 Pacific island countries: Federated States of Micronesia, Fiji, Kiribati, Marshall Islands, Palau, Samoa, Solomon Islands, Tonga, Tuvalu, and Vanuatu.

Source: World Bank (2013a).

events is unknown, such as when extreme weather events are projected to increase at unknown intensities, frequencies, and geographical distributions. Rather than asking what the future is likely to bring, decision makers facing deep uncertainty must ask, "What actions should we take, given that we do not know the future?"

DMU strikes a balance between, on the one hand, "coverage" against uncertainty (analogous to insurance) and, on the other, a society's threshold for acceptable risk and its financial resource constraints. By giving decision makers the tools to weigh trade-offs between the cost of coverage and acceptable risks, DMU helps them better define and select from investments and policy choices that are robust across a wide range of possible futures.

DMU analysis covers many sets of assumptions to understand how strategies and plans perform in a wide range of conditions. It uses statistical analysis and visualizations to identify the specific conditions that would lead to selecting one decision over another. Information is shared in an iterative way with decision makers to build consensus around decisions (World Bank 2013a).

When transport policy makers must decide on long-lived investments in new infrastructure while confronted by deep uncertainty, DMU can provide a wide array of options for location, capacity, and other design features. In contrast to the traditional approach of focusing on the "optimal" option, RDM aims to present the option that minimizes adverse climate impacts and has consensus among stakeholders. Such an approach tends to yield road construction that can withstand temperature increases and climate-smart land-use policies for locating new infrastructure.

DMU allows decision makers to reconsider an investment or policy if new information becomes available, thereby helping them avoid being locked into technologies that are costly to reverse and are maladapted to future conditions, both climatic and nonclimatic. Preserving future choices has a value in itself and can increase the ability to adapt to evolving economic and climate contexts.

BOX 11 Decision Making under Uncertainty in Africa

In Africa, the World Bank applied decision-making techniques to look at the resilience of road networks to future climate change (World Bank 2015f). The study assembled a database of reasonably foreseeable road infrastructure in Africa through 2030 was assembled. Ninety-one possible climate scenarios for each link in the road network were applied to explore climate vulnerability. Based on the assumption that each scenario is equally plausible, a limited but likely set of discrete adaptation responses were evaluated against two criteria: minimizing "maximum regret" and satisfying the widest range of possible futures.

The results constituted a significant case for adapting road design in Africa to temperature stressors but not to precipitation and flood stressors. Although the study was complex and required enormous computational power, its results indicated that methodologies for decision making in the face of deep uncertainty have great potential.

At the World Bank, DMU techniques have been used to explore options that build the resilience of road networks across Africa through 2030 (Box 11). The analysis highlighted the value of adaptation to temperature stressors in road design.

4.4 Enabling Environment

Strengthening the enabling environment is as important as strategic planning and investments in infrastructure solutions. Strengthening clients' capacity to manage considerations of climate change and disaster risk means applying those considerations across policies and regulations, institutions, and investments and requires engagement on a number of fronts.

Policies, plans, and codes need to be aligned with local vulnerabilities to current and future climate change so as to enable adaptation. Attaining that alignment often requires investments in human, institutional, and technical capacity to raise awareness of the issues and the ability to develop and enforce the needed codes and standards. In Morocco, for example, existing standards could make roads more resilient to current climate conditions, but these standards had not been enforced (Box 6).

The World Bank has provided direct support to develop technical guidelines and training programs that build climate resilience into the design of road infrastructure. For example, in the Haiti Center and Artibonite Regional Development Project, the World Bank financed goods, technical assistance, and training. In Madagascar, which is increasingly affected by cyclones, the World Bank helped develop a simple spatial risk categorization for the island to inform the development of resilient building codes (Box 12).[20] The resilience of transport and other infrastructure is being advanced in Madagascar through the use of local expertise; extensive testing of the codes; awareness, training, and regulatory incentives; and a decree to enforce the codes through a simple process of compliance.

Investments in information support systems are needed to collect, organize, store, and analyze climate data. Such data are the basis for risk evaluation and the use of event monitoring tools. They are likewise critical to informed decisions about a system's operation and maintenance needs; and for prevention, early warning, and response capabilities that help minimize disruptions in the event of climate impacts.

The World Bank is supporting the development of early warning weather information systems and contingency plans for emergencies. Early warning systems provide on-demand forecasts that deliver tailored, timely information on weather, flash floods, and fire risk. By focusing on the prevention of adverse impacts from natural disasters, early warning systems can significantly reduce costs.

The transport sector can greatly improve disaster management and recovery by developing contingency plans that ensure service delivery during and after weather events. In the Madagascar Emergency Infrastructure Preservation and Vulnerability Reduction Project, the World Bank is financing disaster risk management capacity strengthening. This includes rehabilitating critical elements of the hydro-meteorological network, early warning systems, and the capacity building for national and local staff in charge of national responses to disasters.

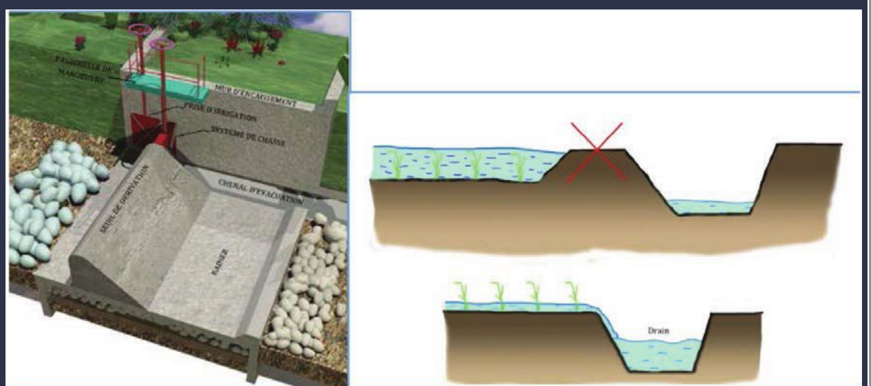
The allocation of adequate funding and resources is an important element of resilient infrastructure systems. With national climate plans providing a framework for climate action, finance ministers will have a key role to play in budgeting to support their implementation. Reviews have been used in a number of countries to evaluate the effectiveness and efficiency of climate-related public spending and to align expenditures with a country's needs and objectives.[21] This experience has highlighted some lessons on how to address the fiscal implications of climate change: (1) include climate

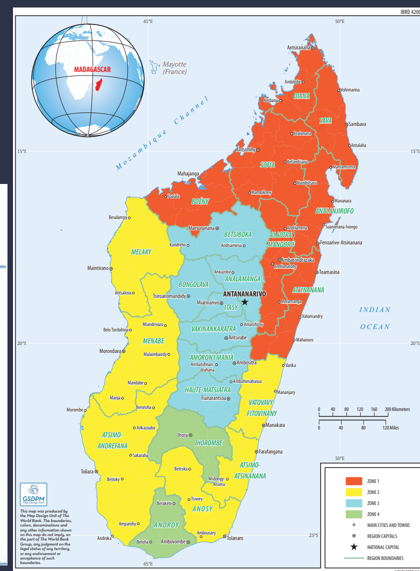
[20] The project was supported by the governments of Norway and Finland through the Trust Fund for Environmental and Social Sustainable Development.

[21] Policy Note, Moving Toward Climate Budgeting, World Bank, 2014.

BOX 12 Risk Planning and Resilient Infrastructure Codes in Madagascar

Madagascar's National Unit for the Prevention and Management of Disasters developed building codes for weather-resistant transport infrastructure, relying mostly on local experts. The country was divided into risk zones based on hydro-geological characteristics, existing assets, river morphology, and projected climate change scenarios. Safety return periods and improvement in designs were then developed for the different risk zones and types of infrastructure, as illustrated here.





The table shows minimum return periods (in years) identified for transport infrastructure:

Zone	Roads		Drainage		Bridges		Dikes
	Surface	Embankment	Longitudinal	Transversal	Decks	Pillars	
High Plateau, High Rainfall	150	150	50	150	300	150	150
High Plateau, Low Rainfall, Occasional Flooding	50	50	50	50	300	100	100
Watersheds in Extreme South	75	75	50	75	300	150	150

The experience of Madagascar provides several important lessons. The codes were developed at very low cost and relied heavily on local knowledge and dedicated national champions. The codes were extensively field tested and discussed with industry and communities. Awareness, training, and regulatory incentives were as important as the codes themselves. A proposed decree on building codes was discussed at length with legal experts and experienced implementers to ensure that potential loopholes would be addressed. The adopted decree was kept very simple to help ensure compliance.

change as a long-term objective in the national budget and expenditure framework, (2) improve financial tracking and performance accountability by spending agencies, and (3) strengthen government financial management systems to efficiently use external climate finance.

The Philippines, for example, completed a Climate Change Public Expenditure and Institutional Review in 2013.[22] It recommend strengthening the planning, execution, and financing framework for climate change; enhancing leadership and

[22] Getting a Grip on Climate Change in the Philippines, World Bank, 2013.

accountability; and building capacity to manage change. The government is institutionalizing these recommendations to deepen the quality of planning, prioritization, and identification of funding gaps so that the entire budget cycle can more effectively support a national climate response. To date, 53 agencies of the Philippines government have prioritized climate change expenditures in their 2015 budget proposals. A common framework for "climate change expenditure tagging" has been implemented across the government and is being piloted by local governments for the 2015 budget. Through its technical budget hearings, the national government has begun examining climate change prioritization in agency budget submissions.[23]

Contingent disaster reconstruction financing by the World Bank is increasingly used to support emergency measures that reduce damage to infrastructure and enable early rehabilitation. The financing is triggered when a national disaster occurs and the government asks the World Bank to reallocate loan proceeds for post-disaster recovery. This has enabled the World Bank-financed China Fujian Fishing Ports Project to upgrade ports to provide shelter from storms, finance improvements to port early-warning systems, and build capacity for response. It has also been used in the Madagascar Emergency Infrastructure Preservation and Vulnerability Reduction Project.

Lastly, having tools in place to **measure and monitor resilience** can help countries proactively adjust approaches to enhance resilience. In that regard, work is under way at the World Bank to develop an approach to measuring the reduction in socioeconomic vulnerability at the national level. Such an indicator will help support policy choices and enhance resilience by reducing the impact of disasters on communities. Further work is planned to apply the approach to nonextreme climate changes and pilot this in other countries and sectors.

The methodology is based on a simple economic model of disaster impacts. Initially piloted for river floods in 90 countries, it provides a qualitative scorecard covering 14 indicators of well being and resilience. The score on poverty as well as on other indicators—access to finance, social protection, health care, and early warning systems, especially for poor people—can be increased by better transport links, especially in rural areas. For instance, in Ethiopia, the incidence of poverty decreased by 6.7 percent after farmers gained access to all-weather roads (Dercon et al. 2009). More generally, greater interconnectedness among regions can mitigate the effects of weather shocks: in colonial India, for example, rainfall shortages led to famine, but these effects disappeared almost completely after communities were connected to railroads (Burgess and Donaldson 2010).

[23] http://www.worldbank.org/en/country/philippines/publication/mobilizing-budget-for-climate-change-in-philippines

4.5 Postdisaster Risk and Recovery Support

Many countries face increasing damage and losses from weather-related events (e.g. Samoa, Belize, and the Philippines). Ensuring that postdisaster building efforts improve climate resilience based on the principle of "building back better" is an imperative. The World Bank's experience suggests the following guiding principles for ensuring focus on enhanced climate resilience:

- Shift from an asset-based to a systems-based approach to capture the interactions between the technical, social, economic, and organizational components of a transport system over time (Annex 3).
- Operationalize the concept of resilience to complement risk analysis when planning and designing transport projects. This means moving beyond risk management to proactively enhancing resilience (Table 6).
- Identify and engage with all the stakeholders who own, manage, and influence the resilience of transport systems before, during, and after disasters.

These guiding principles are informing decisions throughout the various stages of disaster risk management, from preparedness to rebuilding after a disaster (Box 13).

TABLE 6 Risk versus Resilience Approaches

Risk Management	Resilience
Risk analysis calculates the probability that known hazards will have known impacts	Resilience analysis improves the system's response to surprises and accepts uncertainty, incomplete knowledge, and changing conditions
Bottom-up analysis assesses impact of hazards on component's critical functionality	Top-down analysis assesses interdependencies and interactions at a system level
Assesses the impact at one point in time	Includes a temporal dimension
Minimizes probabilities of failure	Minimizes consequences of failure
Strategies include robustness, strengthening, oversizing	Strategies involve adaptation, innovation, flexibility, learning, diversity, redundancy, safe failure

Source: World Bank 2015e. Adapted from Park et al. (2012).

BOX 13 Moving toward Climate Resilience through the Disaster Risk-Management Cycle

Practical measures can be implemented to build resilience in transport systems in all phases of the disaster risk management cycle, from disaster preparedness to rebuilding (see World bank 2015e):

Risk Assessment and Management as Part of Disaster Preparedness

- Define a central agency that can coordinate and mediate the responsibilities across the system.
- Apply a design approach that is sensitive to the environment and the performance of the whole network over time.
- Specify the resilience of the system as a key objective in transport planning.
- Define the role of asset owners in mainstreaming as part of policy development.
- Document the condition of existing infrastructure assets and provide access to such data as part of infrastructure planning and design.
- Engage in cross-sector coordination and innovative financial arrangements to incentivize resilience.
- Increase awareness of resilience so that all stakeholders understand the need for resilience and what it entails.

Emergency Response and Risk Reduction

- Priorities immediately after a disaster are restoring critical lifeline routes and regaining basic access and mobility so that society can quickly resume a basic level of functionality.
- Consider redundancy, diversity, flexibility, and robustness when planning for emergency recovery.
- Effective recovery requires relevant and timely information and the capacity to rapidly mobilize resources.

Postdisaster Recovery and Reconstruction

- Establish an enabling predisaster framework that involves coordination among all stakeholders to improve the resilience of assets and systems after a disaster.
- Predisaster planning must encourage a shift from a "like for like" approach in reconstruction to "building back better."

5

> "The case for climate action has never been stronger. Given the scale of the climate challenge, the vulnerability of transport services (and thus of the markets and communities they serve), and the emerging demand shown in submitted INDCs, mainstreaming the building of resilience in the transport system will require a more systematic approach."

Opportunities and the Way Forward

The World Bank has been working with client countries on how to ensure that transport plans and investments are robust to current and future climate change. Innovative methodologies, tools, and planning approaches have been developed jointly with client countries and other partners and piloted at the local level. However, given the scale of the climate challenge, the vulnerability of transport services (and thus of the markets and communities they serve), and emerging demand shown in submitted INDCs, mainstreaming the building of resilience in the transport sector will require a much more systematic approach.

The good news is that we are not starting from scratch, as demonstrated in this report and by emerging work beyond the World Bank. An important opportunity now exists to work with partners to gather this experience, crowd-in the necessary expertise, and translate it into a comprehensive toolkit. The goal would be a structured framework for the conceptualization, design, and implementation of plans and operations that would enable transport policy makers and practitioners to incorporate climate vulnerabilities in their decisions.

Such a framework would need to be underpinned by training and capacity support. Information and institutional strengthening would be required regarding the challenges of global warming, the implications for the transport sector, and the available tools and techniques to build climate change considerations into planning and investment design. Better integrating climate risk considerations into planning and investments will help reduce the cost of delivering transport services, which are an engine of growth.

At the World Bank, we will scale up resources and expertise to help meet these needs together with our clients and partners. We will deploy our technical expertise, our capacity to convene, and our engagements on the ground to further develop and refine tools and approaches tailored for policy makers, practitioners, and local stakeholders. The process will allow climate change analysis to be more easily integrated into transport plans and investments to enhance local and countrywide climate resilience.

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ANNEX 1 CLIMATE FINANCE TRACKING

The World Bank's internal methodology for Climate Change Adaptation and Mitigation Co-benefits[24] is harmonized across the Multilateral Development Banks that report jointly on an annual basis.[25] It is closely aligned with the International Development Finance Club through Common Principles for Mitigation[26] and Adaptation[27] Finance Tracking.

The methodology is built on the premise that development finance is being provided in a world shaped by climate change. It recognizes that activities on climate change extend beyond financial support in many areas, to include, for example providing advice on project design and policy dialogue. Often, technical support to clients on climate change is small in financial terms, but delivers major impacts for low-emission and climate-resilient development.

Mitigation finance is based on a typology that focuses on the type of activity to be executed, and not on its purpose, the origin of the financial resources or actual results. An activity is classified as related to climate change mitigation if it promotes "efforts to reduce or limit greenhouse gas (GHG) emissions or enhance GHG sequestration." The typology of mitigation activities is included in the 2014 Joint Report on MDB Climate Finance.

Adaptation finance is calculated based on a context- and location-specific, conservative and granular approach that is intended to reflect the specific focus of adaptation activities and reduce the scope for over-reporting of adaptation finance against projects. Adaptation finance tracking relates to tracking the finance for activities that address current and expected effects of climate change, where such effects are material for the context of those activities.

The reporting of adaptation finance is limited solely to project activities that are identified in the project document and that:

1. Set out a clear context of risks, vulnerabilities and impacts related to the effects of climate change and the project: the context is set through the use of authoritative published analyses, such as academic journals, national communications to UNFCCC, IPCC reports, World Bank's Climate Change Knowledge Portal (cllimateknowledgeportal.worldbank.org), or original analyses using records from trusted sources and incorporating best existing knowledge. The analyses should include not just historical climate and weather patterns but projected changes appropriate for the life span of the activities supported by the project, e.g., for land-use planning, it would be 50+ years; for bridges, 30–50 years, etc.
2. Make an explicit statement of intent to address the identified climate risks and vulnerabilities as part of the support from the project.
3. Set a clear and direct link between the risks and vulnerabilities identified in the first step and the project activities included in the components and subcomponents or in policy actions.

This is important for distinguishing between a development project contributing to climate change adaptation and a standard "good development" project. For example, revising building codes for infrastructure design to consider the increased frequency or severity of extreme events would be considered a climate adaptation co-benefit.

[24] http://go.worldbank.org/RM27OYR5F0

[25] http://documents.worldbank.org/curated/en/2015/06/24641149/

[26] http://www.worldbank.org/en/news/feature/2015/04/03/common-principles-for-tracking-climate-finance

[27] http://www.worldbank.org/en/news/press-release/2015/07/09/development-banks-common-approach-climate-finance

While mitigation projects often may be classified by technology, whether a project is adaptation or not depends on setting the local context. For example, while high-volume drainage systems in roads located in areas that have always had high precipitation and runoff would be normal good practice, the same drainage systems incorporated in infrastructure where runoff is increasing or projected to increase due to the effects of climate change—and as a direct response to these events—would be considered adaptation to climate change.

In all cases a granular approach is applied to the financing of those project elements that directly contribute to (or promote) mitigation or adaptation.

ANNEX 2 WORLD BANK ADAPTATION PROJECTS IN THE TRANSPORT SECTOR

Project Name	Fiscal Year	Total Commitment Amount ($m)	Adaptation for Transport (%)	Policy Development/Reform/ Enabling Environment	Hard Measures	Soft Measures	Capacity Building	Knowledge Management/ Climate Services	Details
China: Anhui Shaying River Channel Improv	FY11	100	48%		X				River channel designed to account for climate change driven drought or flooding
Kiribati: Road Rehabilitation Project	FY11	20	94%		X				Roads designed and constructed so as to take into account rainfall changes and sea level rise
Samoa: Post Tsunami Reconstruction	FY11	10	71%	X	X				Repairing infrastructure in line with improved knowledge on adaptation needs and updating coastal infrastructure management plans
Timor Leste: Road Climate Resilience Proj	FY11	20	85%		X	X	X		Improving road corridor resilience, establishing response systems and capacity building
Mozambique: Maputo Municipal Development Prog II	FY11	50	24%	X	X				Reconstruction of roads with improved drainage and development of a master urban transport plan
Mali: Urban Local Government Support Project	FY11	70	14%		X				Funding for high priority roads to improve drainage and other climate related resilience
OECS Countries: Regional Disaster Vulnerability Reduction. Projects	FY11	47	11%		X		X		Rehabilitation and construction of bridges to be more resilient, and capacity building for infrastructure maintenance

Project Name	Fiscal Year	Total Commitment Amount ($m)	Adaptation for Transport (%)	Policy Development/Reform/ Enabling Environment	Hard Measures	Soft Measures	Capacity Building	Knowledge Management/ Climate Services	Details
Cambodia: Typhoon Ketsana Emergency Operation	FY11	40	69%		X	X			Reconstruction of roads with improved drainage and development of national and provincial risk maps, including risks and vulnerabilities to transport
Bangladesh: ECRRP Additional Financing—AF	FY11	75	2%		X				Construction of cyclone shelters and access road networks
India: Bihar Kosi Flood Recovery Project	FY11	220	25%		X				Reconstruction of roads and bridges following flooding to be more resilient, with new drainage to reduce risk of flooding
St. Vincent and the Grenadines: Hurricane Tomas Emergency Recovery Loan	FY11	5	13%		X				Rehabilitation of hurricane damaged road to improve resilience
Togo: Emergency Infrastructure Rehab Add Finance	FY11	15	7%		X				Rehabilitating urban roads, including drainage expansion to limit future flooding
St. Lucia: Hurricane Tomas ERL	FY11	15	40%		X				Rehabilitation of critical road infrastructure, and design to be more resilient
Kiribati: Pacific Aviation Investment—Kiribati	FY12	23	1%		X				Subcomponent to finish seawall construction
Cameroon: Lom Pangar Hydropower Proj. (FY12)	FY12	132	6%		X				Construction of access roads to new dam
Brazil: Sao Paulo Sustainable Transport Project	FY13	300	1%	X					Updating States' transport master plans to include climate risk
Ethiopia: Road Sector Support Project	FY14	320	4%	X					Financing project preparation for future operations, including on road climate resilience

Project Name	Fiscal Year	Total Commitment Amount ($m)	Adaptation for Transport (%)	Policy Development/Reform/ Enabling Environment	Hard Measures	Soft Measures	Capacity Building	Knowledge Management/ Climate Services	Details
Haiti: Ctr & Artibonite Reg Dev.	FY14	58	35%	X	X		X	X	Rehabilitating and climate proofing critical road network locations, developing guidelines for climate resilient roads, support for regional planning capacity, and support for information systems for climate and disaster risk
Mozambique: Roads and Bridges Management Maintenance	FY14	55	59%	X	X		X		Piloting a climate resilient road and building capacity for contractors and service providers along
Samoa: Enhanced Road Access Project	FY14	20	91%	X	X				Strengthening resilience of roads and supporting regulatory reforms for road asset management and standards for climate resilience
Timor-Leste: Road Climate Resilience Project	FY14	40	97%		X	X	X	X	Improving road climate resilience, design of emergency maintenance and response systems and capacity building
Tuvalu: Aviation Investment Project	FY14	6	25%		X				Mitigating impacts of climate change on the road network
Samoa: Development Policy Operation	FY14	15	14%	X					Road use regulations revised to enhance climate resilience
Grenada: 1st Programmatic Resilience Building DPC	FY14	15	7%	X					Improved design standards for roads and bridges
OECS Countries: (APL2)LC Disaster Vulnerability Reduction	FY14	68	25%		X	X			Reconstruction of roads and bridges to be more resilient and development and operationalization of a bridge maintenance plan, including integrated climate analysis
China: Fujian Fishing Ports Project	FY14	60	28%		X	X	X		Upgrading of ports to provide shelter from storms, improvement of port early warning systems and capacity building

Project Name	Fiscal Year	Total Commitment Amount ($m)	Adaptation for Transport (%)	Policy Development/Reform/ Enabling Environment	Hard Measures	Soft Measures	Capacity Building	Knowledge Management/ Climate Services	Details
Dominica: Disaster Vulnerability Reduction (APL3)	FY14	38	28%		X				Rehabilitation of selected primary and secondary roads and bridges to reduce vulnerability
Djibouti: 2nd Urban Poverty Reduction Pj-PREPUD II	FY14	6	16%		X				Financing of urban roads and drainage to reduce exposure to flood risks
Sri Lanka: Improving Climate Resilience	FY14	110	20%		X				Augmenting and improving roads and bridges to increase resilience to climate change
Bangladesh: Emergency Cyclone Recovery Project AF	FY14	140	33%		X				Construction of additional cyclone shelters and associated access roads
St. Vincent and the Grenadines: RDVRP (AF)	FY14	41	25%		X				Bridge rehabilitation and road realignment to repair flood damage and increase disaster resilience
India: Odisha Disaster Recovery Project	FY14	153	3%		X				Improvement of road infrastructure in urban areas to be more resilient
Bosnia and Herzegovina: Floods Emergency Recovery Project	FY14	100	40%		X				Rehabilitation of key road infrastructure following flooding
Burundi: Infrastructure Resilience Emergency	FY15	25	40%		X		X	X	Rehabilitation of key roads to include climate resilience and drainage, capacity building, and development of risk evaluation monitoring tools
Fiji: Transport Infrastructure Investment Proj	FY15	50	100%	X	X				Upgrading road infrastructure to be more resilient and updating design standards and specifications of roads to incorporate climate change impacts
Macedonia, FYR Road Rehabilitation	FY15	71	3%	X	X				Rehabilitating roads while accounting for climate impacts to prevent flooding, and financing economic evaluations of potential road investments with climate resilience measures

Project Name	Fiscal Year	Total Commitment Amount ($m)	Adaptation for Transport (%)	Policy Development/Reform/ Enabling Environment	Hard Measures	Soft Measures	Capacity Building	Knowledge Management/ Climate Services	Details
Vanuatu: Aviation Investment Project	FY15	60	28%		X				Strengthening the climate resilience of airport infrastructure
Vietnam: HCMC Green Transport Development	FY15	124	19%		X				Incorporating climate resilience along bus corridor
Mozambique: Second Climate Change DPO	FY15	50	14%	X					Vulnerability survey of unpaved roads in three provinces approved and design standards are revised to strengthen climate resilience
Belize: Climate-Resilient Infrastructure.	FY15	30	37%		X		X		Retrofitting and rehabilitation of existing primary and secondary roads to improve resilience and capacity building in the Ministry of Transport and Works on climate risk
Bangladesh: Multipurpose Disaster Shelter Project	FY15	375	10%		X				Improvement and construction of roads to provide connectivity to disaster shelters
India: Jhelum and Tawi Flood Recovery Proj	FY15	250	16%		X				Reconstruction of road infrastructure to better withstand flooding

ANNEX 3 ENHANCING RESILIENCE OF BELIZE'S TRANSPORT NETWORK THROUGH A PARTICIPATORY EVALUATION AND PRIORITIZATION PROCESS

The government of Belize integrated a participatory and information-based process into its administrative country structures and routines. The method was developed and implemented in about 18 months and included the participation of three main groups: (1) a team of technical representatives from public, private, and NGO entities; (2) CEOs from all involved ministries; and (3) the cabinet. The prioritization process was based on two pillars: ***flood susceptibility evaluation*** and the determination of socioeconomic criticality of the primary and secondary road network. For the hazard evaluation, an indicator-based approach was used, and criticality was assessed through a participatory multicriteria evaluation process.[28]

The flood susceptibility evaluation applied an indicator-based approach that considered two criteria: *Flooding at stream crossings* and *Indications of prior river floods* that impact segments of the road network (Figure 8). The choice of the methodology was determined by (1) the lack of sufficient hydro-meteorological and bathymetric data and of suitable-resolution topography; (2) the extent and large scale of the analysis needed; and (3) limited time and financial resources. The following data and information was used: a digital elevation model; the stream network; an inventory of the bridges and culverts that included information on their type, material, size, and condition; countrywide small-scale flood susceptibility based on assessments conducted in 1993; flood extent mapped after Tropical Depression 16 and flood records from newscasts. Additional information was collected during a field visit and in-depth conversations with engineers from the Ministry of Works and Transport.

[28] A summary of the process can be found in Annex 2 in the Project Appraisal Document available from http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2014/08/05/000350881_20140805100313/Rendered/PDF/PAD7120PAD0P120IC0Disclosed08050140.pdf

The criterion of *flooding at crossings* was determined on the basis of the following observations and assumptions: (1) flooding occurs most frequently at crossings of streams and roads due to insufficient capacity of road drainage structures (bridges and culverts); and (2) where stream crossing are in bad condition (obstructed or damaged), the hydraulic capacity is further reduced and the problem increased. These two assumptions translated into the indicators *number of streams crossing the road*, and *condition of the crossings*.

The criterion *Indications of past river floods* aims at integrating all available information on past events, indications from experts and existing studies, and flood characteristics. *Flood susceptibility* information and *flood records* from newspapers, expert information, and mapping of the flood extent after Tropical Depressions 16 formed the information base. In addition, *type of flooding* is also included given the varied impacts on transportation networks: flash floods occur in sloped areas, have a quick onset, and recede quickly after the rainfall events, whereas floods in plane areas may rise more slowly but may stay longer and thereby impede traffic for a longer time.

Weights were assigned under the assumption that the indicators as well as the criteria differ in the level of contribution toward overall flood susceptibility. For the analysis, the road network was segmented into 5 km stretches, and the analysis classified each stretch as having high, medium, or low susceptibility.

The criticality analysis was carried out through a Multi Criteria Evaluation (MCE) approach which is a decision-making tool developed to prioritize and rank options. It is based on the combined consideration of multiple qualitative and quantitative criteria. A key feature of an MCE is its emphasis on the judgment of a decision-making team in establishing criteria and estimating relative importance (weights) for each performance criterion (Figure 9). Thus, it is a participatory approach that can involve a multitude of stakeholders.

FIGURE 8 **Flood Susceptibility Analysis Approach:** The river flood susceptibility consists of two criteria (dark blue and dark orange boxes) which are composed of multiple indicators (light blue and light orange boxes). Thepercentage values shown are the weights applied to each criterion and indicator.

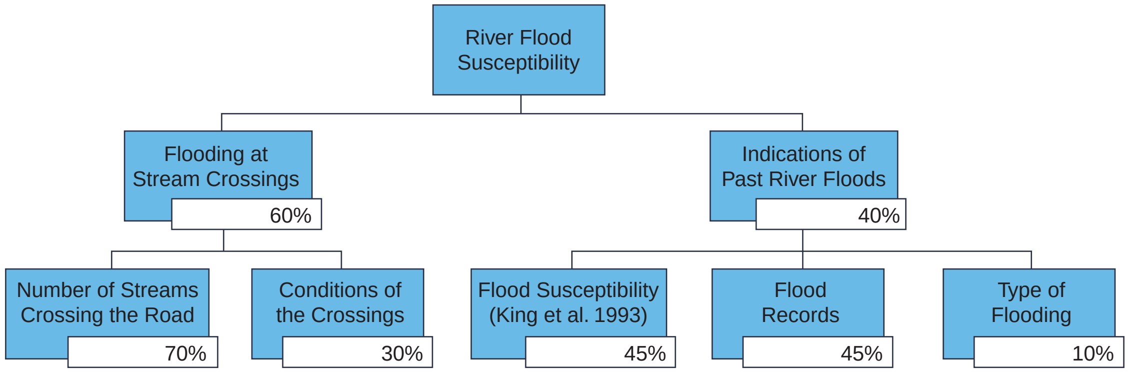
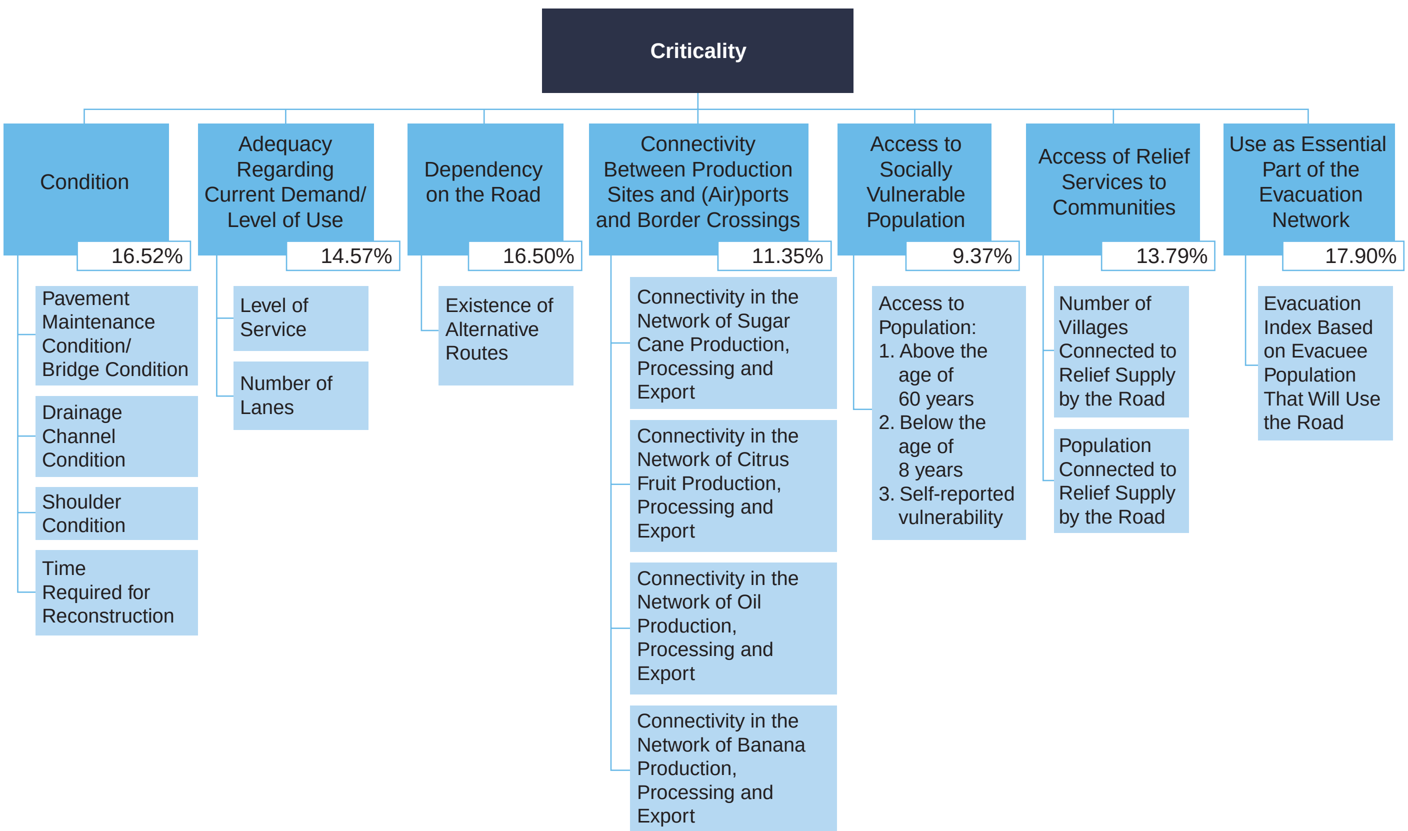


FIGURE 9 Criticality Is a Result of the Seven Criteria (top tier of boxes) Weighted by the Percentages Shown. Each criterion is evaluated according to the indicators in the second tier of boxes.



The result of the MCE process and calculations is an overall criticality value for each road stretch of the primary and secondary road network.

The combination of high criticality and high flood susceptibility yielded four priority areas (Figure 10). The findings were presented to the cabinet, which selected the area around Belize City as the first intervention. The government of Belize has since leveraged additional funds to address the other priority sites.

FIGURE 10 Priority Areas for Climate Resilience Intervention Based on Socioeconomic Criticality and Flood Susceptibility