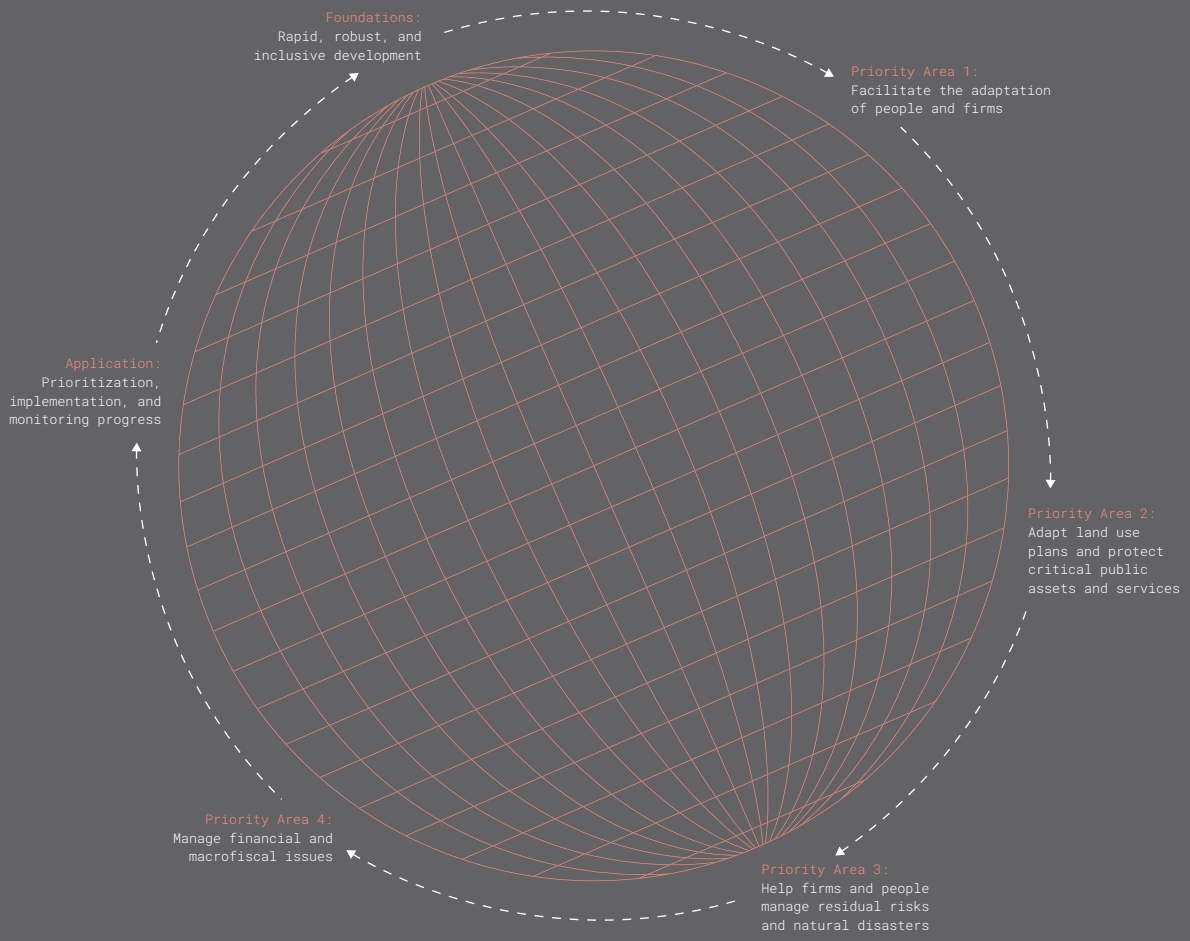
The Adaptation Principles

A Guide for Designing Strategies for Climate Change Adaptation and Resilience



Stephane Hallegatte
Jun Rentschler
Julie Rozenberg

WORLD BANK GROUP

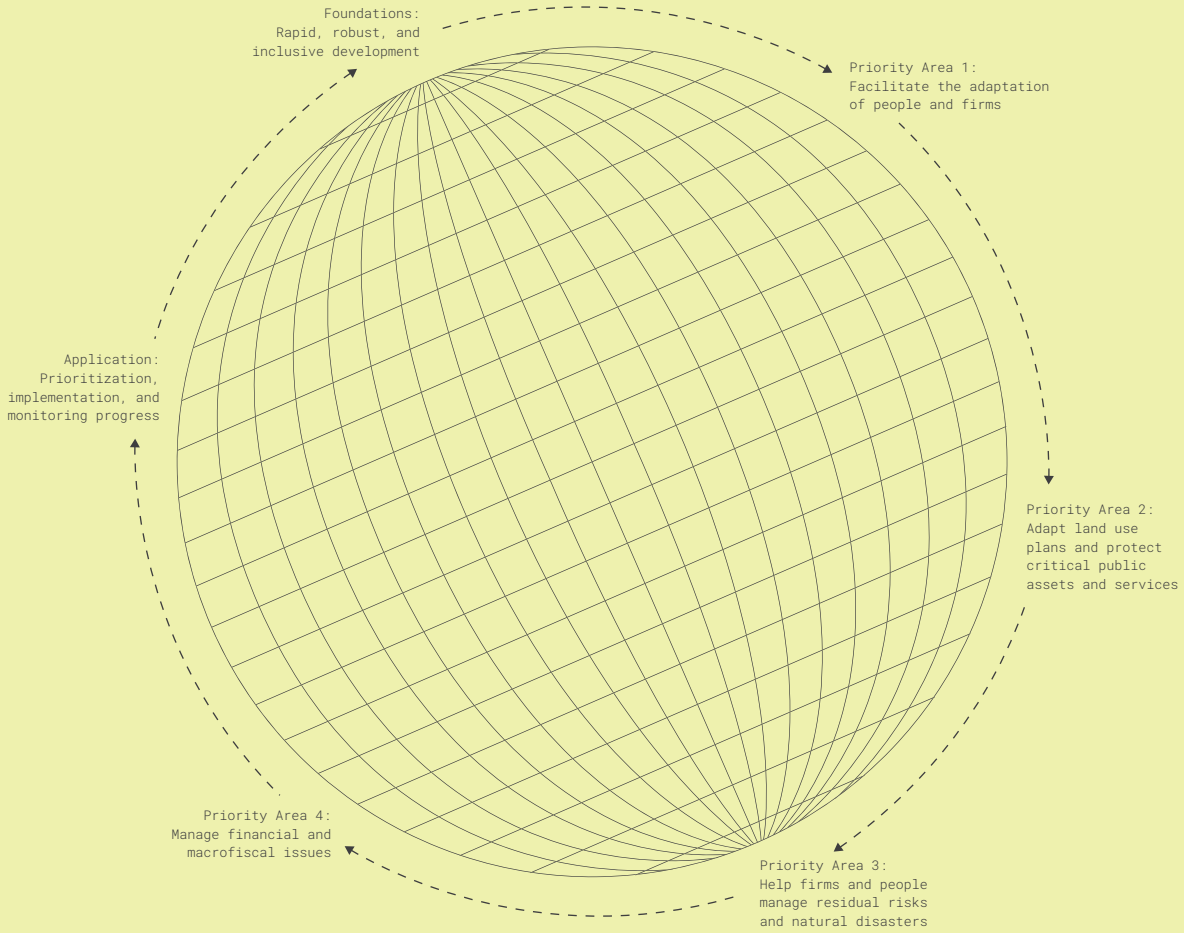
1818 H Street NW, Washington, DC 20433
Telephone: 202-473-1000; Internet: www.worldbank.org

Attribution—Hallegatte Stephane, Jun Rentschler, Julie Rozenberg. 2020. *Adaptation Principles—A Guide for Designing Strategies for Climate Change Adaptation and Resilience.* Washington, DC: World Bank.

Cover design by Brad Amburn.

The Adaptation Principles

A Guide for Designing Strategies for
Climate Change Adaptation and Resilience



Stephane Hallegatte
Jun Rentschler
Julie Rozenberg

WORLD BANK GROUP

Acknowledgements

The Adaptation Principles was prepared by Stephane Hallegatte, Jun Rentschler, and Julie Rozenberg. The report includes contributions from Samuel Fargher, Adrian Fozzard, Xenia Kirchhofer, Wei-Jen Leow and Onur Erdem. Ferzina Banaji, Donna Barne, Joana Lopes, Catherine Sear, and James Sullivan supported its launch and outreach. It was produced with financial support from the Global Facility for Disaster Reduction and Recovery, under the overall guidance and leadership of Bernice Van Bronkhorst, Global Director of the Climate Change Group of the World Bank.

As World Bank peer reviewers, Christian Bodewig, Nicola Ranger, and Gregor Schwerhoff provided invaluable comments and suggestions. Useful suggestions, comments, inputs, or data were also received from Miria A. Pigato, Martijn Regelink, Emma Dalhuijsen, Oliver Mahul, Wei-Jen Leow, Emmanuel Skoufias, and Mary Elinor Boyer. James Daniel and Matthieu Bellon, from the International Monetary Fund, also provided important feedback and comments.

Lucy Southwood was the production editor. Brad Amburn designed the report.

Acronyms

BCP	business continuity plans
Cat-DDOs	Catastrophe Deferred Drawdown Options
CGE	computable general equilibrium (model)
CPEIR	climate change public expenditure and institutional review
CVA	climate vulnerability assessment
DSGE	dynamic stochastic general equilibrium
EIU	Economist Intelligence Unit
EU	European Union
FONDEN	Fondo de Desastres Naturales / natural disasters fund
GDP	gross domestic product
GFDRR	Global Facility for Disaster Reduction and Recovery
IBRD	International Bank for Reconstruction and Development
IO	input-output
IMF	International Monetary Fund
ISO	International Standards Organisation
LMIC	low- and middle-income countries
MDB	multilateral development bank
M&E	monitoring and evaluation
NDC	nationally determined contribution
NPV	net present value
PCRAFI	Pacific Catastrophe Risk Assessment and Financing Initiative
PD-PFM Review	Post-Disaster Financial Management Review and Engagement Framework
PFM	public finance management
PIM	public investment management
PMT	proxy means testing
PPP	public-private partnership
PPP*	purchasing power parity
R&D	research and development
RDM	robust decision making
SOE	state-owned enterprise
TFP	total factor productivity
UK	United Kingdom
UNDP	United Nations Development Programme
US	United States

**used in figures only*

All dollar amounts are US dollars unless otherwise indicated.

Contents

Toolboxes

COVID-19 spotlights

The Adaptation Principles:

A summary

Climate change is causing risks and pressures that increasingly force societies to rethink their priorities and principles for achieving societal well-being and economic development.

Proactive and robust actions are crucial to safeguard the continued potential of sustainable development. If prioritized according to countries' objectives, needs, and risks, such actions can help reduce and manage climate risks, accelerating development and poverty reduction.

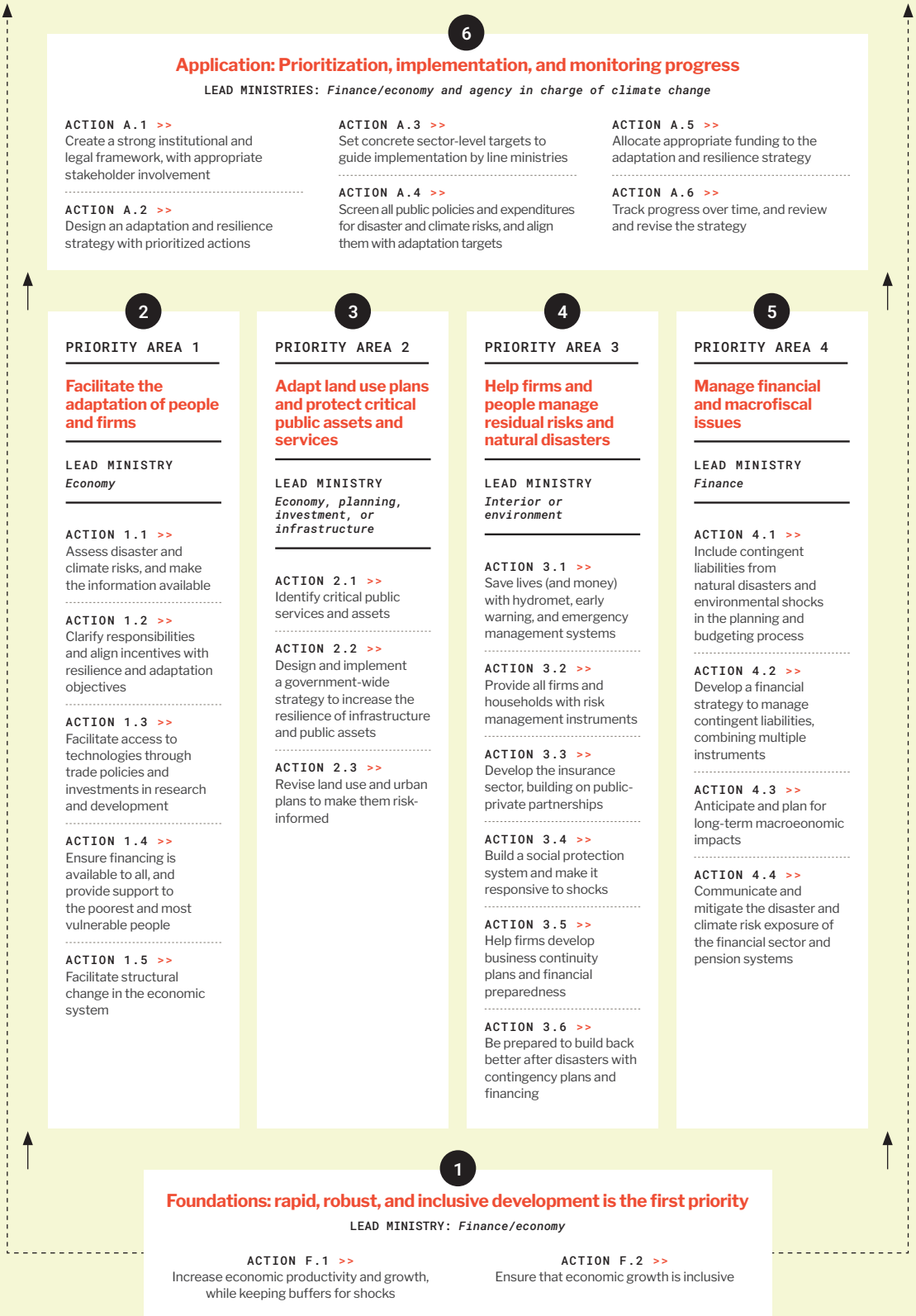
This guide aims to help ministries of finance or economy—who oversee the wider economic system—approach adaptation challenges. It does not go into detailed adaptation strategies at sector level; rather, it focuses on concrete macroeconomic-level actions. These actions reflect universal principles for effective climate change adaptation, though the relative importance and sequence of these actions will differ by country.

The actions pertain to six principles of climate change adaptation, which correspond to common policy domains (*figure S.1*):

1. Ensure development is rapid and inclusive and offers protection against shocks
2. Facilitate the adaptation of firms and people
3. Adapt land use and protect critical public assets and services
4. Help firms and people cope with and recover from disasters and shocks
5. Anticipate and manage macroeconomic and fiscal risks
6. Prioritize, implement, and monitor interventions

FIGURE S.1 >>

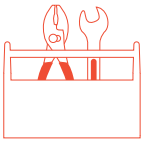
Priority areas and concrete actions for climate change adaptation and resilience policy: an overview



This guide contains practical tools, concrete examples and other information to guide decision makers through the principles of adaptation and help governments formulate effective strategies that enable their societies to thrive in a time of climate change. These include:

SCREENING QUESTIONS >>

to identify the most urgent and effective actions to increase climate resilience and guide the selection of the priorities.



TOOLBOXES >>

offering concrete quantitative examples of how these questions can be answered using commonly available data and methods.

INDICATORS AND TARGETS >>

to monitor and evaluate progress towards the objectives mandated by a national adaptation strategy. *Annex 1* lists proposed indicators or targets, though the list is not exhaustive and other options are available.

COVID-19 SPOTLIGHTS >>

providing information on how the current health and economic crisis changes the priorities and preferred solutions for building resilience and adapting to climate change.

A common theme to each of the policy areas and proposed actions is the large uncertainty on future climate change, especially at the local level, and future vulnerabilities. The direct implication is the need to design adaptation and resilience strategies in a risk management and continuous learning framework. This means avoiding measures that are designed for a precise scenario of the future, instead prioritizing interventions that are robust and flexible, and can be adjusted over time as more information becomes available.

Lay the foundations for adaptation through rapid, robust, and inclusive development

LEAD MINISTRY: *Finance/economy*

Policies to reduce poverty and catalyze robust economic development are most effective for reducing vulnerability to climate change. Poverty and the lack of access to basic services—including critical infrastructure, financial services, health care, and social protection—are strong predictors of vulnerability to climate change. No targeted adaptation strategy can be successful without eradicating extreme poverty and ensuring high-vulnerability populations have the financial, technical, and institutional resources they need to adapt.

ACTION F.1 >>

Increase economic productivity and growth, while keeping buffers for shocks

Recommendations to improve economic growth and accelerate development have been widely studied and advocated elsewhere, so it is not a focus in this document. But without appropriate economic and social policies, targeted adaptation measures alone cannot reduce vulnerability to climate change in a significant manner. Macroeconomic stability and the usual buffers against shock also improve countries' ability to deal with unexpected shocks or stresses, including climate-related ones.

ACTION F.2 >>

Ensure that economic growth is inclusive

It is vital that nobody is left behind. And while rapid development usually reduces poverty and therefore extreme vulnerability to climate change, it can also hide large heterogeneity across regions or socioeconomic groups. Ensuring smallholder farmers have resilient livelihoods and all populations have access to infrastructure services (such as sanitation) and risk management tools (such as savings accounts, health care coverage, and social protection) is the most efficient way of reducing the long-term impact of climate change and natural disasters. *Toolbox A*—in the main text of this guide—offers examples of how to explore these dimensions using commonly available data and specialized indicators, such as the University of Notre Dame Adaptation Initiative's *ND-GAIN Index* or the World Bank's *Socioeconomic Resilience Indicator*.

While good development and the eradication of extreme poverty can do much to reduce future climate change impacts (and short-term disaster losses), additional adaptation and resilience actions can also be beneficial and highly cost-effective. This guide therefore also covers four priority areas for action.

PRIORITY AREA 1 >>

Facilitate the adaptation of people and firms

LEAD MINISTRY: *Economy*

The good news is that private actors have an incentive to increase their resilience and adapt to climate change. However, they face a range of obstacles, from the lack of information and behavioral biases to imperfect markets and financial constraints. Governments need to minimize these obstacles to maximize the economy's adaptive capacity and prevent (as much as possible and desirable) climate change impacts and natural disasters.

ACTION 1.1 >>

Assess disaster and climate risks, and make the information available

Governments must ensure the information people need to adapt to climate change and manage natural risks is widely accessible, free (or cheap enough), and in a simple format that decision makers can use. People and firms need information on many kinds of threat—those from natural hazards, threats to human capital and key sectors, and cross-border threats, including risks linked to food prices. One important consideration relates to uncertainty on future climates and the likelihood of various natural hazards. When deciding how to communicate climate change information to the public, governments must ensure they communicate the large uncertainty around future climate change impacts, and not only one "most likely" scenario.

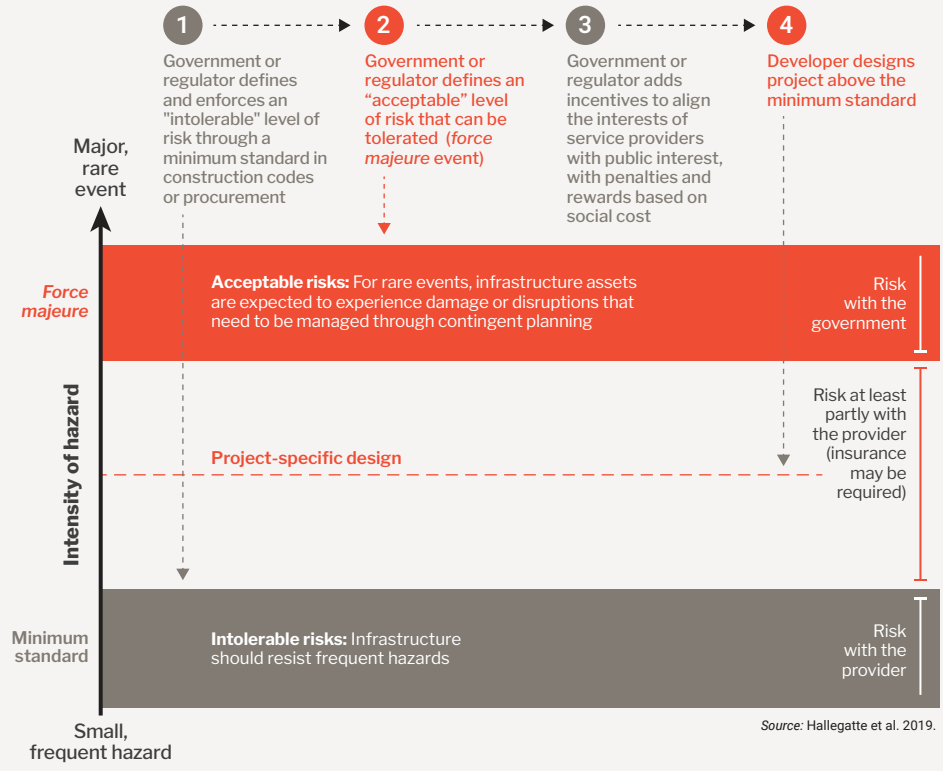
ACTION 1.2 >>

Clarify responsibilities and align incentives with adaptation and resilience objectives

To ensure that private actors—households and firms—are making the right decisions to manage climate change and natural disasters, governments should clearly establish responsibilities and liabilities in law, and communicate these to all actors. Private actors should be informed about the extent of disaster protection provided by public investments and infrastructure. For example, in the Netherlands, the level of flood protection that the government is required to provide to the population is legally defined, so individuals and firms can decide where to live and invest, and what additional flood management measures they need to invest in. And when private firms provide public services—such as electricity supply—then regulation is needed to define risk management responsibilities in a way that aligns private actors' incentives with public interest (including in the case of *force majeure*) (*figure S.2*).

FIGURE S.2 >>

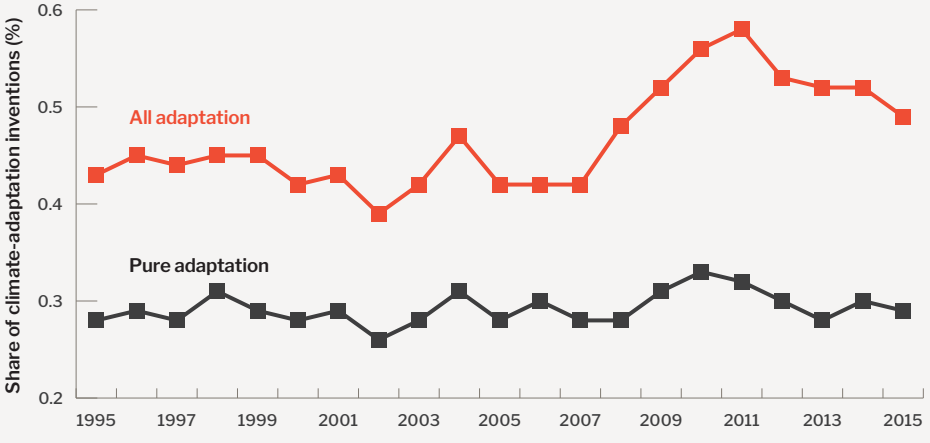
Creating the right resilience incentives for infrastructure service providers requires a consistent set of regulations and financial incentives



Source: Hallegatte et al. 2019.

FIGURE S.3 >>

Innovation for climate change adaptation as a share of total innovation



Source: Glachant et al. 2020, based on PATSTAT data.
Note: Pure adaptation refers to technologies for climate change adaptation that are not simultaneously classified as mitigation technologies.

ACTION 1.3 >>

Facilitate access to technologies through trade policies and investments in research and development

Effective adaptation will depend on countries being able to draw on the best available technologies for mitigating climate change impacts, especially in the agriculture and health sectors. But there are many obstacles—from traditional knowledge spillover and lack of capacity to trade barriers—that impair access to and adoption of technologies.

International patent registrations show that innovation in adaptation is not growing as a share of total innovation (*figure S.3*) and is concentrated in high-income countries and a handful of middle-income countries. Transfers of this innovation are also insufficient, with almost no transfers to low-income countries, where needs are likely the largest. This suggests the need for countries to support all types of innovation—from high-tech solutions to institutional and process-based innovation—with a focus on local needs, and to facilitate technology transfers with appropriate regulations, trade policies, and capacity-building investments.

ACTION 1.4 >>

Ensure financing is available to all, and provide direct support to the poorest and most vulnerable people

High upfront costs or affordability issues may stop private actors from implementing effective solutions. Even if these costs are more than compensated in the long term by avoided impacts and losses, the lack of financing can be a serious obstacle for credit-constrained firms and households. And in the absence of external support, hundreds of millions of people in or close to poverty will be impacted by climate change and have limited ability to respond and adapt. Direct support through social protection or subsidies for resilience-building interventions can play a key role in reducing their vulnerability. *Toolbox B*—in the main text of this guide—reviews methodologies to identify the most at-risk population due to the combination of poverty and vulnerability.

ACTION 1.5 >>

Facilitate structural change in the economic system

Climate change will affect latent comparative advantage. For example, it will make some countries less productive in certain types of agriculture, to the benefit of others; it will also cause the decline of some sectors and the growth of others. Governments need to manage and facilitate economic transition, deal with coordination issues, and ensure social consequences are minimized. In practice, however, the risk is that an important sunset sector (one that is bound to lose competitiveness in coming years and decades) becomes non-profitable exactly when the country needs to be making large investments to boost another sector. Experience from regions where coal mining or heavy industries disappeared in Europe shows how difficult it is to manage a successful transition, especially when a region has a narrow economic base, is isolated geographically, and has a population with limited skills and investment capacity. Governments have various options for addressing this situation:

- **Support sunrise sectors and activities to maximize their development potential.** Climate change may create new comparative advantages in some countries, and those where key sectors will be negatively affected must prepare to capture the opportunities climate change creates. However, if these comparative advantages face obstacles such as high upfront capital investments, increasing returns to scale, or network effects, then a country may struggle to turn such latent advantages into growth and economic opportunities. Several studies offer guidance on how industrial policies can help transform latent comparative advantages into real economic opportunities, especially if countries face the risk of a low-productivity trap.

- **Manage sunset sectors and activities to facilitate a smooth transition.** Some economic sectors may be strongly affected by climate change, with significant implications for jobs and tax revenues. For example, some agricultural production may become non-competitive or unsustainable, snow-based tourism may disappear from low-altitude mountains and summer destinations may become too hot to attract tourists. Targeted policies can help declining industries better manage the drop in activity (for example, by ensuring the least productive firms close first). This may be costly, but it can be justified by distributional considerations or the desire to smooth a transition.

- **Support economic diversification to hedge against climate risks.** Diversifying away from narrow economic bases is key to reducing vulnerability to climate change and other technological or preference shocks, including those caused by decarbonizing the world economy. But it is also desirable for governments to diversify their economy to accelerate economic growth.

PRIORITY AREA 2 >>

Adapt land use plans and protect critical public assets and services

LEAD MINISTRY: *Economy, planning, investment, or infrastructure*

Beyond direct support to households and businesses, governments have a transformative role to play in ensuring their country, their economy and their citizens can adapt to climate change. This is particularly the case to ensure the adaptation of important public assets and infrastructure systems such as power systems, roads, water and sanitation, and essential services such as health care, education, safety and security. Urban and land use plans also influence massive private investments in housing and productive assets, so it is vital these adapt to evolving long-term climate risks to avoid locking people into high-risk areas.

ACTION 2.1 >>

Identify critical public services and assets

Critical public services such as energy, water, health care, civil protection, and education need to take a thorough approach to assessing and managing climate risks. Not only can their reconstruction be costly; they also provide critical services which people's well-being depends on. For a systematic risk and vulnerability assessment, governments must develop inventories of key public assets, including primary health care facilities, hospitals, and schools. Assessing the resilience of service delivery in critical sectors can also be a useful exercise. In networked systems, such as transport or power systems, the criticality analysis described in *toolbox C*—in the main text of this guide—can help governments identify the most important assets or system components, to invest more resources in their resilience (*figure S.4*).

ACTION 2.2 >>

Design and implement a government-wide strategy to increase the resilience of infrastructure and public assets

There is a consensus among experts that governments have a key role to play in ensuring the resilience of critical infrastructure and that they should adopt a whole-of-government approach. Infrastructure disruptions in developing countries are estimated to cost firms more than $300 billion and households over $90 billion each year. But if countries have the right data, risk models, and decision-making methods available, the incremental cost of building the resilience of infrastructure assets is small—only around 3 percent of investment needs.

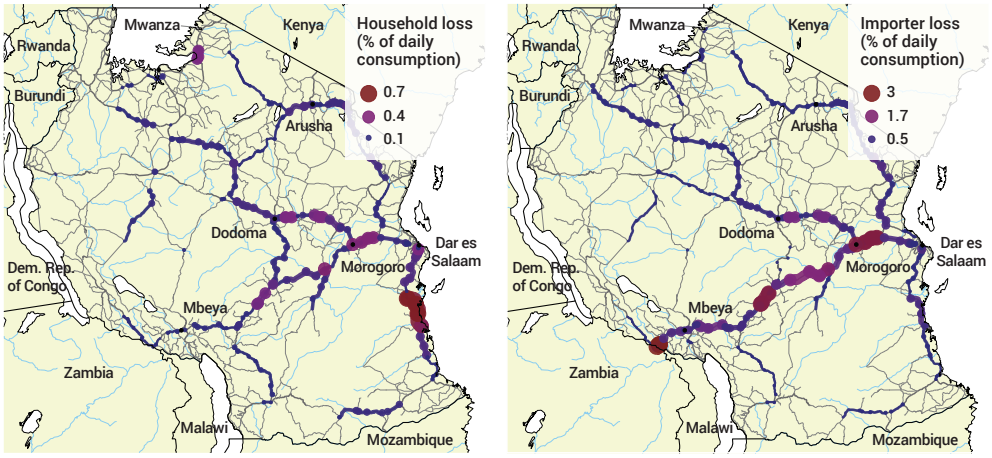
The main challenge to making infrastructure more resilient is thus not primarily a financing one. Rather, it is a question of governance and the ability to make and enforce good decisions, designs, operations, and maintenance. One priority is focusing on the early stages of infrastructure system development: designing regulations, producing hazards data and master plans, or the initial stages of asset design (*toolbox D* in the main text of this guide). This is when small, low-cost investments can significantly improve the overall resilience of infrastructure systems, generating huge benefits. The other priority is improving maintenance. As well as increasing the vulnerability of infrastructure assets, poor maintenance also increases infrastructure investment needs by 50 percent in the transport sector and more than 60 percent in the water sector. Using an infrastructure asset management system to ensure proper maintenance, utility companies can better manage their operations, reduce operational costs, and boost resilience.

FIGURE S.4 >>

The criticality of a road depends on how it is used

a. Critical roads for household consumption

b. Critical roads for international clients



Source: Hallegatte et al. 2019.

ACTION 2.3 >>

Revise land use and urban plans to make them risk-informed

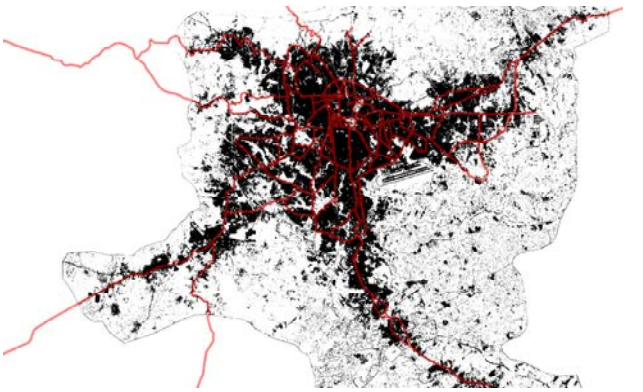
Land markets are powerful tools for driving new construction in a way that efficiently meets population needs. However, they are also imperfect, and often fail to fully internalize climate change and natural hazards. In some countries, land markets are even dysfunctional, with most of the population living in dwellings that have informal arrangements and no land use or urban planning. As a result, developments often occur in risky areas, especially when developers do not carry the cost of future climate change impacts. Land use regulations can help by ensuring that new development takes place in safe areas or those that can be easily and cheaply protected. They can also avoid unchecked urban development that leaves too little porous green space, further increasing runoff and flood risk.

Where possible, governments should mandate local authorities to revise their land use and urbanization plans, using hazard maps that consider climate change (*toolbox E* in the main text of this guide). Choices around the localization of power, water, sanitation, and transit infrastructure guide spatial development and influence land use, land use intensity, land values, and employment and population densities (*figure S.5*). Planners can use infrastructure master plans and new investments to guide urban growth towards safe zones. Risk-sensitive land use and urbanization plans must also abide by construction norms and building regulations. The quality of construction and the role played by building regulations are key determinants of climate resilience. In places with little capacity to create and enforce risk-sensitive land use and urban plans, alternative approaches include allocating the riskiest land such as flood zones to non-residential use—for example, by creating urban parks to minimize the risk of encroachment.

FIGURE S.5 >>

Urbanization in Addis Ababa, Ethiopia, closely follows the major public transport lines

Source: NASA, MODIS Imagery 2002–2013 for built-up area and OpenStreetMap for road infrastructure.



PRIORITY AREA 3 >>

Help firms and people manage residual risks and natural disasters

LEAD MINISTRY: *Interior or environment*

While effective risk mitigation can go a long way in reducing losses and damages, some natural shocks are too extreme and intense to be prevented. Governments must develop strategies to ensure that when disasters do occur, people and firms can cope without devastating long-term consequences, and can recover quickly.

ACTION 3.1 >>

Save lives (and money) with hydromet, early warning, and emergency management systems

Weather forecasts enable the anticipation of and preparation for extreme events, and timely evacuation can save thousands of lives. Preparation reduces physical damage and economic losses—for example, shuttering windows ahead of a hurricane can reduce damage by up to 50 percent. The benefits of providing universal access to early warning systems globally have been repeatedly found to largely exceed costs, by factors of at least 4 to 10. There is also a set of good practices to ensure that early warnings are communicated properly so that people can act upon them and that shelters meet communities' needs. This includes considering gender issues, access for people with disabilities, and how to organize shelters in times of epidemics and pandemics like COVID-19.

ACTION 3.2 >>

Provide all firms and households with risk management instruments

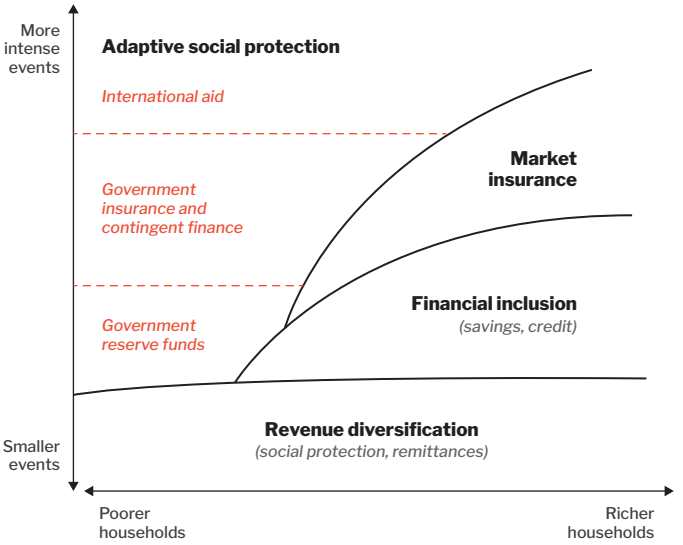
Helping households cope with and recover from shocks requires a holistic and flexible risk management strategy with a range of policy instruments appropriate for different disasters and affected populations. Poorer and richer households have different needs and can be supported with different instruments (*figure S.6*).

FIGURE S.6 >>

Risk finance strategies for households and governments

Source: Hallegatte et al. 2016b.

Note: Instruments targeting households are in black; instruments for governments or local authorities, in red.



ACTION 3.3 >>

Develop the insurance sector, building on public-private partnerships

Domestic disaster insurance markets can be an effective channel for developing the resilience of disaster-exposed households and businesses. Governments can use their own resources to support domestic insurance markets and reach households and businesses with insurance products, realizing their policy goals of expanding the population's financial resilience to disasters. The Turkish Catastrophe Insurance Pool and the Mongolian Livestock Insurance Pool are good examples of public-private partnerships that have substantially increased insurance penetration at the local level.

But developing insurance markets is challenging, particularly in low-income environments. Where insurance is not compulsory, pick-up rates remain low. This includes high-income countries, even where insurance is heavily subsidized.

ACTION 3.4 >>

Build a social protection system and make it responsive to shocks

For the poorest households, savings are often not an option, and high transaction costs and affordability issues make access to private insurance challenging. These households need well-targeted and easily scalable social safety nets.

Adaptive social protection systems have proven to be critical for channeling resources to those who are most in need due to climate stresses. Based on existing social protection systems, adaptive systems can respond quickly to disasters or slow-onset climate crises by:

- Scaling up or providing additional resources to regular beneficiaries—for example, in Fiji, all beneficiaries of the Poverty Benefit Scheme received exceptional transfers after Tropical Cyclone Winston in 2016

- Scaling out or providing support to additional beneficiaries during bad times or years—for example, the number of beneficiaries of Ethiopia's Productive Safety Net Program depends on rainfall.

Toolbox F—in the main text of this guide—discusses methodologies to estimate the benefits (and benefit-cost ratios) of investing in adaptive social protection systems, taking beneficiary vulnerability into account.

It is important to design post-shock or postdisaster support in a way that does not disincentivize adaptation to long-term trends. For example, support to areas that are increasingly affected by drought should not lock people in place, especially if the trend is expected to worsen over time. Instead, postdisaster support should help people change activity or migrate if that will improve their prospects.

SPOTLIGHT S.1 >>

COVID-19

Exiting the COVID-19 crisis more resilient than before?

A few months into the COVID-19 crisis, almost all countries have boosted their social protection systems to help their populations manage the pandemic and the consequences of needed containment measures. If designed and implemented sustainably, and if efforts are maintained over the long term, any improvements made during the current crisis could improve all social protection systems' capacity to scale up quickly and efficiently next time countries are affected by a major shock, including climate-related shock. This includes, for example, creating and maintaining household registries and electronic payment mechanisms.

ACTION 3.5 >>

Help firms develop business continuity plans and financial preparedness

Individual firms' ability to cope with a shock and continue to produce in the aftermath of a disaster depends on many factors, but they can do a lot to become more resilient. The usual recommendation is to identify threats, assess risks, and consider mitigation options. This allows firms to invest in prevention—for example, by adding a generator in case of power outage, investing in movable flood protection, or even elevating critical equipment. It also helps them prepare for residual risk. Preparing business continuity plans (BCPs) can ensure a firm's management and workers know what to do in case of disaster, to maintain or restore production as fast as possible. BCPs should consider a firm's full supply chain and include issues that may affect suppliers (or suppliers' suppliers) and clients. Other things to consider include financial issues, such as how to manage a drop in sales, increased supply prices, or the urgent need to replace expensive pieces of equipment. Access to contingent credit lines and appropriate insurance are among the many tools that firms can include in their BCP.

ACTION 3.6 >>

Be prepared to build back better after a disaster with contingency plans and financing

When a disaster hits and old or low-quality assets are destroyed, countries can build back better, under improved building norms, thereby improving both productivity and resilience. But this does not always happen, often because the urgency to reconstruct leaves little time and few resources to rethink the design or spatial footprint of cities and infrastructure. Building back better depends on the ability to plan and implement the reconstruction process efficiently, or on the existence of plans prepared before the crisis occurs.

PRIORITY AREA 4 >>

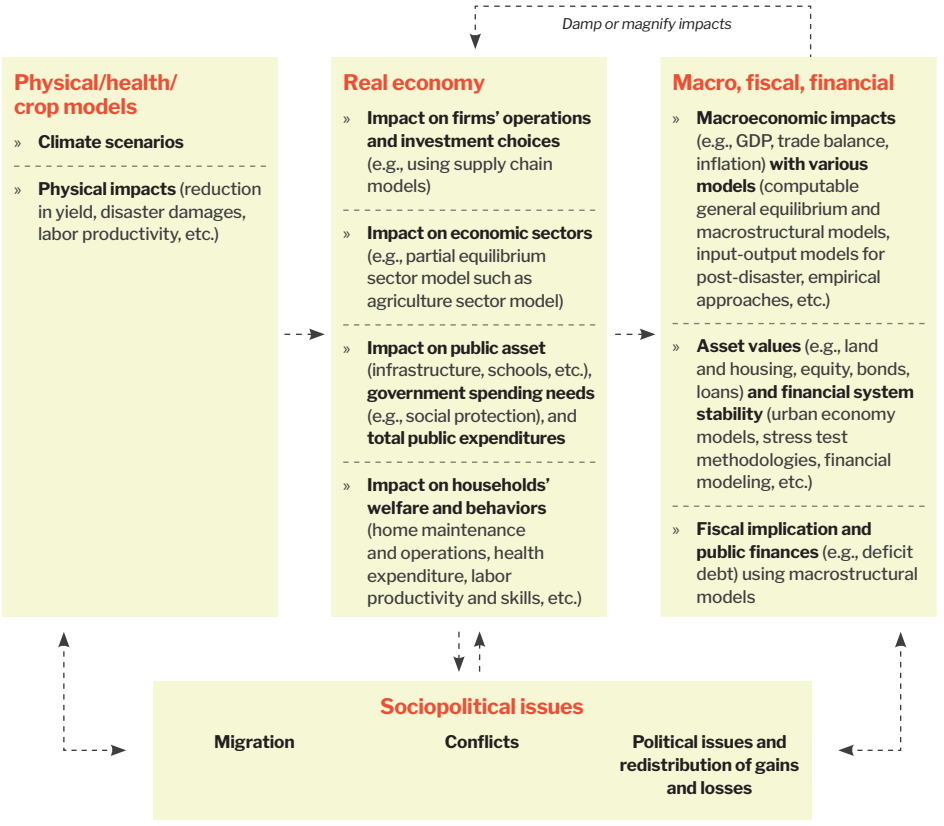
Manage financial and macrofiscal issues

LEAD MINISTRY: *Finance*

The impact of climate change on the economy will affect activity and tax revenues, and strong impacts on major sectors (especially exporting ones) can affect a country's trade balance and capital flows. The combination of these factors may result in new risks for macroeconomic stability, public finances and debt sustainability, and the broader financial sector. Governments will need to manage these risks, considering the many channels involved (*figure S.7*). However, the macro-level impacts of climate change are extremely uncertain, and all quantified assessments should be considered as a partial approximation and used in a way that considers both this uncertainty and the possibility of surprises.

FIGURE S.7 >>

Climate change affects macrofiscal and financial aggregates



ACTION 4.1 >>

Include contingent liabilities from natural disasters and environmental shocks in the planning and budgeting process

Contingent liabilities only materialize if a certain event occurs—for example, if a flood damages roads, the government is responsible for repairing them. Including contingent liabilities in the budget planning process and making them part of the deliberation will ensure that authorities cannot ignore climate and disaster risks.

Assessing risks for public finance should include:

- **Explicit contingent liabilities**, which are relatively easy to estimate and based on public asset and infrastructure inventories (*toolbox G* in the main text of this guide). For example, if the state owns the public roads, it is responsible for fixing them.

- **Implicit contingent liabilities**, which are linked to other forms of commitment. For example, governments will provide humanitarian and financial resources to support populations that are affected by a disaster or small and medium enterprises that cannot cope with the shock without going bankrupt. This expectation or political commitment creates an implicit liability that is more difficult to estimate (*toolbox F* in the main text of this guide).

- **Tax revenues**, which also fall during a disaster, increasing the funding gap. For example, in 2018, Argentina lost an estimated $1.5 billion in tax revenue, mostly due to reduced export tax revenues after a severe drought in 2017. Tax revenue estimates are even more uncertain, as they depend on GDP impacts that are difficult to measure and anticipate with models (*toolbox H* in the main text of this guide).

ACTION 4.2 >>

Develop a financial strategy to manage contingent liabilities, combining multiple instruments

When a disaster or another environmental shock hits, there are urgent financial needs related to emergency response and humanitarian support to affected populations (Priority Area 3) and longer-term recovery and reconstruction costs, which can have a strong impact on public finance. In parallel, tax revenues often drop during the crisis and recovery phase. As a result, governments and local authorities can struggle to finance postdisaster response and reconstruction, while liquidity constraints can also affect their short-term response.

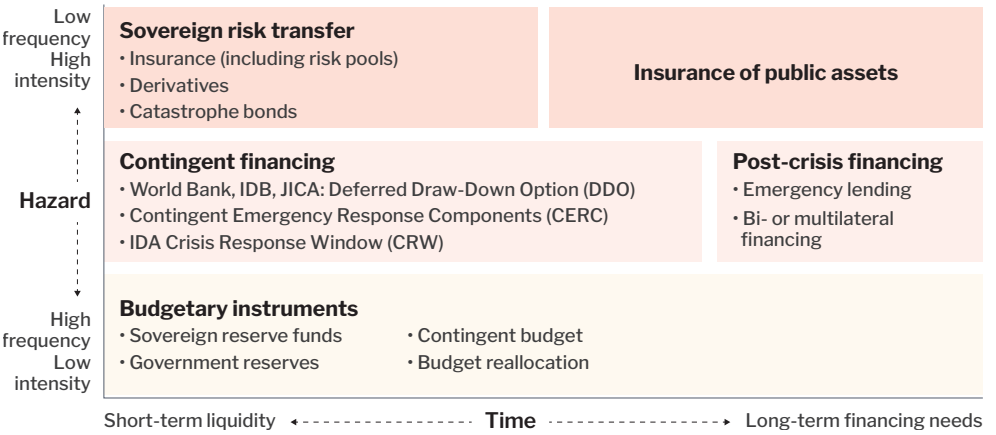
Regardless of their origin, the most robust way to manage unexpected shocks is maintaining fiscal space in normal conditions, with manageable structural deficit and debt levels. It is also preferable to have a reasonably diversified and resilient tax collection system.

Various instruments—such as contingent credit lines, insurance and catastrophe bonds, regional risk-sharing facilities, state contingent debt instruments and international aid—are available to cover the contingent liabilities created by natural hazards and other environmental risks. None of these instruments can meet all the needs, so a combination of tools is preferable (*figure S.8*). Some can cover short-term liquidity needs, while others are better for larger, longer-term reconstruction needs. Some are better placed for frequent, low-intensity events, while others can better manage massive shocks. It is also important to consider that instruments differ in terms of cost, timeliness, transparency, and predictability.

As well as needing specific tools to address resource mobilization in postdisaster situations, the urgency and chaos of the situation creates specific challenges on the expenditure side. These need to be considered through a disaster-sensitive public finance management system.

FIGURE S.8 >>

Financing instruments to cover contingent liabilities from natural disasters



Source: World Bank 2017.
Note: IDB = Inter-American Development Bank, JICA = Japan International Development Cooperation Agency, IDA = International Development Association.

ACTION 4.3 >>

Anticipate and plan for long-term macroeconomic impacts

Climate change will provoke other long-term changes in tax revenues and spending needs, with additional implications for economic growth and public finances. It is important for governments to understand these risks and construct an appropriate response strategy. They can use macrofiscal risk assessments as a standalone analysis, such as with the World Bank and International Monetary Fund's (IMF) Climate Change Policy Assessments, or embed them into other long-term, macro-level assessments. Two joint World Bank-IMF diagnostics can include disaster and climate risk: the *Debt Sustainability Analysis*, which can include macrofiscal risks of climate change impacts, mitigation and adaptation plans; and the *Financial Sector Assessment Program*, which can include climate and disaster risks in the financial sector assessment, especially in stress testing exercises.

Whichever approach governments use, looking at long-term effects will mean exploring long-term growth impacts, their consequences on public finances, and the uncertainty of possible assessments. Here, again, it is important to consider both revenue and spending. If, for example, a large part of a country's tax revenues come from export duty on a small set of vulnerable commodities, the country is highly exposed. Likewise, if sea level rise will require large investments in coastal defenses, the cost could threaten the position of public finances. *Toolbox I* —in the main text of this guide—reviews the methodologies available for such assessments. It also stresses their limitations, which need to be considered in decision making.

ACTION 4.4 >>

Communicate and mitigate the disaster and climate risk exposure of the financial sector and pension systems

One role of the financial system is to help the economy manage risks. But a history of financial crises has shown that it can also magnify the impact of a shock, if this shock exceeds the financial sector's capacity. Governments must therefore assess their financial system's ability to absorb climate shocks, to ensure it can play the role of adaptation facilitator and not create a crisis (see *toolbox J* in the main text of this guide, for example, on stress testing approaches).

Climate change and natural disasters can impact the financial sector balance sheets through four overlapping channels:

- **Operational risk**, such as damages to financial infrastructure
- **Market and liquidity risk**, such as brutal changes in asset valuations
- **Credit risk**, including shocks that adversely affect borrower repayment capacity or lower collateral prices
- **Underwriting risk**, including errors in pricing of (re)insurance liabilities.

Transparency alone could help reduce future losses. Information on firms' exposure to disaster and climate risks can help investors and decision makers adjust investments and portfolios to reduce exposure and future losses. Transparency on disaster and climate risks, as advocated by the Task Force for Climate-related Financial Disclosures,[1] would also send a strong signal to firms' management that this is a topic of concern for investors, creating an incentive for all firms to manage their long-term risks better.

Regulators could also consider imposing appropriate requirements to ensure firms' risk management approaches adequately capture investment risk profiles regarding natural hazards and other adaptation-relevant climate risks. Authorities can set out regulatory guidance or supervisory expectations to enhance firms' responses to these risks and actively monitor their implementation by integrating climate risk into existing regulatory frameworks. They should aim to address all aspects of firms' governance, risk management, and disclosure practices.

Prioritization, implemention, and monitoring progress

LEAD MINISTRIES: *Finance/economy and ministry or agency in charge of climate change (often environment)*

To effectively implement and assess these actions, governments must not only prioritize actions to make them compatible with available resources and capacity; they must also establish a robust institutional and legal framework, and a consistent system for monitoring progress. The objective is to ensure that all government departments and public agencies adopt and mainstream the adaptation strategy in all their decisions, and that governments continuously monitor and evaluate the impact of their decisions and actions, so they can address any challenges and adjust their actions accordingly.

ACTION A.1 >>

Create a strong institutional and legal framework, with appropriate stakeholder involvement

The policy actions discussed in this report require an appropriate institutional and legal framework. Indeed, climate change framework laws can be crucial for formulating short-and long-term climate change targets—for example, most climate change framework laws have a "knowledge" or "data" component, which can help ensure that climate change-related information is available to public and private decision makers (*Action 1.1*). To ensure that climate change is properly addressed, a strong institutional framework is also needed, that:

- Adapts the mandates of existing ministries, agencies, or institutions
- Creates new agencies or committees when necessary (for example, water management agencies at the watershed level)
- Establishes an overarching coordination body to ensure stakeholder involvement at each stage of the adaptation and resilience process, from strategy design to implementation and monitoring.

ACTION A.2 >>

Design an adaptation and resilience strategy with prioritized actions

Once they have established the appropriate institutional and legal framework, governments can design their adaptation and resilience strategy, with precise interventions, investments, and policies. No country has the capacity and resources to implement all possible measures and interventions for increasing resilience. So, prioritizing interventions is one of the adaptation strategy's (and the finance ministry's) main roles, as this will ensure the efficient use of limited resources. Multiple tools are available for prioritization, from traditional methods for appraising investments to more holistic approaches that account for societal benefits and uncertainty (see *toolbox K* in the main text of this guide and an illustration in *figure S.9*). The latter are crucial, as some interventions that may not be justified on the basis of pure economics are essential to protect communities from catastrophic risks. Overall, prioritization methodologies enable decision makers to identify a concrete subset of interventions that are most likely to deliver large net benefits. While some of these will target short-term priorities, they should also align with long-term plans and objectives—for example, governments should ensure COVID-19 recovery programs align with long-term growth objectives (*spotlight S.2*).

SPOTLIGHT S.2 >>

COVID-19

A stimulus and recovery package that builds resilience

To accelerate recovery once the COVID-19 health emergency is under control, many governments are planning to introduce massive stimulus packages. These can be improved by considering not only the short-term needs for jobs and economic activity, but also actions to boost the resilience and sustainability of future development paths.

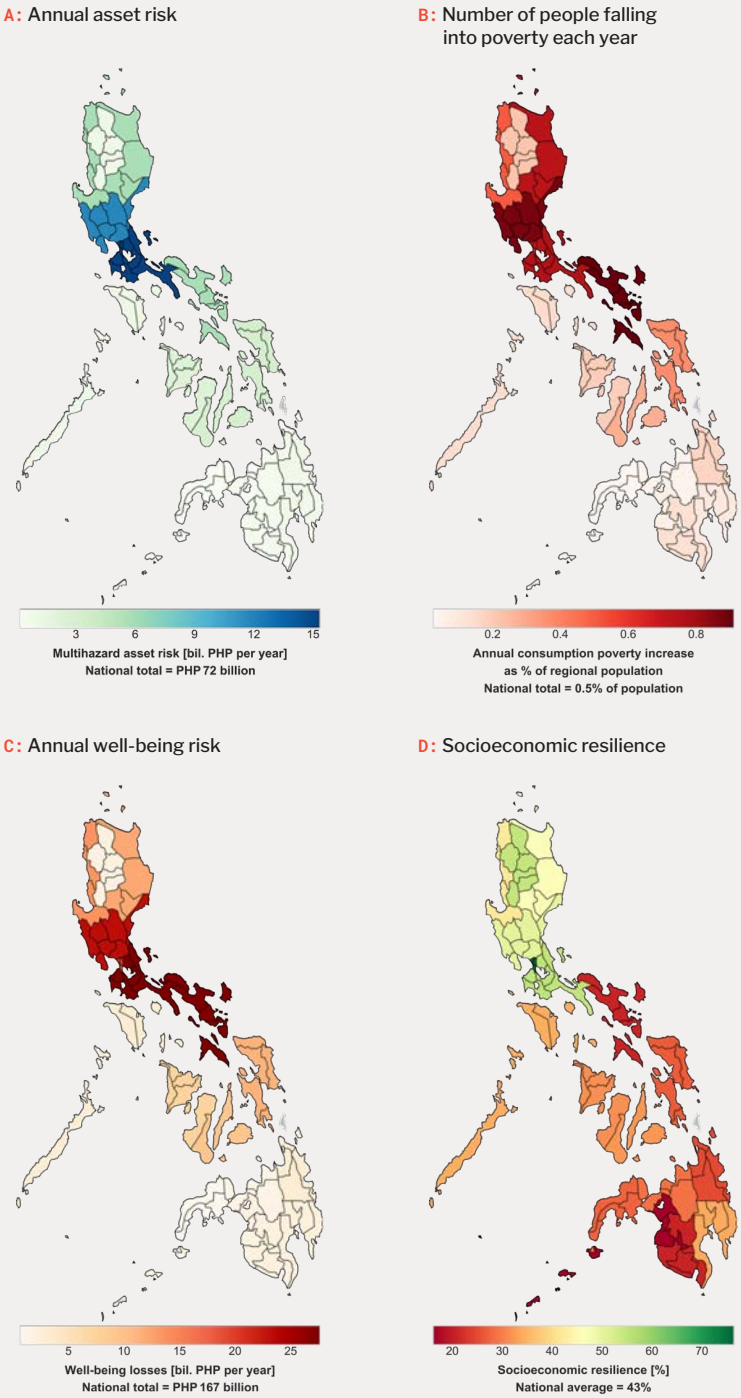
Governments can use a sustainability checklist, for example, to screen potential projects, policies, and measures for inclusion in a stimulus package. Checklists should include:

- Short-term questions, such as: *How many jobs will be created? Over which timeline?*
- Long-term questions, such as: *Does the intervention enhance the long-term growth potential (for example, by improving the population skillset)? Does it make the economy and population more resilient? Does it facilitate the transition to a zero carbon economy and contribute to protecting and building natural capital?*

The key objective is to maximize short- and long-term gains through a careful selection of interventions.

FIGURE S.9 >>

Using different metrics to measure risk can lead to different priorities for action



Source: Walsh and Hallegatte 2020.

ACTION A.3 >>

Set concrete sector-level targets to guide implementation by line ministries

Transport, energy, water, environment, social protection, and other ministries will implement and fund most adaptation and risk reduction interventions, and local authorities will also be important players. To allocate responsibilities, an adaptation and resilience strategy can set sector-level targets for 2025 or 2030, leaving detailed policy implementation for achieving the targets to the relevant ministries. The main text of this guide provides a list of potential indicators that can be used to set these goals. Having a representative body such as parliament approve a list of targets could significantly improve ownership and accountability and strengthen the strategy's authority. It could also help institutionalize a formal and regular reporting process (*Action A.6*).

ACTION A.4 >>

Screen all public policies and expenditures for disaster and climate risks, and align them with adaptation targets

Adaptation measures can only be cost-effective if all investments and planning decisions consider climate-related risks in their design. To mainstream adaptation measures in this way, governments must systematically screen relevant policies and expenditures—even those without an explicit adaptation or climate rationale—to avoid any negative effects on adaptation objectives. One priority is improving public investment management (PIM) to include specific actions and controls that will ensure public investments are consistent with adaptation strategy objectives and consider disaster and climate risks. The ultimate goal is mainstreaming climate change considerations in PIM across all institutions and all projects. Multiple tools are readily available to help governments conduct such a screening process. These include the World Bank Group's climate risk screening tools, which help project development teams assess possible climate change or disaster risks to their project and identify interventions for reducing risks and increasing resilience.

ACTION A.5 >>

Allocate appropriate funding to the adaptation strategy

Once an adaptation and resilience strategy has been prepared, it needs to be appropriately funded. A small dedicated adaptation budget may be needed, especially for monitoring and evaluating progress. However, most of the funding needs are for sectoral interventions—for example, more resilient roads, investments in irrigation, financial protection instruments, and so on. To fund such interventions, governments can create dedicated funds with the mandate of funding investment in resilience or climate change measures (adaptation and/or mitigation). But it may be preferable to integrate adaptation and resilience funding into sectoral budgets, rather than create dedicated budgets. For example, funding investments to increase resilience in the transport system through the transport infrastructure budget would ensure investments in the transport system and in transport resilience are consistent and synergetic. Budget tagging and expenditure reviews (*toolbox L* in the main text of this guide) can help track resources spent on adaptation and resilience, even when they are integrated in general budgets.

ACTION A.6 >>

Track progress over time, and review and revise the strategy

Adaptation and resilience strategy can be further strengthened as new challenges and insights become apparent over time. Continuous tracking of progress indicators can highlight specific sectors in which implementation lags behind. If milestones are missed, implementation challenges—such as capacity or resource constraints, or coordination failures between implementing bodies—may become apparent that were not accounted for in the initial strategy design. Flexibility in the adaptation strategy would allow course corrections and adjustments to be programmed as integral elements of the strategy, rather than being regarded as admissions of failure. Such strategy revisions are also likely to become necessary as new challenges and risks arise—for example, the COVID-19 pandemic forced governments to reevaluate their approach to emergency management. Scientific advances and technologies are also likely to become available, enabling actors to implement actions in more targeted, cost-effective ways.

The Adaptation Principles:

Introduction

Climate change is causing risks and pressures that increasingly force societies to rethink their priorities and principles for achieving societal well-being and economic development.

Proactive and robust actions are crucial to safeguard the continued potential of sustainable development (GCA 2019). If prioritized according to countries' objectives, needs and risks, such actions can help reduce and manage climate risks, and accelerate development and poverty reduction.

This guide aims to help ministries of finance or economy—who oversee the wider economic system—to design national strategies for climate change, adaptation, and resilience. It does not go into detailed adaptation strategies at sector level; rather, it spells out concrete macroeconomic-level actions to help countries' socioeconomic systems adapt to the challenges of climate change. These actions reflect universal principles for effective climate change adaptation, though the relative importance and sequence of these actions will differ by country.

Climate change impacts—and therefore the benefits of adapting to them—are often far in the future and uncertain in magnitude and even in nature. But this guide emphasizes that interventions dedicated to adapting to long-term climate change can also make countries more resilient to today's shocks and hazards. Despite the uncertainty around future climate change, most of the interventions highlighted here are robust, in the sense that they will deliver benefits independently of the exact manifestation of climate change. So, while policy design needs to manage and consider long time horizons and uncertainties, these are not obstacles to designing and implementing robust and efficient adaptation and resilience strategy.

This guide is organized in sections that cover various policy domains, starting with the foundations (rapid and inclusive development). It then focuses on four priority action areas in turn, with recommendations on allocating responsibility and actions that governments can implement. The guide concludes with recommendations for prioritizing, implementing, monitoring, evaluating, and regularly reviewing an adaptation and resilience strategy. The annexes provide examples of indicators that governments can use to define policy targets or track progress over time and how to use indicators to identify policy priorities.

Throughout the guide, there are practical tools, concrete examples and other information to guide decision makers through the principles of adaptation and help governments formulate effective climate change adaptation strategies that enable their societies to thrive in a time of climate change.

TAKING ACTION >>

Tools for formulating effective climate change adaptation strategies

Screening questions >>

Identify and tailor actions

Every country faces a unique set of opportunities and risks. Some may have already achieved impressive progress in implementing climate change adaptation measures in certain sectors, but less so in others. Designing a climate change adaptation strategy will require decision makers to carefully evaluate their country's unique set of risks and past achievements in adaption, to identify priority measures.

The screening questions in this guide will help decision makers identify the most urgent and effective actions that can help increase climate resilience, and tailor them to their country's specific needs and circumstances.

Toolboxes >>

Evaluate risks and opportunities

How should a country evaluate its unique climate risks and socioeconomic vulnerability? A wide range of data sources and analytical tools exists to help decision makers quantify risks and make informed planning and investment decisions, even in the face of uncertainty about the long-term implications of climate change and socioeconomic trends.

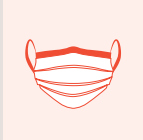
The toolboxes in this guide highlight key quantitative indicators and the main analytical approaches that can be applied to address these questions. These tools are also essential for answering the screening questions to guide future actions.

Sample targets and indicators >>

Monitor and evaluate progress

A national adaptation strategy can only be effective if it is implemented consistently, and its progress is monitored continuously. A range of indicators can help governments assess their implementation progress. The good news is that the majority of such indicators are based on socioeconomic data that most countries already collect. Monitoring the indicators can help a government to not only track progress, but also adjust and improve its strategy as new insights are won.

The concrete indicators proposed in this guide can help decision makers monitor and evaluate progress towards the objectives mandated by a national adaptation strategy.



COVID-19 >>

Explore how the pandemic changes response

The COVID-19 pandemic has created a major financial and economic crisis, though it is still too early to evaluate its magnitude, duration, and implications. Governments across the world have started to respond to COVID-19, through emergency strengthening of health care and social protection systems. They are also likely to implement large recovery and stimulus package to hasten the recovery. After the crisis is over, this response is bound to leave countries with even larger debts.

The COVID-19 spotlights in this guide explore how the current context of health and economic crisis changes the priorities and preferred solutions to build resilience and adapt to climate change, over the short, medium, and long term.

Foundations:

Rapid, robust, and inclusive development is the first priority

LEAD MINISTRY:
Economy or finance

Poverty—in terms of income and access to financial and public services—is one of the main reasons why countries and people are highly vulnerable to climate change (Hallegatte et al. 2016b). Together, these factors determine to a large extent how people can manage climate change and the accompanying risks. For example:

- Many smallholder farmers in low-income countries have low incomes, few savings and little diversification. This makes them highly vulnerable to losing crops to drought, floods, or pests. Their savings are often in livestock, housing, or some other material form, which can be lost in a natural disaster.

- Many cities in low- and middle-income countries (LMICs) lack basic infrastructure to cope with climate-related risks and provide the services the population needs to manage these risks. For example, many informal settlements lack basic drainage infrastructure, have congested and vulnerable road networks, and poor-quality housing, leaving inhabitants vulnerable to high temperatures, floods, or landslides.

- Many people in LMICs have limited access to health care or constrained health coverage, so any disease—whether related to climate stresses and shocks or not—can push them in poverty. With the expected impact of higher temperatures on many water or vector-borne diseases, better access to health care will help reduce social vulnerability.

Development and poverty reduction are therefore extremely effective adaptation options. With climate change impacts expected to increase rapidly over the next decades, getting people out of poverty-driven climate-vulnerability situations is urgent. As climate shocks become more frequent, experience shows that poor people can be trapped in a vicious cycle of disaster loss, lack of capacity to recover, and reduced resilience when the next shock strikes. Only rapid and inclusive development can ensure that nobody is left behind.

TAKING ACTION >>

Screening questions

Identify actions to lay the foundations for climate-resilient societies

A strong, robust, and inclusive economy can lift everyone, and thus increase people's capacity to manage risks and cope with shocks. But in which areas could further progress be made? The following questions can help decision makers identify shortcomings and guide them towards the actions needed to strengthen the foundation of resilient societies.

ACTION F.1 >>

Rapid and robust development

Is the economy fulfilling its potential in terms of productivity and economic growth?

Does the macroeconomic system have appropriate buffers against unexpected shocks?

Could include: *sustainable public and private debt levels; foreign currency reserves*

ACTION F.2 >>

Inclusive development

Is economic growth inclusive?

Could include: *growth in income among the bottom 40 percent; income of the bottom 20 percent; fraction of population living on less than $1.90 a day*

Are farmers' productivity and income growing?

Could include: *incomes levels; access to irrigation, hybrid seeds and mineral fertilizers*

Is the country on track to achieve universal access to modern infrastructure services?

Could include: *electrification rates; access to improved water and sanitation*

Is the country on track to achieve universal financial inclusion?

Could include: *progress in increasing access to saving accounts, borrowing, and insurance*

Is the country on track to achieve universal access to health insurance coverage to prevent catastrophic health expenditure?

Could include: *out-of-pocket health expenditure; access to basic health care*

Does the country offer widespread social protection coverage?

Could include: *share of population covered by social protection; transfer amount as share of income*

Is the country actively managing risks in vulnerability hotspots created by conflict or exclusion?

Could include: *number of conflict-related victims per year; existence of a peace-building initiative*

ACTION F.1 >>

Increase economic productivity and growth, while keeping buffers for shocks

LEAD MINISTRY: *Economy or finance*

The priority for reducing future climate change impacts is rapid and inclusive development and poverty reduction. So, although all the recommendations in this section aim to ensure consistent and inclusive growth, they are also relevant for climate change adaptation. Recommendations to improve economic growth and accelerate development have been widely studied and advocated (see, for example, IMF 2014), and typically include:

- **Good governance**, with the right institutions and rule of law, macroeconomic stability, and low barriers to entry for new products and firms, to make sure people have the right incentive to invest and create jobs with a conducive business environment
- **Investment in human capital,** including health and education, to ensure everyone can achieve their potential and contribute to development and growth
- **Investment in efficient infrastructure and trade networks**, to increase productivity and benefit from domestic and international trade.

Economies are more resilient if they have buffers that can be mobilized in case of unexpected shocks. This includes keeping fiscal space in case of unexpected spending needs or drop in revenues, but also a manageable level of private debt and currency reserves.

TAKING ACTION >>

Sample targets and indicators

- Average productivity growth
- Economic growth
- Debt-to-GDP ratio
- Structural deficit

ACTION F.2 >>

Ensure that economic growth is inclusive

LEAD MINISTRY: *Economy or finance*

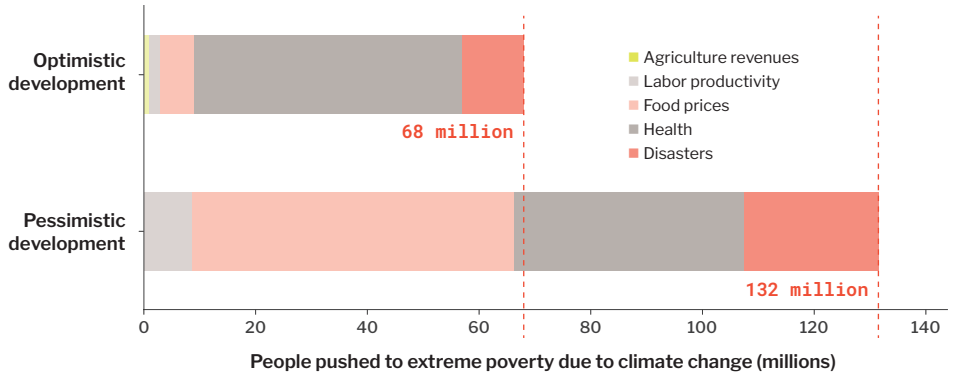
Although economic growth usually benefits the poor (Dollar et al. 2013), rapid economic growth can hide large heterogeneity across regions or socioeconomic groups (Ravallion 2016). Since vulnerability to climate change is highest among the poorest, inclusive economic growth that benefits the poorest will be most efficient in terms of reducing the impact of climate change and natural disasters. Three aspects are particularly important: smallholder farmers' livelihoods, access to infrastructure services—for example, sanitation services in poor urban neighborhoods—and access to risk management tools such as savings accounts, health care, and social protection. *Toolbox A* offers concrete quantitative examples of how these dimensions can be explored using commonly available data and specialized indicators, such as the University of Notre Dame Adaptation Initiative's *ND-GAIN index* or the World Bank's *Socioeconomic Resilience Indicator*.

Improve the livelihoods of smallholder farmers

Smallholder farmers in low-income countries are particularly vulnerable to climate change, as they directly depend on climate conditions—for example, for irrigation—and because their seeds and species may not be adapted to future climate conditions. In modeling estimates, the impact of climate change on agriculture has the biggest effect on poverty, through reduced yields or increased food prices (*figure 1*).

FIGURE 1 >>

Climate change impacts on the poorest people, by source



Source: Jafino et al. 2020.

Climate-smart agricultural practices can increase productivity and resilience (Cervigni and Morris 2016). But making practices more productive and resilient requires a major shift in land, water, soil nutrients, and genetic resource management to ensure more efficient resource use. Crop improvement, smarter input use, strengthening crop resistance to pests and diseases, and reducing post-harvest losses can contribute to sustainable agricultural intensification, increasing food production (Beddington 2010; Tilman et al. 2011). Innovation is needed to increase yields, and all farmers—even poor ones—must broadly adopt new techniques that result from innovation. Helping rural households enter nonagricultural occupations can also reduce their vulnerability to climate change. For example, combining cash transfers with other diversification interventions, such as vocational training or productive investment grants, helps households diversify their income sources and become more resilient to drought (Macours et al. 2012).

Achieve universal access to infrastructure services

Globally, the infrastructure gap continues to be large: 940 million people lack access to electricity; 663 million have no access to safe drinking water; 2.4 billion lack adequate sanitation facilities; and 1 billion live more than one kilometer away from an all-season road. Uncounted numbers cannot access work and education opportunities because transport services are unavailable or unaffordable. Providing universal access to reliable infrastructure services is central to increasing public health and welfare, thus ensuring sustainable economic development.

To achieve ambitious poverty reduction and sustainable development goals in a resilient and low-carbon way, countries must continue to invest in infrastructure

TAKING ACTION >>

Sample targets and indicators

- Poverty headcount or change in poverty headcount (last five years)
- Growth in income of bottom 40 percent
- Average income of farmers
- Percentage of farmers with access to fertilizers or improved seeds
- Average share of household budget spent on food and beverages
- Access to modern energy, improved water, or sanitation
- Number of power or water outages per year
- Share of population with a bank account, health care coverage or covered by social protection
- Total social protection spending
- Number of conflict-related deaths in the last year

development. How much they need to spend depends not only on their goals, but also on the efficiency with which they pursue them (Rozenberg and Fay 2019). In LIMCs alone, new infrastructure could cost 2–8 percent of gross domestic product (GDP)—that is between $640 billion and $2.7 trillion—a year, depending on how much electricity they want to make available for universal access, the technologies they use for sanitation, the policies they put in place to limit urban sprawl or redirect transport demand toward public transit and trains, the subsidies they give for irrigation, and so on.

Accelerate financial inclusion, access to health care, and social protection coverage

Boost financial inclusion: People use financial instruments, notably their savings, to smooth consumption and limit the effects of income shocks (Kinnan and Townsend 2012; Morduch 1995). However, most households—and almost all poor households—have no or little savings in financial form. Instead, poor people often save in kind, with livestock or housing investments, which tend to be more affected by natural hazards than financial savings.

Access to credit allows households to finance otherwise unaffordable risk reduction and climate change adaptation investments, and loan repayments are often less than households pay in ongoing repairs or coping with climate change impacts. After a shock, a lack of access to finance is a significant obstacle to recovery and reconstruction, slowing down the return to normalcy and prompting people and firms to rebuild as fast as possible at the expense of quality (Benson and Clay 2004; Hallegatte and Dumas 2009). Accelerating financial inclusion—particularly ensuring that poor people have access to financial products that meet their needs and have small transaction costs—would therefore enhance adaptation and risk management (World Bank 2013).

At the same time, further action could support the positive impacts of remittances on resilience. In 2014, the global burden of remittance transfer costs stood at 6.8 percent of overall transfers. Costs tend to be highest in sub-Saharan Africa, where they average 9 percent (Ratha et al. 2020).[2] This partly reflects limited competition among service providers. The United Nations Open Working Group on Sustainable Development has proposed reducing remittance costs to 3 percent, which would translate into more than $20 billion annual savings for migrants. Commonly available technologies such as instant mobile phone money transfers could help streamline processes and reduce transaction costs.

SPOTLIGHT 1 >>

COVID-19

Strong health care systems are vital

The current crisis linked to COVID-19 illustrates the need for stronger health care systems that can quickly detect emerging diseases and promptly react in the case of an epidemic. There are clear synergies with building the population's resilience to health-related climate change impacts. We can expect significant investments in health care systems in the next few years to improve the world's ability to manage epidemics and new diseases, and there is an opportunity to ensure that these new systems are designed to swiftly identify emerging diseases due to climate change and provide a prompt, appropriate response. In the context of "One health", the need to respond quickly to emerging diseases also applies to diseases affecting animals and livestock.

Improve health care and universal health coverage: Climate change is expected to increase the burden of disease. For example, higher temperatures will affect vulnerable elderly and infant populations and the incidence of water-borne diseases, diarrhea, and some vector-borne diseases such as dengue and malaria will increase. The World Health Organization estimates that 100 million people fall into poverty each year paying for health care (WHO 2014). Financial risk protection varies widely, and out-of-pocket health expenditures are extremely high and variable for people in low-income countries. Improving health care coverage and lowering out-of-pocket expenses would help the poor manage catastrophic health expenditures, efficiently reducing both poverty and the health impacts of climate change (Jamison et al. 2013).

Countries can provide health coverage at all income levels, but context and implementation challenges will determine the optimal path they take. Whichever this is, insurance coverage alone is not enough. Improving health care systems—through staff training, vaccination programs, information campaigns, access to rapid diagnostic kits and drugs for treatment—is essential. With significant investments over the next 20 years, low-income countries can raise their health care levels to match the best middle-income countries today (Jamison et al. 2013).

Create strong social protection systems: Savings, borrowing, and insurance have their limits, particularly in the poorest households. Social protection programs therefore have a key role to play, but 55 percent of the world population is not covered by any program today (ILO, 2017). Even if they are not designed to protect people against natural disasters and cannot be adjusted or scaled up in response to a shock, social protection programs can increase the share of income poor households receive from transfers, improving their resilience to localized shocks.

In Bangladesh, the Chars Livelihood Programme protected 95 percent of recipients from losing their assets after the 2012 floods (Kenward et al. 2012). And in Mexico, beneficiaries of *Prospera*—the national cash transfer program previously known as *Oportunitades* or *Progresa*—are less likely to withdraw their children from school after a shock (de Janvry et al. 2006). In the United States (US), nondisaster programs such as Medicare and unemployment insurance automatically increase their support to affected populations after a hurricane makes landfall (Deryugina 2017). Postdisaster support through nondisaster programs is also more than five times larger than the dedicated transfers that follow federal disaster declarations.

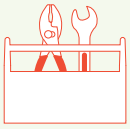
Ensure adaptation strategies include support for people in conflict zones, who are particularly vulnerable

Even in countries with rapid economic growth, entire regions or communities can be left behind due to political or armed conflicts, or exclusion based on ethnicity or religion. Such regions or communities are likely to become hotspots of vulnerability to natural disasters and climate change, with potential consequences for the rest of the country through migration or unrest. Adaptation strategies should ensure that development and progress reach excluded and conflict-ridden areas and communities.

TAKING ACTION >>

Toolbox A

A simple indicator-based analysis to identify priorities for action



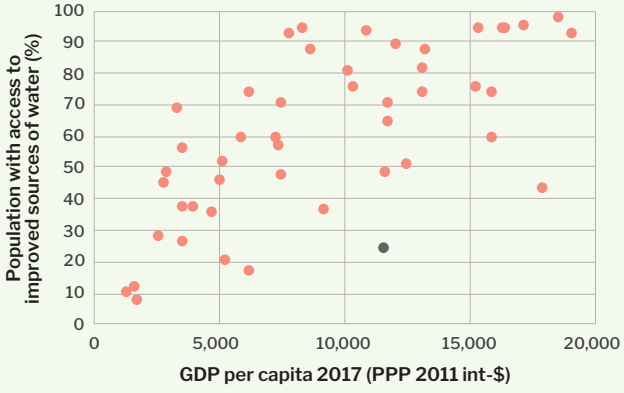
If the socioeconomic context and development trends do not help reduce people's vulnerability to climate change, it is unlikely that targeted intervention can make a big difference. A simple analysis based on available indicators can help identify which socioeconomic trends are problematic from a climate change vulnerability perspective, and therefore identify promising opportunities for change. *Annex 2* provides some examples of how widely available indicators, such as the World Development Indicators, can provide insights on possible policy priorities to ensure that development contributes as much as possible to adaptation and resilience.

For example, *figure A.1* shows that Mongolia lags other countries at similar income level in terms of access to improved sources of water, suggesting the existence of opportunities to build the population's resilience in this sector. Feyen et al. (2020) provide an indicator-based analysis to look at the correlation between exposure and vulnerability to disasters and climate change, and macrofinancial risk indicators generated by the Economist Intelligence Unit (EIU). This analysis highlights that most countries that are heavily affected by disasters or expect to be strongly affected by climate change already face significant macrofiscal risks. *Figure A.2* illustrates this correlation with disaster losses and public debt risks.

It is also possible to use some of the indicators recently developed to measure socioeconomic vulnerability or resilience. These have different scopes, focuses, strengths and weaknesses. But most allow users to first explore aggregated indicators (such as resilience or vulnerability) and then explore disaggregated indicators (such as farmer productivity or

FIGURE A.1 >>

Indicators of access to improved water sources



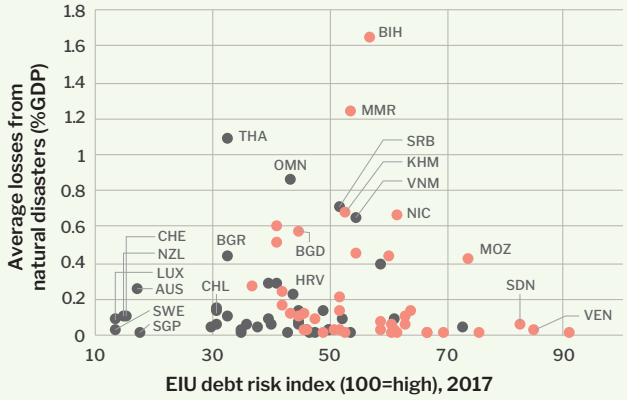
Source: World Development Indicators, World Bank.
Note: Pink dots represent all countries with available data. The gray marker denotes Mongolia. GDP is expressed as 2011 international $ in purchasing power parity (PPP).

exposure to storms) to identify opportunities for improvement in a given country. Examples of such indicators include:

- **InfoRM (Joint Research Centre, European Commission):** InfoRM measures the risk of humanitarian crisis and disasters and how the conditions that lead to them affect sustainable development. It calculates risk as the combination of three equally weighted components: hazard and exposure, vulnerability, and lack of coping capacity.
- **ND-GAIN Index (University of Notre Dame Adaptation Initiative):** An ND-GAIN score measures a country's preparedness for climate change, including but going beyond natural hazards, and depending on its readiness and vulnerability. It measures a country's vulnerability by assessing its exposure, sensitivity, and capacity to adapt to the negative effects of climate change, looking at six sectors: food, water, health, ecosystem services, human habitat, and infrastructure. It measures a country's readiness by assessing its ability to leverage investments and convert them into adaptation actions, looking at economic, governance, and social readiness.
- **World Risk Index (UN University and University of Bonn):** This index measures the vulnerability of 171 countries to natural disasters. It is composed of four main indicators: exposure to natural hazards; susceptibility, which depends on socioeconomic conditions; coping capacity, which depends on preparedness, governance, and security; and adaptive capacity related to future natural events.
- **Global Climate Risk Index (GermanWatch):** Published annually, this index analyzes the extent to which countries have been affected by weather-related losses, including storms, floods, and heat waves. The index is populated with data from Munich Re's NatCatSERVICE and the International Monetary Fund (IMF), among others.

FIGURE A.2 >>

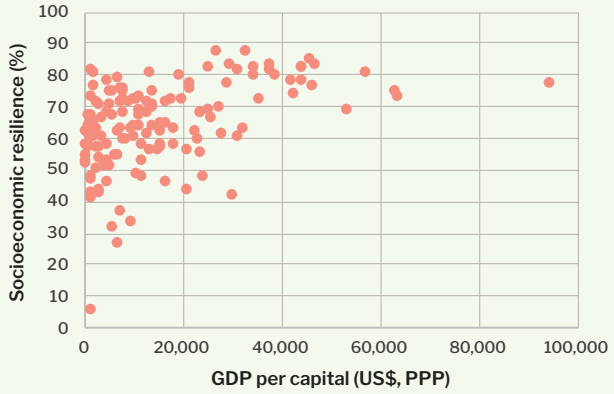
Average losses from natural disasters and EIU debt risk index, 2017



Source: Feyen et al. 2020, based on EIU's Credit Risk Model, GermanWatch, ND-GAIN, and World Development Indicators.
Notes: Countries above (below) country median in Notre Dame Readiness indicator in gray (pink). Average losses (% GDP) are between 2005 and 2017.

FIGURE A.3 >>

Socioeconomic resilience (percent) by GDP per capita, 149 countries



Source: Based on Hallegatte et al. 2016b.
Note: Here, PPP=purchasing power parity.

TAKING ACTION >> Toolbox A

The World Bank developed the **Socioeconomic Resilience Indicator**, now available in 149 countries (*figure A.3*). Socioeconomic resilience is defined as a country's or population's ability to cope with and recover from direct damages caused by natural disasters. It is estimated with a simple model of how households can manage disasters, and estimates of direct disaster impacts (UNISDR 2015). For each country, it provides an estimate of socioeconomic resilience and risk to well-being.

Socioeconomic resilience depends on three main dimensions:

- The difference in exposure and vulnerability between richer and poorer people: if poor people are more exposed or vulnerable, the same economic loss in absolute terms will have a bigger impact on their well-being
- Access to tools and instruments to manage the shock, such as remittances, savings, emergency borrowing, insurance, and social protection
- The government's capacity to respond and support the population.

Because the indicator is based on a model, it can also be used to estimate the benefits of various interventions, in all the covered countries. For example, *figure A.4* shows the benefits of 11 different policy interventions in terms of reduction in asset and well-being losses in Malawi.

The same reduction in asset losses—of, say, $1,000—reduces well-being losses more if the beneficiary is a poor household, for whom $1,000 is a lot. Similar estimates are available for all countries on the World Bank platform (Hallegatte et al 2016b).

FIGURE A.4 >>

Effects of policy options on asset and well-being losses in Malawi

Source: Hallegatte et al. 2016b.

Priority Area 1:

Facilitate the adaptation of people and firms

LEAD MINISTRY:
Economy

Adaptation is not the sole responsibility of the government. All private actors—households and firms—have an incentive to minimize the impacts of climate change on their own well-being or productivity. The government's role is to ensure that all actors, especially the poorest and most vulnerable, can access the resources they need to adapt to climate change and maximize the efficiency of the adaptation process.

Three main constraints prevent private actors from taking adaptation actions: access to data and technologies, access to financing instruments and resources, and the need to coordinate with other actors. The latter is a challenge in the absence of public action or facilitating institutions such as business associations.

TAKING ACTION >>

Screening questions

Identify actions to enable firms and people to adapt

People need to be empowered to take effective adaptation and risk management decisions. But do they have the information, tools, and resources they need? The firms that provide goods, services, and jobs also need to adapt so they can offer people sustainable and resilient livelihoods. Are they on track to do so? The following questions can help decision makers identify shortcomings and guide them towards the actions needed to enable firms and people to adapt.

ACTION 1.1 >>

Data and information

Have comprehensive climate and risk assessments been completed?

Could include: *hazard maps for the most important threats are publicly available*

Is the uncertainty on current and future risks publicly communicated?

Should include: *several contrasted scenarios for possible future climate change are available to inform on uncertainty in climate projections*

Can all economic actors and public agencies access data on natural risk at an affordable cost and in a practical format?

Could include: *open risk data repositories are available*

ACTION 1.2 >>

Responsibilities and incentives

Are roles and responsibilities for disaster and climate risk management clearly defined?

Could include: *presence of a designated disaster management authority; a disaster risk management framework law is passed, clarifying responsibility and liabilities*

Does the country have institutions and agencies in charge of managing shared resources?

Could include: *watershed agency is established to share water across various users*

Do private actors know the level of residual risk they are exposed to, or the level of protection offered by public infrastructure and instruments?

Could include: *maps of residual flood risks, accounting for public flood defenses, are available*

ACTION 1.3 >>

Technology and innovation

Has the government addressed trade barriers that limit the use of essential technologies?

Could include: *average tariff on disaster management technologies or goods*

Are policies in place to actively support adopting or developing new technologies for resilience?

Could include: *existence of—and investment in—an agriculture extension program*

ACTION 1.4 >>

Financing and support to the poorest and most vulnerable people

Can private actors access adequate financing for adaptation-related investments?

Is the government providing specific financing instruments to facilitate people's investments in adaptation and risk reduction?

Could include: *volume of financing in windows targeting climate change adaptation*

Has the government identified and started supporting the most vulnerable population groups, whose poverty prevents them from adapting to climate change?

Have actions been taken to mitigate the most severe impacts of climate change?

Do vulnerable groups have access to affordable financial instruments that can help them manage risks and reduce their vulnerability?

Could include: *total amount of resilience support to poor vulnerable communities*

ACTION 1.5 >>

Strategic structural transitions

Does the government have policies in place to actively manage the strategic decline of sunset sectors?

Could include: *skills retraining schemes; social protection*

Is the economy diversified, rather than being concentrated in one sector that may be vulnerable?

Could include: *share of exports in one agricultural commodity*

Does the country have a diversification strategy, based on either assets—such as investments in education—or active industrial policies?

ACTION 1.1 >>

Assess disaster and climate risks, and make the information available

LEAD MINISTRY: *Environment (or disaster risk management or climate change agency)*

Governments need to ensure the information people need to adapt to climate change and manage natural risks is widely accessible, free, or affordable, and in a simple format that decision makers can use. They can assess needs from firms or households, for instance using surveys. In Turkey, IFC and EBRD (2013) show, for instance, that 76 percent of firms lack information on technological solutions for adapting to climate change, and 78 percent lack access to financial instruments to implement them. Data and knowledge on future climate change and climate change impacts have a public goods nature, and private actors will tend to underinvest, in the absence of public support. Information needs and technical capacity also differ across actors—for example, between a national power utility and a household—so different information platforms and tools are required. Ideally, rather than simply provide information, the data platform will support decision making.

People and firms need information on:

- **Threats from natural hazards:** The first step is identifying spatially disaggregated threats from natural hazards, including floods, storms, and landslides. Global datasets and models can give all countries a rough indication of the spatial distribution of disaster and climate risks. These include the simple metrics for the 11 types of natural hazards recorded in the ThinkHazard database[3] or the climate change scenarios collected in the Climate Change Knowledge Portal.[4] Several providers offer more detailed information from global models.[5] Maintaining consistent georeferenced records of past disasters and investing in risk data and models—such as hydrological models, maps of flood hazards and digital elevation models—is vital. Countries can then use these hazard maps to assess risks by combining them with exposure maps of the population and assets and vulnerability models that describe impacts or damage to people and assets. There are many examples of natural risk assessments, such as the UNDRR's Global Assessment Report (UNISDR 2015), the Global Facility for Disaster Reduction and Recovery (GFDRR) country profiles,[6] and other, more detailed assessments.

- **Threats to human capital:** It is important to consider the effect of climate change on health and productivity, especially for people whose livelihoods depend on outdoor tasks. It is well documented that higher temperatures lead to lower labor productivity (Hallegatte et al. 2015). With climate change scenarios projecting that summers may exceed

50°C in several regions, the macroeconomic impacts on productivity are likely to become significant in many countries (Heal and Park 2016).[7] It is also well documented that natural disasters leave victims with mental health issues that can make it difficult to return to a normal life, even after physical recovery (Berry et al. 2010). Mental health challenges have a major and direct impact on quality of life, while the cost of mental health care and effects on labor productivity have financial and economic implications.

» **Threats to key sectors:** To analyze possible effects on agricultural production, tourism, or infrastructure service delivery, a first step is identifying which of the main production or employment sectors are most sensitive to climate variability. There are many tools to then estimate how climate change could affect productivity. For example, the AgMIP data portal[8] offers many agriculture scenarios, based on multiple climate and crop models. For energy demand and generation or water availability, the *Climate Change Knowledge Portal*[4] has country-averaged indicators and geospatial information to serve as an input for such assessments. The Inter-Sectoral Impact Model Intercomparison Project's dataset[9] also provides indicators for physical impacts such as water availability and impacts on water-borne diseases, other health issues, coastal flood risks, fisheries, ecosystems, and permafrost, which is important for infrastructure design in cold regions. Countries can use such analyses to estimate the economic costs of climate change to these sectors—for example, whether rising water scarcity will increase the cost of water provision or whether energy demand for air conditioning will increase energy costs.

TAKING ACTION >>

Sample targets and indicators

- Number of weather or hydrological observation stations operational in the country
- Real-time availability of hydromet observations
- Time series of hydromet observations are freely available
- Percentage of country covered by high-resolution digital terrain model or hazard maps for current and future risks, with multiple scenarios
- Risk assessment for main economic sector done and publicly available, including opportunities where competitive advantage may improve
- Data platform providing easy access to hazard and climate change scenario data
- Guidance materials and methodologies available to users on how to access and include disaster and climate information in decision making

» **Cross-border threats, including risks linked to food prices:** Some impacts of climate change will affect regions and countries indirectly. For example, a place where crop yields increase can still be a net loser if yields increase even more in another place, thus diverting investments and jobs. Import costs can also grow in response to productivity losses, so North Africa and the Middle East, which rely heavily on food imports, are particularly exposed to the impact of climate change on global food markets.

Identifying future climate change impacts therefore needs to go beyond direct, localized effects and think more broadly about global consequences and their implications. Countries can start investigating indirect threats by listing their main imports and exports, identifying those that are most sensitive to climate change—like agriculture and forestry—and those that play a key role. For example, countries might import a large share of domestic consumption or export a large share of production. If exports are sensitive, there is a risk of a drop in external income; if imports are sensitive, there is a risk of higher import prices. Both can threaten the trade balance and macroeconomic stability (see *Priority Area 4*).

Many countries have created specific processes for generating and disseminating this information to the public. For example, the United Kingdom (UK)'s Climate Change Act 2008 mandates the government to produce a comprehensive, nationwide, climate change risk assessment every five years, followed by a set of national adaptation plans.[10] The Climate Change Act also creates a common analytical resource in the form of the Committee of Climate Change to help develop and implement regional policy frameworks. Similarly, Costa Rica's Scientific Council on Climate Change is an independent consultative body of academics, researchers and experts to advise the government on climate science and technological development.[11] The council is attached to the Ministry of Environment and Energy's Climate Change Directorate and prepares reports at the ministry's request. It also has the authority to express itself on relevant matters.

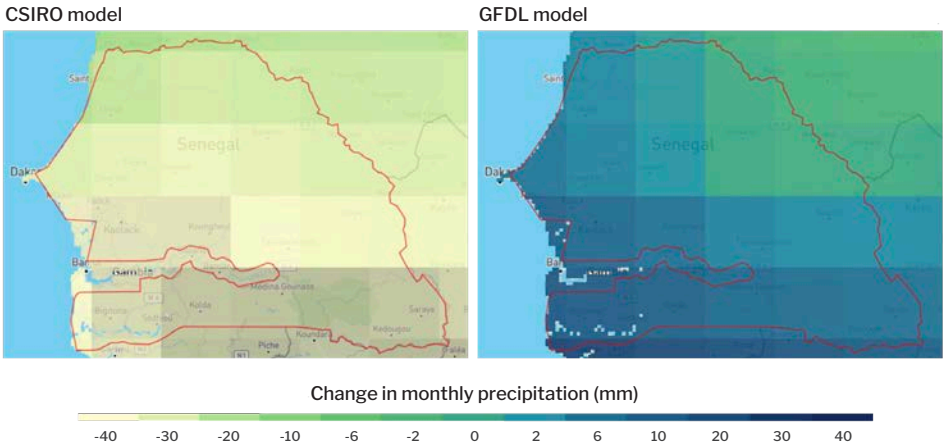
One important consideration relates to uncertainty on future climates and the likelihood of various natural hazards. While uncertainty does not prevent action to reduce risk and build resilience, it impacts on which action to implement. It is preferable to avoid any action that would deliver benefit only if future risks and climate change are exactly as expected based on current models and data, and favor instead robust interventions that deliver benefits in a broad range of possible futures (see *toolbox K* for methodologies).

In thinking about how they communicate climate change information to the public, governments need to ensure they highlight the large uncertainty around future climate change impacts and do not focus on a single "most likely" scenario. Doing so could give households and firms overconfidence in these scenarios and choosing

the adaptation options that work best in them. This could have catastrophic outcomes if future climate change differs from the "most likely" scenario. While there is an understandable temptation to provide a single simple scenario to make it easier for users to access climate information, it could lead to maladaptation and higher, not lower, vulnerability. *Figure 2* illustrates this challenge for Senegal, where some climate models project an increase in annual precipitation while others project a decline. A robust adaptation action must provide benefits in both possible scenarios.

FIGURE 2 >>

Precipitation change over Senegal in 2080–2099 (RCP8.5 scenario), according to two state-of-the-art climate models, and ranging from a significant decline to a large increase



Source: World Bank's Climate Change Knowledge Portal.[4]
Note: CSIRO is Australia's Commonwealth Scientific and Industrial Research Organisation; GFDL is the Geophysical Fluid Dynamics Laboratory in the US.

ACTION 1.2 >>

Clarify responsibilities and align incentives with adaptation and resilience objectives

LEAD MINISTRY: *Economy or finance*

Private actions to manage climate change and natural disasters may be impaired by an unclear allocation of responsibilities. Firms and populations in a flood zone may assume that flood management is the responsibility of the local or national government, so they do not need to make their own investments to reduce risks or adapt to climate change.

To ensure households and firms are making the right decisions, governments should clearly establish responsibilities and liabilities in law and communicate these to all private actors. In the Netherlands, the government is responsible for providing protection from floods, but only up to a certain level. It publishes simple maps outlining residual flooding risks despite the flood defenses. These maps help all private actors decide where to buy a house or build a factory, the construction standards they should implement and the levels of financial preparedness they will need.

Allocating responsibilities may require significant institutional and legal reforms. In 2012, Colombia's Law 1523 created a national risk management policy and system to identify, monitor and analyze risks related to climate change, prepare measures to address situations of emergency, establish relevant financial instruments, and develop a comprehensive communication and stakeholder engagement system.[12] This law preceded the adoption of framework climate change legislation (Law 1931) in 2018, which specifies that the national and territorial risk management plans required under Law 1523 should incorporate actions to foster knowledge generation and reduce risk and vulnerability to climate change. It also mandates the government to develop guidelines for disaster risk management plans.

Countries must also recognize that they may not have the right incentives in place for private actors to adapt (Hallegatte and Rentschler 2015; World Bank 2013). This is generally due to coordination or governance failures. Coordination failures tend to arise from lack of policies to help independent actors coordinate their actions.

TAKING ACTION >>

Sample targets and indicators

- Law allocating responsibilities and liabilities for disaster risk management and climate change impacts passed
- Target level of residual risks published and made publicly available—for example, through residual flood risk maps
- Specialized agencies to manage water sharing at the watershed level established

For example, if multiple actors are interdependent, it may not be profitable for a single actor to invest in resilience, unless all actors do (Kunreuther and Heal 2003). In a world of interconnected supply chains, it may not make sense for a single producer to build their own resilience to floods if they know the production process will be interrupted by a lack of supplies or transport.

Governance failures are usually linked to ill-designed regulations and institutions. In some cases, agencies are put in charge of managing a problem that they do not have adequate resources for or are better managed at a larger spatial scale. In some cases, small municipalities are put in charge of disaster risk or water scarcity management when these challenges would be managed more effectively at agglomeration or watershed levels. In other cases, public agencies or regulators that are best placed to manage risks either do not have the mandate to do so, or have overlapping mandates with other institutions, which can create conflicts and inefficiencies.

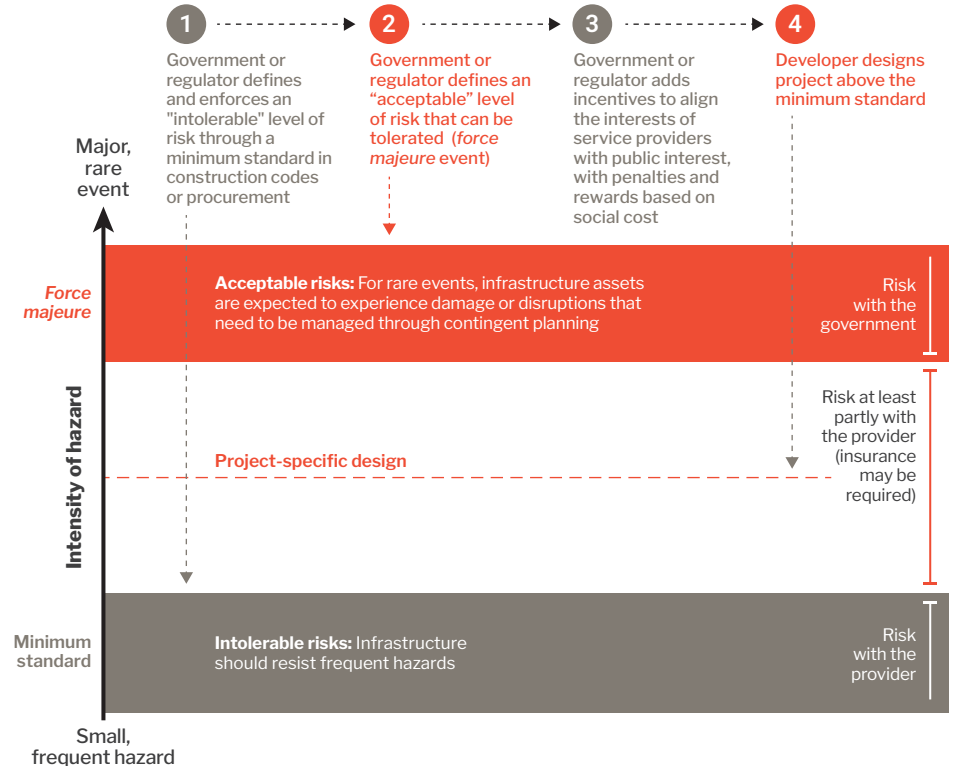
This problem is particularly acute for infrastructure systems—especially when service provision is ensured by private and public actors, for example through public-private partnerships (PPP). If the responsibilities for managing risks from climate change and natural hazards are not carefully and explicitly assigned to the various parties involved—for example, the builder, the operator, the state, and the user—then it is unlikely that adequate risk reduction measures will be implemented. In the aftermath of a disaster, governments usually provide people, firms, and infrastructure owners and operators with support. But the mere possibility of public aid after disasters can create moral hazards, which to some extent can discourage risk management and the purchase of insurance. However, providing support during and after a crisis is a central government mission, and no government should withhold such support just to avoid moral hazard, especially when basic services—such as electricity, water, and transportation—are at stake.

Instead, effective risk management should rely on governments designing a consistent set of regulations and financial incentives to align the interests of infrastructure service providers with the public interest (*figure 3*).

First, for each hazard and infrastructure system, governments or regulators need to define a minimum standard of resistance—that is, a hazard intensity below which the service should not be disrupted. For example, road agencies are responsible for ensuring that all roads can cope with a rainfall event that has a certain annual probability of occurrence. Second, they need to define in a measurable and quantified manner the level of acceptable risk—or *force majeure*—that is, the level at which disruptions and damages have to be tolerated, because avoiding them would be too expensive or technically impossible. Beyond this level, the risk from a natural hazard is usually supported by the public sector (through a *force majeure* clause). Below this level, at least part of the risk needs to be supported by the private

FIGURE 3 >>

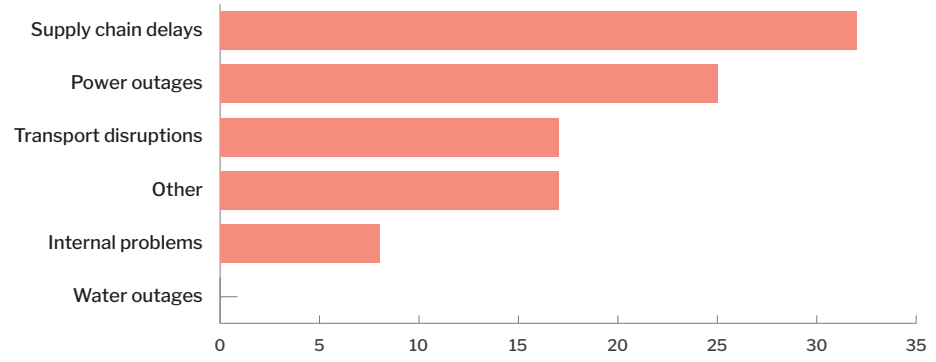
Creating the right resilience incentives for infrastructure service providers requires a consistent set of regulations and financial incentives



Source: Hallegatte et al. 2019.

FIGURE 4 >>

Main causes of delivery delays in Tanzania



Source: Colon et al. 2019.

service provider, to align the provider's interest with the public interest. One way of achieving this is by penalizing an infrastructure operator for disruptions—for example, penalizing electricity utilities for extended power outages due to storms, with fees corresponding to the social cost of such disruptions.

However, coordination issues also occur between private actors. A survey in Tanzania highlighted that, when firms cannot deliver on time, delays are predominantly caused by supply chain and infrastructure disruptions—rather than problems with production (*figure 4*). In such cases, there are few incentives for firms to invest in their resilience, thus locking the overall economic system into a low-resilience equilibrium. While this situation may improve over time as economic growth provides more resources to build resilience, governments can use targeted policies to support and accelerate the process. This includes signaling a target level of resilience that actors can use to calibrate investments (Hallegatte et al. 2019).

Reviewing existing subsidies to remove the ones that favor excessive risk taking is also crucial. For example, poorly designed construction subsidies that make housing more affordable can attract construction onto low-value, high-risk plots and increase the share of buildings in flood zones, while poorly designed agriculture subsidies can incentivize excessive irrigation in situations of water scarcity or lead to deforestation.

Even strong, targeted actions and investments to adapt to climate change are unlikely to be effective if they are undermined by non-aligned measures that create or increase climate risks. When and where subsidies are necessary to maintain access to basic needs and fight poverty, they can often be redesigned to minimize negative impacts on resilience and risk-taking—for example, by making agriculture subsidies independent of quantities produced.

Private actors can sometimes transfer disaster and climate risk to others. This happens, for example, when developers sell flood-prone houses at prices that do not fully internalize the flood risks (Bin and Polasky 2004; Holway and Burby 1990). Imperfect land markets and a lack of hazard risk data can incentivize people to build in at-risk areas, unless public intervention—such as mandating to inform potential buyers with hazard information or regulating construction in at-risks areas—discourages them from doing so.

Public action may also be necessary to manage damages and externality from private adaptation actions, particularly when it comes to shared resources like water. For example, adaptation in agriculture can lead to unsustainable water use that threatens long-term underground reserves or ecosystem health (Damania et al. 2017). In such cases, governments may have to adjust operational rules for hydropower dams and manage difficult trade-offs between the needs for energy generation, irrigation, and recreational activities, while preserving enough flow to ensure healthy ecosystems.

In another example, air conditioning use can threaten power system reliability and lead to higher outdoor temperatures in cities (Stone et al. 2010; Silva et al. 2010). In one case study, Viguié et al. (2019) simulated the effect of more frequent and hotter heat waves on airconditioning in Paris, France. To maintain all buildings at 23°C, they projected an average increase of 1.134 terawatt-hours in final annual energy consumption. The extra energy consumption from cooling during a heat wave corresponds to 81 percent of the city's average daily electricity consumption for offices and housing. This additional demand represents a significant challenge and can lead to outages, especially in places where power systems are already under strain and struggle to keep pace with growing energy consumption. Air conditioning systems also release hot air outside of buildings. This increases outdoor temperatures, impacting not only on outdoor thermal comfort, but also on indoor comfort in dwellings without air conditioning (and for homeless people). In all these cases, authorities should develop appropriate regulations to ensure adaptation by one actor is not at the expense of others.

ACTION 1.3 >>

Facilitate access to technologies through research and development investments and trade policies

LEAD MINISTRY: *Economy or finance, with environment/infrastructure*

Effective adaptation will depend on countries being able to draw on the best available technologies for mitigating climate change impacts, especially in the agriculture and health sectors (GCA 2019). New technologies, improvements in crop varieties, smarter input use, and methods to strengthen crop resistance to pests and diseases and reduce postharvest losses could all help tackle food security challenges (FAO et al. 2015; Beddington 2010; Tilman et al. 2011). Improved crops and more efficient water and soil use can increase farmers' incomes and their resilience to climate shocks (Cervigni and Morris 2016). Developing and adopting higher-yielding and more climate-resistant crop varieties and livestock breeds is one way to make agricultural systems more climate-resilient (Tester and Langridge 2010). For example, a randomized control trial in Orissa, India found that a flood-resistant rice variety yielded 45 percent more than the most popular variety at the time (Dar et al. 2013).

However, a recent global analysis of adaptation-related patents highlighted the following three key challenges (Glachant et al. 2020):

» Innovation for climate change adaptation—at least in proportion of total innovation—has not increased over time (*figure 5*), even though identified needs have arguably increased significantly.

» Innovation for adaptation occurs primarily in high-income countries and in a handful of middle-income countries. Analysis of international patents suggests that not only are there close to no patented innovations in low-income countries, but patented innovations from middle- and high-income countries are not transferred to these countries (*table 1*).

TABLE 1 >>

Distribution of exported patented climate change adaptation technology inventions between income groups

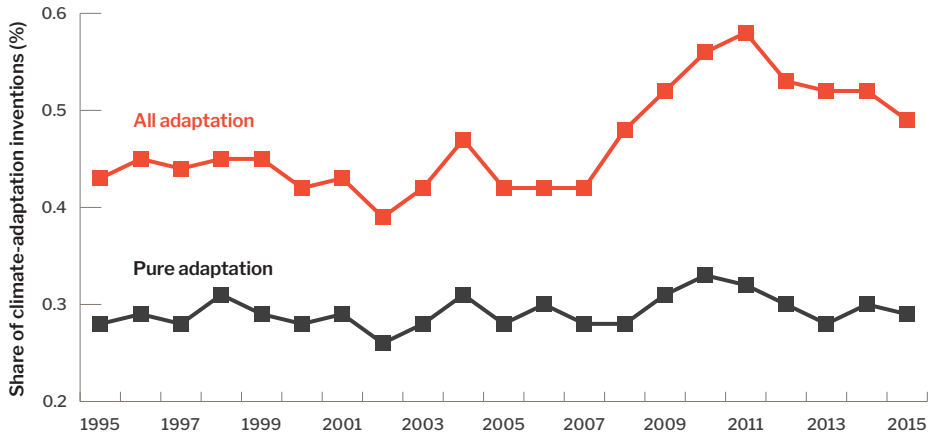
	DESTINATION:		
ORIGIN:	**High income**	**Middle income**	**Low income**
High income	66% (69%)	27% (24%)	0% (0%)
Middle income	5% (7%)	<1% (<1%)	0% (0%)
Low income	<0.1% (<0.1%)	<0.01% (<0.01%)	0% (0%)

Source: Glachant et al. 2020, based on PATSTAT data.
Note: Results for all technologies appear in parentheses.

» Adoption of available new technology in low-income countries is often slow and limited. For example, high transport costs and poor distribution systems mean that fertilizer application remains low in Africa (Gilbert 2012). Other barriers to the widespread adoption of new technologies include cultural issues, a lack of information and education, and implementation costs. In some cases, technologies, goods, or services that could support adaptation are difficult to import, due to a lack of internal capacity or trade policies and barriers. Policy change may be the most efficient way to help people access adaptation-related technologies, since developing domestic technologies and producers can be long and costly.

FIGURE 5 >>

Innovation for climate change adaptation as a share of total innovation



Source: Glachant et al. 2020, based on PATSTAT data.
Note: "Pure adaptation" refers to technologies for climate change adaptation that are not simultaneously classified as mitigation technologies.

TAKING ACTION >>

Sample targets and indicators

- Share of farmers using improved crops and climate-smart practices
- Share of research and development (R&D) or percentage of patents related to climate change adaptation
- Total amount invested in R&D on adaptation-related or resilience-related challenges
- Amount invested by the public or private sector in R&D on adaptation-related or resilience-related challenges
- Average tariff applied to imports of resilience-related technologies

ACTION 1.4 >>

Ensure financing is available to all, and provide support to the poorest and most vulnerable people

LEAD MINISTRY: *Economy or finance, with social affairs/social protection*

Adaptation—preventing and reducing future losses due to climate change—makes economic sense, and private actors are incentivized to contribute to it. However, high upfront costs may stop them from implementing effective solutions. Even if these costs are more than compensated in the long term by avoided impacts and losses, the lack of financing can be a serious obstacle for credit-constrained firms and households.

Financial inclusion and a well-managed, stable financial system are important for increasing an economy's adaptive capacity. However, ensuring that financial solutions are accessible to all may require specific measures such as mobile banking to access savings and credit possibilities in rural households. Financial inclusion alone may not be enough to allow the poorest households to invest in managing risks or coping with shocks, so, governments must take a role and responsibility in this.

Poor people are disproportionally affected by climate-related shocks and stressors. Not only are they more exposed and invariably more vulnerable to climate-related shocks; they also have fewer resources to adapt to climate change. Poor people tend to invest less in preventing and mitigating the adverse effects of natural hazards and climate change. In China, Indonesia, the Philippines, Thailand, and Vietnam, wealthier households are more likely to invest in proactive adaptation measures (Francisco et al. 2011).

TAKING ACTION >>

Sample targets and indicators

- Number of firms/people accessing dedicated financing instruments such as guarantees, subsidized loans
- Total borrowing for adaptation through dedicated windows
- Most vulnerable populations and communities (occupations, localizations, poverty, ethnicity, and so on) identified and information published
- Share of poor and vulnerable population receiving support for adaptation
- Total subsidy/spending targeting poor and vulnerable populations to support adaptation action

In the absence of external support, hundreds of millions of people in or close to poverty will be impacted by climate change and have limited ability to respond and adapt. Governments are widely considered to be responsible for supporting vulnerable populations and helping them adapt to external stressors, such as climate change. Multiple instruments can help with this, from direct cash transfers to reduce poverty to targeted subsidies for efficient irrigation equipment or air conditioning. But they all require governments to first:

- Identify the populations that are most vulnerable to climate change and least able to adapt
- Identify the impact channels through which they will be affected
- Design policies to support their ability to cope with and adapt to these impacts (*toolbox B*).

Social safety nets targeted to poor households can be complemented by activities focused on climate adaptation and mitigation. Such safety nets have seen a dramatic expansion across the developing world over the last decade, involving conditional and unconditional cash transfers or, where appropriate, in-kind benefits. There are three main types of safety net intervention that support household adaptation and mitigation to climate change.

1. Regular cash transfers that build household resilience to climate-related shocks and worsening livelihood conditions by facilitating livelihood diversification, building savings, and avoiding negative coping strategies.
2. Reinforcing these cash transfers with accompanying measures focused on various development objectives such as economic inclusion and increases in productivity, human capital formation and climate adaptation that are typically delivered through social workers, community organizations and in partnership with civil society organizations. Explicitly climate-adaptive measures that can amplify the impacts of cash transfers on household resilience include:
    - Behavior change interventions with information on timing of rainy and lean seasons or which crops to diversify out of or into
    - Savings interventions to generate a buffer to absorb climate shocks or enable investments in adaptation or livelihood portfolio adjustments
    - Skills training and coaching to support livelihood diversification

- Early childhood development, nutrition and health interventions focused on raising household and community capability to manage the impact of climate shocks on child development, nutrition, or food security.

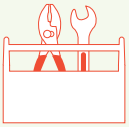
3. Public works—where beneficiaries provide community services or build assets for cash or in-kind benefits—as part of adaptive social protection. As well as promoting adaptation by providing cash to beneficiaries, such initiatives have potential for climate mitigation through climate-sensitive works like reforestation, irrigation, combatting soil erosion, and water security, and by generating community assets that tackle the root causes of climate change vulnerability in a community.

Governments can layer these three social safety net instruments for additive impact. Regular cash transfers—whether conditional or unconditional—are the foundation to help households navigate the impacts of climate change. Adding accompanying measures that explicitly focus on climate resilience can reinforce their climate-adaptive potential in specific areas, as can public works. For example, such initiatives can be concentrated in areas, households or communities that are particularly vulnerable to climate change.

All these interventions can be made "shock-responsive", triggered by covariate climate shocks like droughts and floods to support an expanded number of affected households and communities in the event of a climactic shock. See *Action 3.4* for more on shock-responsive social protection.

TAKING ACTION >>
Toolbox B

Identifying climate change impacts on poor populations and poverty and defining priorities for action



Poor people are more vulnerable to environmental scarcity, stresses, shocks, and climate change impacts (Hallegatte et al. 2015). Economic models based on national accounts—such as computable general equilibrium (CGE) models—can underestimate this vulnerability. However, dedicated analysis of poor people's situations, based on household surveys or microsimulations, can help identify vulnerability hotspots and opportunities for high-return interventions. This toolbox presents two complementary approaches, with examples from Burundi, Georgia, and Tanzania, to illustrate how countries can better inform policies.

Microsimulation and household-level analyses

Hallegatte et al. (2015) use the World Bank's *International Income Distribution Data Set*, a global database of household surveys describing the distribution of income and occupations in 92 countries. Using microsimulation techniques, they projected the evolution of these households until 2030, driven by demographics, socioeconomic change, and climate change, to identify which impacts are most important for poverty outcomes in the 92 countries. Illustrating the results in Burundi and Georgia, ***figure B.1*** shows that climate change is expected to have a larger impact in Burundi for each metric. For example, income is predicted to drop by 4 percent in Burundi and 2.5 percent in Georgia by 2030. The biggest impact in Burundi will be the change in food prices, while in Georgia, it is labor productivity. Governments can use this type of analysis alongside the simpler indicator-based approach proposed in ***toolbox A*** to identify priorities for adaptation to minimize the impact of climate change on poverty and poor people.

Dedicated household surveys

Household surveys can be highly effective to better understand the risks and challenges faced by a specific population in a specific context. Collecting household-level data on income levels and disaster risk allows researchers to study exposure, disaster loss, and recovery capacity in relation to poverty. For example, Erman et al. (2019) collected a representative dataset on income levels and flood risk from households in Dar es Salaam, Tanzania—such as how many people are affected by flooding, how they are affected, the mechanisms and tools they use to recover, and how effective these are—to understand the extent of the challenges and potential solutions. Surveys can provide both spatial and socioeconomic information to help identify vulnerability hotspots, which in turn can inform targeting and policy design.

FIGURE B.1 >>

Projected impact of climate change by 2030 in Burundi and Georgia

Source: Hallegatte et al. 2015.
Note: The figure shows the impact of climate change on GNI (gross national income), income for the poorest 40 percent and rise in extreme poverty (in the high-impact and high-poverty scenario).

ACTION 1.5 >>

Facilitate structural change in the economic system

LEAD MINISTRY: *Economy or finance*

Climate change will affect latent comparative advantage. For example, it will make some countries less productive in certain types of agriculture, to the benefit of others. It will also cause the decline of some (sunset) sectors and the growth of other (sunrise) sectors.

The challenge is the combination of long-term uncertainty with timing constraints. With perfect foresight, an economic system would move away from sunset sectors and progressively invest in sunrise sectors, moving jobs, opportunities, and profits with minimal losses.

In practice, however, the risk is that the sunset sector becomes non-profitable exactly when large investments are required to boost another sector. Experience from regions where coal mining or heavy industries disappeared in Europe shows how difficult it is to manage a successful transition, especially when a region has a narrow economic base, is isolated geographically, and has a population with limited skills and investment capacity. In France, unemployment is still higher than average in areas where coal mines were closed decades ago (*figure 6*).

TAKING ACTION >>

Sample targets and indicators

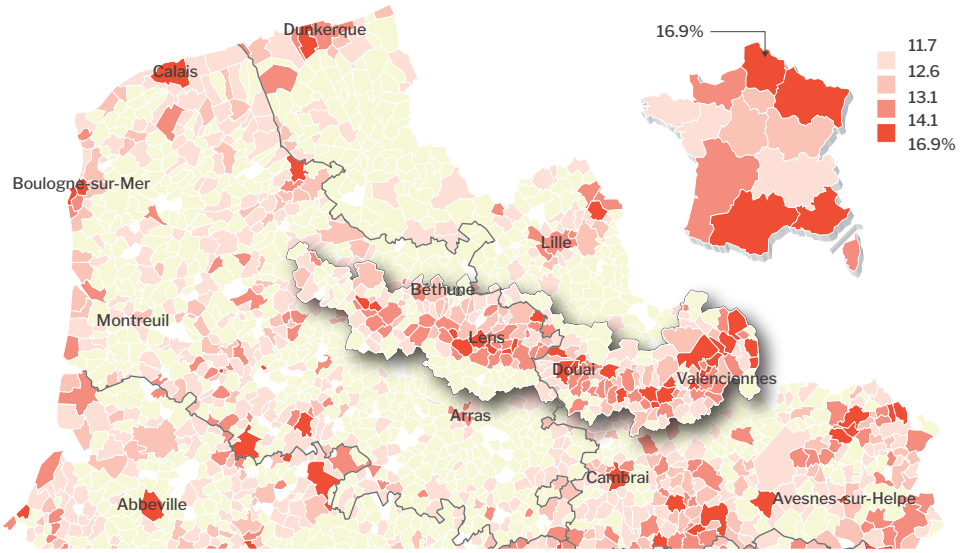
- Strategy to manage the decline of negatively affected sectors published, or to support the development of nonaffected or positively affected sectors published
- Share of GDP, employment or exports in sectors expected to be negatively or positively affected
- Measure of economic diversification—for example, number of exported products—or latent diversification

There are few success stories of fully satisfactory economic rejuvenation outcomes in mono-industry coal mining towns. While economic diversification and rejuvenation is an objective shared by many regions, coal mine closures often mean the loss of the main regional employer. That dramatically reduces overall re-employment potential for workers and exposes the risks of a narrow economic base. The compounding effect is significant. Rejuvenating local economies in coal-dependent regions is a complex challenge and can fail, even with good intentions and enough funds. For example, the UK targeted various forms of regional aid at several of its main mining areas to foster job creation. This included a program of coalfield site reclamation and redevelopment that disbursed more than £600 million between 1996 and 2007 (World Bank Group 2018). British coal mining regions have received European Union (EU) support, both through its standard structural funds and specific programs like the RECHAR program, which deployed

more than £250 million over 10 years. Despite this, decades after the UK's major waves of mine closures, labor market impacts can still be felt, especially in areas where difficulties are entrenched, such as South Wales. Mobility support for workers to relocate out of mono-industry coal mining towns may sometimes represent a better option.

FIGURE 6 >>

Unemployment in northern France's coal basin, 30 years after the coal mine closures



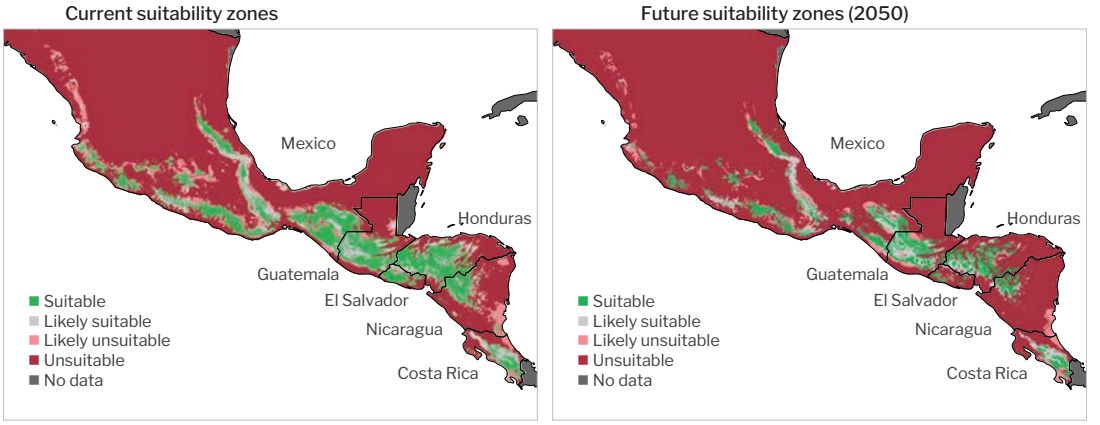
Source: Mission Bassin Minier.

Managing transitions will be crucial for minimizing the impacts of climate change. For example, coffee production employs 10 percent of the labor force in Honduras, but climate change is expected to have significant adverse impacts on coffee yields throughout Central America (*figure 7*). The area of land that is climatically suitable for coffee production is expected to decrease by 42 percent in the coming decades (Bunn et al. 2018). When these activities are affected, the impacts will go beyond individuals losing their job or firms going bankrupt, possibly leading to macroeconomic crises with system-wide spillover effects.

If their main economic activity is in crisis, countries can struggle to free up resources to invest in new sectors. To avoid this issue, they will need to take proactive measures, such as shifting to new activities before the old ones collapse. This allows new sectors to grow and facilitates the strategic and managed decline of others. Indeed, considering the deep uncertainty around the nature and magnitude of future climate change impacts, diversifying economic activities is a no-regret strategy. See also *Priority Area 4* for a discussion of macroeconomic impacts.

FIGURE 7 >>

Suitability of land for coffee production under current and future (2050) climatic conditions



Source: Bunn et al. 2018
Notes: Suitable areas include 13 sub-categories based on different dry season characteristics. Projected 2050s conditions are based on a modal projection across 19 general circulation models for the RCP 6.0 emissions scenario.

Support sunrise sectors and activities to maximize their development potential

Climate change may create new comparative advantages in some countries, and those where key sectors will be negatively affected must prepare to capture the opportunities created by climate change. However, if these latent advantages face obstacles such as high upfront capital investments, increasing returns to scale, or network effects, then a country may struggle to turn them into growth and economic opportunities. Several studies offer guidance on how growth-enhancing policies can be indispensable for turning latent comparative advantages into real economic opportunities, especially if countries face the risk of a low-productivity trap (Harrison and Rodriguez-Clare 2009; Rodrik 2004).

To realize a latent comparative advantage, governments may need to solve coordination failures within and across sectors to develop new activities—for example, by supporting interdependent sectors (Rosenstein-Rodan 1943; Pack and Westphal 1986; Okuno-Fujiwara 1988; Murphy et al. 1988). Although a changing climate may make one region suitable for producing a new agricultural product, for this to be profitable, farmers will need to invest in new equipment or seeds and have access to adequate supply chains and markets. Without public actions to create relevant markets or invest in the necessary infrastructure to facilitate access, it may be impossible for individual producers to shift to a new product.

In this context, governments can seize opportunities by identifying potential new comparative advantages — for example, through exchanges between government organizations and the private sector (Rodrik 2004; Harrison and Rodríguez-Clare 2009). In some cases, such as agriculture, tourism, or energy, a latent comparative advantage can be observed in advance, justifying a targeted industrial policy.

Manage sunset sectors and activities to facilitate a smooth transition

Some economic sectors may be strongly affected by climate change, with significant implications for jobs and tax revenues. For example, some agricultural production may become non-competitive or unsustainable, snow-based tourism may disappear from low-altitude mountains and summer destinations may become too hot to attract tourists. Targeted policies can help declining industries and better manage the drop in activity (for example, ensuring that the least productive firms close first). Although this may be costly, it can be justified by distributional considerations or a desire to smooth a transition and lessen the impact on welfare and social stability.

Governments have long used policies to create regional balance, jobs, and activity where unemployment is higher or the population poorer, or to smooth economic transitions. Labor markets are seldom flexible; structural economic changes or trade liberalization often lead to a rise in unemployment, as skill and institutional issues prevent workers from moving from sunset to sunrise sectors. After trade liberalization displaced workers from Brazil's de-protected industries (Muendler 2010; Menezes-Filho and Muendler 2011), it took several years for the growth sectors to absorb them (see Porto 2012). The social costs of such a transition may justify transient support to declining industries to allow time for retraining and to shift workers toward growing sectors. Japanese industries used this approach to make the transition toward high-productivity, high-skill industries more socially acceptable (Peck et al. 1987).

Lessons from the trade adjustment literature suggest that it is more efficient to subsidize employment in growing sectors than support workers in declining industries (Porto 2012). Governments can either support firms in sunrise sectors to enable them to absorb sunset sector workers more rapidly, or directly support workers through social safety nets and retraining schemes.

Support economic diversification to hedge against climate risks

Diversifying away from narrow economic bases is key to reducing vulnerability to climate change and other technological or preference shocks. But there are also pure short-term economic reasons for diversifying the economy. When successfully accomplished, export diversification has yielded benefits and has often been associated with higher levels and stronger resilience of GDP growth (Hesse et al. 2008). This success is driven by the wider range of higher value-added products that provide a hedge against single-commodity price volatility and the development of sectors that have greater technological spillovers. Yet, as evidenced by many stalled attempts, diversification can be challenging. And while diversification appears unambiguously positive in low- and middle-income countries, the most advanced economies seem to benefit instead from export specialization.

There are different ways of supporting the diversification of an economy (Gill et al. 2014). The traditional form supports new activities downstream of existing specialization that use the same skills and competencies. This includes, for example, oil-producing countries focusing on energy-intensive industries and agriculture-dominated economies focusing on agrobusiness. Another option is diversifying an economy's production factors by investing in better education, new skills, knowledge, and natural capital to make countries less dependent on a narrow set of assets. This, in turn, makes them less vulnerable to direct impacts on these assets—such as where water scarcity leads to a decline in agricultural land productivity—or indirect effects on their productivity—for example, where lower tourism flows reduce the revenues derived from pristine beaches. Intangible assets like knowledge and human capital are important for building competitive economies that are more flexible, adaptable, and resilient to a wide range of external shocks.

Governments can promote diversification through:

- Public investments in health and education, innovation and institutions, and natural asset protection
- Effective policies to support the reallocation of economic resources to new activities, such as labor market policies to overcome constraints on mobility or barriers to the entry of women in the workforce, and access to finance
- An appropriate incentive framework based on a clear, transparent, and predictable business and investment climate
- Policies to reduce specific market and institutional failures, such as the lack of access to knowledge about new products, technologies, or international standards
- Investments in infrastructure and coordinated policy reforms to reduce trade costs.

SPOTLIGHT 2 >>

COVID-19

Stimulus and recovery program and economic diversification

The COVID-19 pandemic is likely to lead to a major economic crisis, and many governments will be preparing recovery and stimulus packages to help their economy restart when the virus is under control. Depending on their design, these packages can support or impair diversification and resilience. In particular, when governments provide direct support to firms—either through subsidized or guaranteed loans or bail-out grants—there is a risk that this support will go primarily to incumbents, while younger firms in new sectors or deploying new technologies get no support and go bankrupt. Governments should therefore review stimulus packages to ensure that they do not reinforce specialization in sectors that are in decline, have limited growth prospects, or are highly vulnerable to climate change impacts.

Some countries are going further and using the bail-out of affected firms to encourage a transition in favor of other policy goals. For example, in 2008/2009 many countries supported their automobile industry to favor low-emissions (especially electric) cars. Today, the government of France is helping Air France with a €7 billion subsidy in exchange for environment-related commitments, such as reducing CO_2 emissions from domestic flights by 50 percent by 2024, and sourcing 2 percent of its fuel from sustainable sources by 2025.

Similar commitments are possible in favor of resilience. For example, many utilities have received exceptional government support to weather the COVID-19 crisis; governments could tie this support to renewed and tightened commitments regarding the reliability and resilience of power or water systems.

Priority Area 2:

Adapt land use plans and protect critical public assets and services

LEAD MINISTRY:
Economy, planning, investment, or infrastructure

Certain adaptation actions cannot be implemented by private actors and will require direct public action. These include protecting or adapting assets that are owned by the government or other public entities, those that are privately owned but designed, built or operated following strict public regulations and guidance that leave little room and few incentives for private actors to act, and those that are considered to be government responsibility. The latter typically include assets within the health, education, security, and safety sectors. Public action is also important for including climate change in land use or coastal management plans, which constrain and drive private investments in infrastructure and buildings and can serve as coordination mechanisms for private actors.

This dimension of adaptation and resilience also tends to involve decisions and investments with long lifetimes, as many infrastructure assets are designed to last for more than 50 years. At the same time, the spatial patterns created by infrastructure and land use plans are almost irreversible. As a result, it is important to consider even climate change impacts that are only expected over the long term in today's decision making. Including long-term impacts means decision makers must carefully consider uncertainties and prioritize solutions that are robust (deliver benefits in a large range of possible futures) and flexible enough to be adjusted when new information is available.

TAKING ACTION >>

Screening questions

Identify actions to strengthen the resilience of public infrastructure and critical services

While the actions of individuals can go a long way in adapting to a changing climate, they are not enough. People's resilience to climate change depends on the resilience of their cities, and of the critical infrastructure systems and public services they rely on. Have governments taken adequate measures to ensure that spatial and urban planning is risk-informed and climate-smart? Are their measures sufficient to ensure that lifeline infrastructure systems and essential public services are equipped to handle the impacts of climate change? The following questions can help decision makers identify shortcomings and guide them towards the actions needed to strengthen the resilience of public infrastructure and critical services.

ACTION 2.1 >>

Public services and infrastructure

Does the government have a georeferenced inventory of government assets?

Should include: *hospitals; schools; fire and police stations; infrastructure assets such as roads, bridges, and electricity generation; and so on*

Did the government identify critical services and assets that need to be protected or strengthened in priority?

Could include: *criticality analysis of transport or energy systems; stress testing of hospital systems*

Have the authorities assessed and addressed the risks to public service and infrastructure assets?

Could include: *risk assessments of critical infrastructure and public services; risk-informed asset maintenance*

ACTION 2.2 >>

Strengthening new assets and infrastructure

Does the government have standards and norms that account for criticality of assets and exposure to natural hazards? Are they adjusted regularly to respond to climate change?

Should include: *hospitals; schools; fire and police stations; infrastructure assets such as roads, bridges, and electricity generation; and so on*

ACTION 2.3 >>

Risk-informed land use and urban planning

Is risk-informed land use and urban planning legally required and consistently enforced?

Could include: *long-term plans supported by laws; enforcement mechanisms; strategic retreat options*

Are nature-based solutions and ecosystem services an integral part of a country's risk reduction strategy?

Could include: *systematically conducted environmental risk assessments; restoration and preservation of protective ecosystems*

Are areas that are impossible or too costly to protect in the long term identified and known by the public? Is risk information available to buyers of land or buildings?

Could include: *long-term maps with areas that are expected to benefit from protection investments published*

ACTION 2.1 >>

Identify critical public services and assets

LEAD MINISTRY: *Economy, planning, investment, or infrastructure*

Critical public services such as energy, water, health care, civil protection, and education need thorough climate risk assessment and management. Not only can their reconstruction be costly; they also provide critical services which people's well-being depends on. Even relatively short disruptions in power, health care or education can have long-term adverse consequences, especially for vulnerable groups, such as children (Hallegatte et al. 2019). The police, military, fire, and other civil protection services maintain security and safety and are a crucial part of any response to large climatic shocks, such as floods. Ensuring the resilience of their facilities and accessibility can mean the difference between effective response and a devastating prolonged disaster.

TAKING ACTION >>

Sample targets and indicators

- Critical infrastructure and services identified
- Inventory of public assets and infrastructure prepared, including hospital, school, and university buildings, their condition, exposure to hazards, and maintenance history
- Gaps in infrastructure and public assets identified
- Investment plans to increase the resilience of public services and infrastructure systems completed

For a systematic risk and vulnerability assessment, governments must develop inventories of key public assets, such as primary health care facilities, hospitals, and schools. The government of Vietnam, for example, is establishing an inventory of over 750 health care facilities, detailing their georeferenced location, type, and capacity. Using flood hazard maps, a countrywide risk assessment shows that about 34 percent of all health care facilities in Vietnam's coastal provinces would be affected by flooding with a 100-year return period (Rentschler et al. 2020). Such asset inventories can help authorities identify at-risk facilities or under-served areas and determine priorities for resilience investments. Updating them regularly and making them accessible to decision makers can help strengthen the assets themselves and the resilience of critical public services.

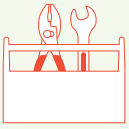
Criticality analysis (*toolbox C*) also helps identify which part of networked systems—which include transport, electricity, and telecommunications—play a particularly important role for the functioning of the full system. This makes it possible to focus resources on key assets, maximizing adaptation and resilience spending efficiency.

Insufficient services and missing infrastructure assets can magnify the vulnerability of the full system. For example, a region that is connected to the national grid by a

TAKING ACTION >>

Toolbox C

Using criticality analyses to identify key infrastructure vulnerabilities and gaps in services and networks



Criticality analysis is an important tool for identifying the most important infrastructure assets and their vulnerability, and to prioritize those interventions that will give the largest benefits.

As part of its climate vulnerability assessment, the government of Fiji applied this approach to the transport system. The sector contributes approximately 12 percent to Fiji's GDP and receives around 30 percent of the government's annual capital budget. It is therefore not realistic to expect a large increase in spending in this sector: it is more important to improve the efficiency of spending. Using an asset database coupled with modeling tools developed by the World Bank, a criticality analysis of Fiji's road network aimed to identify the transport assets that were most likely to result in high economic losses if damaged. For each component of the road network, the analysis estimated the number of trips that would become impossible in case of failure of or damage to the asset and assessed additional travel distances and extra costs to the road user for trips that would remain possible. The components that would cause the largest impacts on the whole network if damaged are considered "critical".

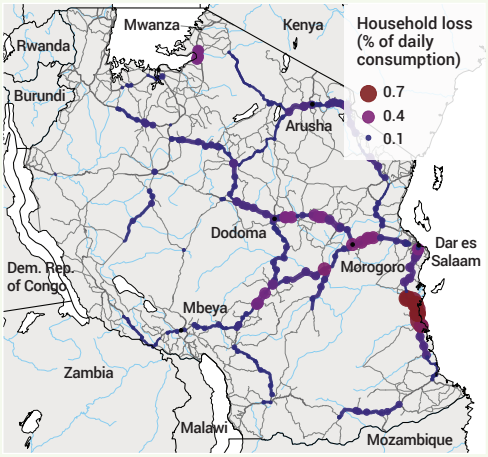
A similar study was performed for the Tanzanian road network and its vulnerability to floods. The study evaluated the consequences in different supply chains of disrupting each road infrastructure asset for various durations. The main conclusion was that the most critical transport infrastructure assets differ across supply chains. ***Figure C.1*** shows the possible effects of a one-week road disruption on household consumption and

exports. Comparison of the maps reveals that investment priorities depend on policy objectives. For example, segments of the coastal trunk road south of Dar es Salaam are critical for maintaining household consumption and food security, but less relevant for manufacturing and trade. For the latter, improving the road east of Morogoro is a priority. This segment carries large freight flows between Dar es Salaam port and landlocked countries such as the Democratic Republic of Congo and Zambia.

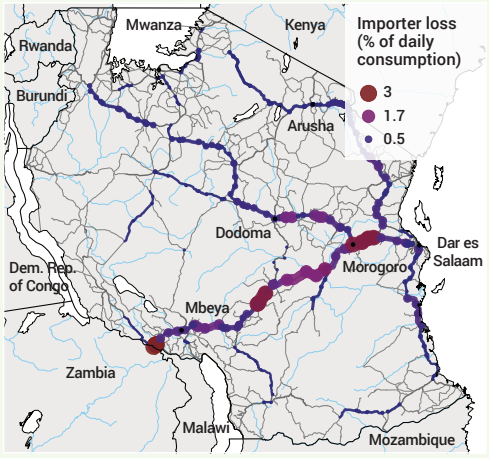
FIGURE C.1 >>

The criticality of a road depends on how it is used

a. Impacts of road disruption on households' consumption



b. Impacts of road disruption on international clients



Source: Hallegatte et al. 2019.

unique transmission line can be excessively vulnerable in case of storm, regardless of the robustness of this line. Similarly, the inability to detect emerging diseases in one region can make an entire country (or the whole world) more vulnerable. So, system-level analysis is important. It should not only consider which links, assets, or services can be strengthened, but also which additional links, assets, or services can be created to build redundancy and resilience.

The Fiji Climate Vulnerability Assessment (CVA) identified 125 projects in 10 sectors that would build the country's resilience (*table 2*). These were based on the national development priority and strategy, as stated in its 5- and 20-year development plans, and the identified climate change risks. After prioritizing the projects for implementation, the government can translate the list of priorities into an investment plan for public asset and infrastructure,[13] with costings and identifying responsible public agencies. Different agencies can then use this plan to prepare their work program and budget requests, alongside their many other missions and responsibilities, and the Ministry of Finance can use it to estimate additional financing needs for climate change adaptation (see *Priority Area 4* and *Spotlight 4*).

TABLE 2 >>

Extract from the Fiji Climate Vulnerability Assessment list of priority interventions

TRANSPORT						
Intervention description	Time frame	Cost (F$, millions)	Responsible agency	Type of intervention	Status	Comments
Jetty replacement and upgrade works package—Phase II	Medium term	127.50	Fiji Roads Authority	Investment	Planned	
Road renewal and replacement works pacakage—Phase II (climate upgrade portion)	Medium term	262.00	Fiji Roads Authority	Investment	New	Includes upgrades to 450 km of sealed and 1,425 km of unsealed roads
Highest priority water crossings works package—Phase II	Medium term	356.00	Fiji Roads Authority	Investment	Planned	Includes bridges/ crossings/culverts/ footbridges

Source: Government of Fiji and World Bank 2017.

Assessing the resilience of service delivery in critical sectors can also be a useful exercise. This includes using a scenario-based approach to discuss responses in health care, public school, or social protection systems. It is particularly useful in the health care sector, which plays a key role after a natural disaster, especially in the event of massive casualties (Tariverdi et al. 2019). The same applies for social protection systems, which need to be stress-tested to ensure they can deliver postdisaster support to affected populations. For example, electronic transfers may be impaired if large areas are without power. And because schools are often used as shelters, it is important to plan so they can reopen quickly to ensure children do not miss out on education for prolonged periods.

ACTION 2.2 >>

Design and implement a government-wide strategy to increase the resilience of infrastructure and public assets

LEAD MINISTRY: *Economy, planning, investment, or infrastructure*

More resilient infrastructure is good economics, but a governance and financing challenge

The lack of resilient and high-quality infrastructure can impose substantial costs on firms and households. Infrastructure disruptions have indirect costs for households, as their impact on company productivity reduces jobs and wages. They also have direct costs through reduced consumption and well-being. Such disruptions are estimated to cost firms in developing countries more than $300 billion and households over $90 billion each year (Hallegatte et al. 2019).

The incremental cost of increasing the resilience of newly constructed infrastructure assets depends on the sectors and assets in which countries are investing, but it remains small in all cases if the right data, risk models, and decision-making methods are available. For example, increasing the resilience of the assets that are exposed to hazards would increase investment needs in power, water and sanitation, and transport in low- and middle-income countries by $11–65 billion a year (*figure 8*). Although not negligible, it represents only 3 percent of infrastructure investment needs and less than 0.1 percent of LMIC GDP. At the global level, this would not affect current infrastructure affordability challenges. But country-level analysis has shown that the cost will be much higher for countries with high exposure to climate change and natural hazards (see, for example, Government of Fiji and World Bank 2017).

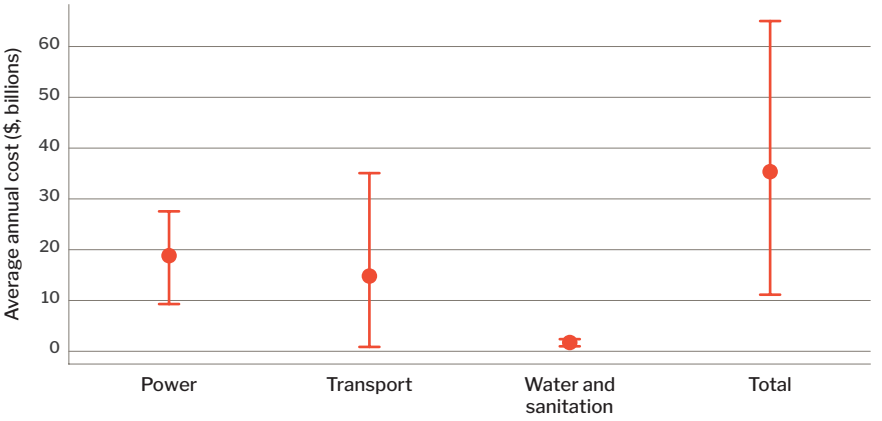
TAKING ACTION >>

Sample targets and indicators

- Strategy to manage critical assets and infrastructure is approved and published
- Agency in charge of coordinating resilience of critical assets and infrastructure is created and operational
- Asset management systems with evidence-based maintenance plans are in place
- Construction standards for infrastructure and building are updated, accounting for local hazards and criticality, and enforcement mechanisms are in place
- Expected recovery time for critical infrastructure systems—power, transport, water—after a major event
- Revised legal framework to allocate risks across stakeholders, including in PPPs and buildings
- State-owned enterprises have included climate change in their strategy and decision making

FIGURE 8 >>

Estimated annual capital cost of increasing the resilience of new public assets in low- and middle-income countries, 2015–2030



Source: Hallegatte et al. 2019.
Note: In some countries, costs will be higher and require prioritization.

What are the returns on investment for increasing the resilience of exposed infrastructure to natural disasters? If projects are well selected, designed, and implemented (see *Action A.2*), the World Bank's *Lifelines* report suggests that investing $1 in making infrastructure more resilient avoids, on average, $4 in socioeconomic losses (Hallegatte et al. 2019). In total, building all new infrastructure assets in a more resilient way would bring a net benefit of $4.2 trillion over the full lifetime of the new infrastructures. The urgency of investing in better infrastructure is also evident. With massive infrastructure investment taking place in developing countries, the stock of low-resilience assets is growing rapidly, which will only increase the costs of natural hazards and climate change. The median cost of delaying action by one year is $100 billion.

Although investing in resilience is good economics, financing these investments is not necessarily easy. While each $1 spent brings back $4, only a fraction of these $4 is in the form of avoided repair costs. Most is in the form of avoided disruption costs, which are difficult to capture and monetize to finance more investment in resilience. More resilient infrastructure also requires effective and proactive operation and maintenance, which has both technical and governance challenges, from the need to monitor each asset continuously to the fact that budget cuts are too often managed by postponing maintenance, with high long-term costs.

Improving decision making and governance with the right institutions

Table 3 shows five recommendations and 15 concrete actions for infrastructure resilience, based on Hallegatte et al. (2019). Different countries take different approaches to infrastructure resilience, but common principles have been widely applied. These principles, discussed in detail in the Organisation for Economic Co-

operation and Development's *Good Governance for Critical Infrastructure Resilience* (OECD 2019), are consistent with typical recommendations on the governance of risks (see, for example, Renn 2008; Wiener and Rogers 2002; World Bank 2013). There is a consensus among experts that governments have a key role to play in ensuring the resilience of critical infrastructure and should adopt a whole-of-government approach. Sectoral ministries and agencies and the ministries responsible for resilience to hazards and threats need to oversee and work with local authorities in infrastructure services delivery and regulation. This goes right down to municipality level, which are responsible for supplying drinking water and managing urban transit and transportation in many countries.

TABLE 3 >>

Recommendations and actions for building infrastructure system resilience

RECOMMENDATION	ACTIONS
1 Get the basics right	1.1: Introduce and enforce regulations, construction codes, and procurement rules
	1.2: Create systems for appropriate infrastructure operation, maintenance, and postincident response
	1.3: Provide appropriate funding and financing for infrastructure planning, construction, and maintenance
2 Build institutions for resilience	2.1: Implement a whole-of-government approach to resilient infrastructure, building on existing regulatory systems
	2.2: Identify critical infrastructure and define acceptable and intolerable risk levels
	2.3: Ensure equitable access to resilient infrastructure
3 Create regulations and incentives for resilience	3.1: Consider resilience objectives in master plans, standards, and regulations and adjust them regularly to account for climate change
	3.2: Create economic incentives for service providers to offer resilient infrastructure assets and services
	3.3: Ensure that infrastructure regulations are consistent with risk-informed land use plans and guide development toward safer areas
4 Improve decision making	4.1: Invest in freely accessible natural hazard and climate change data
	4.2: Make robust decisions and minimize the potential for regret and catastrophic failures
	4.3: Build the skillls needed to use data and models and mobilize the know-how of the private sector
5 Provide financing	5.1: Provide adequate funding to include risk assessments in master plans and early project design
	5.2: Develop a government-wide financial protection strategy and contingency plans
	5.3: Promote transparency to better inform investors and decision makers

Source: Hallegatte et al. 2019.

The most common solution for improving the coordination of risk management is to place an existing multiministry body (or, if necessary, a new body) in charge of information exchange, coordination, and perhaps implementing risk management measures (World Bank 2013). The body in charge of critical infrastructure can be given special powers to collect information, perform assessments, impose certain actions and ban others. For example, the recent Australian Security of Critical Infrastructure Act, aimed at protecting the country from sabotage and espionage, mandates the creation of a registry of critical infrastructure assets. It also gives the minister of the Department of Home Affairs the right to request information about these assets to determine whether any risk to national security is associated with an asset. The minister can impose or prohibit certain actions if there is "a risk of an act or omission that would be prejudicial to security".

A body in charge of infrastructure resilience needs to be appropriately staffed and funded. However, it cannot, and should not, replace the regulatory bodies in charge of sectors, which should be a priority in low-capacity countries. Various decisions or regulations need to be coordinated across sectors, but their design and practical implementation are better conducted by each sector regulator to ensure consistency with other regulations and prevent conflicts. In practice, implementation will vary, depending on whether the regulation of an infrastructure sector is carried out directly by the government, by an independent agency, or through a contract (Eberhard 2007).

Priorities for action

The main challenge to making infrastructure more resilient is not primarily a financing one; rather, it is an issue of governance and the ability to make and enforce good decisions, designs, operations, and maintenance.

The first priority is focusing on the early stages of infrastructure system development—designing regulations, producing hazards data and master plans—or the initial stages of asset design (see *toolbox D* and *Action A.2* for discussions on how to incorporate resilience considerations into public investment management). At these early stages, small investments can significantly improve the overall resilience of infrastructure systems and generate very large benefits. For example, changing the location of new infrastructure during the initial stages of a project can reduce risk levels. But mobilizing resources during the early stages of project preparation is particularly challenging as preparation budgets tend to be small. This makes it difficult to conduct adequate risk assessments, even if they can generate massive savings over an asset's lifetime.

When resources become available to do a serious analysis of risk levels and mitigation options, the smart solutions (such as moving a road) are no longer available. The only solutions available during the latter stages of a project are strengthening and hardening, which come at a much higher cost. Doing risk

assessments early could help achieve resilience at a much lower cost. It is also important to remember that future climate impacts are highly uncertain, and robust solutions that perform acceptably in a large range of possible futures are preferable to solutions that are optimal for the "most likely" scenario but could lead to catastrophic outcomes in case of surprises.

The second priority is improving maintenance (Hallegatte et al. 2019). Poor maintenance can increase infrastructure investment needs by 50 percent in the transport sector and more than 60 percent in the water sector (Rozenberg and Fay 2019). An analysis of OECD countries suggests that each additional $1 spent on road maintenance saves, on average, $1.50 in new investments, making better maintenance extremely cost-effective (Kornejew et al. 2019). Utility companies can use an infrastructure asset management system to ensure proper maintenance and better manage their operations. Such a system would include an inventory of all assets and their condition, as well as the strategic, financial, and technical aspects of managing the assets across their life cycle. This would help companies move away from a reactive approach toward an evidence-based, preventive maintenance schedule.

In many countries, state-owned enterprises (SOEs) will be key players when it comes to implementing resilience in strategic industries and the energy, water, transport and communications sectors, as they are responsible for much of the public investment in these areas. As shareholders, governments can require SOEs to incorporate specific resilience objectives, targets, and indicators in their statements of corporate intent or performance contracts. Corporate governance arrangements mainstream these reforms through dedicated board subcommittee and other specialized units addressing climate change risks across activities and investments. Governments can support these efforts through training and capacity building for officials responsible for SOE oversight and management. The World Bank Group's SOE leadership training toolkit integrates climate as a crosscutting dimension and can be leveraged and customized to include country and sector-specific risks and opportunities to address climate risks and resilience. Guidance is also available from the Task Force on Climate-related Financial Disclosures, which has issued 11 recommendations across the four core elements of governance, strategy, risk management, and metrics and targets to help firms think through and report on climate change.[14] The task force website and good practice handbook provide many examples of companies that are applying these recommendations.

Governments should also develop a legal framework and institutional structure to ensure that disaster resilience is incorporated into PPP projects. Many governments have a disaster risk framework and a PPP framework, but the two rarely interact. Even in Japan, where PPPs are well developed and natural hazards well managed, guidelines for including resilience in PPPs exist, but are not mandatory. Incentives for operators to incorporate resilience in their assets depend on the contract type,

with "build, operate, transfer" models creating a stronger incentive than "build, transfer, operate" models. However, they can be weakened by excessively broad *force majeure* clauses, which transfer the risk from the private to the public sector. When they are too broad, these clauses reduce the incentives for actors to build and operate an infrastructure asset in a way that considers low-probability risks.

Force majeure clauses in contracts are essential for establishing PPPs at a reasonable cost and can be designed to minimize any negative impacts on incentives for resilience. One solution is to include a quantified definition of *force majeure* for each event category and define it as applicable only in extreme cases. Ideally, a third party would decide whether the return period[15] or intensity of an event was enough to trigger the *force majeure* clause.

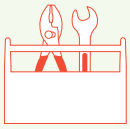
The contract can then determine the allocation of risk in terms of both missed revenues and restoration costs, ensuring that the private operator always bears a significant share of the cost. Mandatory or nonmandatory insurance could also ensure the sustainability of services, protecting the private operator against losses while minimizing costs to the public sector and maintaining the incentive to build more resilient assets and systems. Operators can also be required to prepare business continuity plans (BCPs) for every likely hazard (see ***Action 3.5***).

PPP design must consider context-specific factors, including the maturity of the PPP market, the risk tolerance of private sector players, and other risk factors such as vulnerability to commodity price shocks. These factors will determine how much risk they can transfer to private operators, creating trade-offs for government between incentivizing resilience and mobilizing private sector finance. When the private sector is unable to bear the risks from natural hazards, it becomes even more important to use alternative tools, such as strong construction codes and procurement rules.

TAKING ACTION >>

Toolbox D

Regulations, codes, and standards



Well-designed regulations, codes, and procurement rules are the simplest approach to enhancing the quality, reliability, and resilience of infrastructure services. In the most widely applied solution, governments define the level of service expected from public or private infrastructure providers and apply it through:

- **Procurement rules**, when the asset is publicly owned—for example, roads
- **Market regulations**, when private actors provide services such as electricity
- **Contractual engagements**—for example, through performance indicators for procuring and monitoring PPPs

Regardless of the financial model, strong procurement rules and appropriate performance indicators in tender processes can ensure a minimum level of service and reliability. Although countries can define construction codes and regulations based on existing international standards, those at different income levels—or with different preferences in terms of reliability—will want to design regulations and codes that are adapted to their needs.

With climate change and other long-term environmental trends, standards and codes need to be revised regularly. According to Vallejo and Mullan (2017), approximately one-third of OECD countries are revising at least one mandatory national infrastructure standard to account for climate change adaptation, but similar processes are lacking in low- and middle-income countries. Sweden, for example, updated its road drainage standard in 2008, introducing a climate safety factor to cope with the anticipated increase in rainfall due to climate change. Similarly, the European Commission mandated the Centre Européen de Normalisation to include climate change in the European civil engineering technical standards (the Eurocodes), especially for transport and energy infrastructure (European Commission 2014). Several national standards organizations have produced risk management guidelines that include climate change and resilience considerations for infrastructure (British Standards Institution 2011; Council of Standards Australia 2013; US National Institute of Standards and Technology 2015). And in 2015, the International Standards Organisation (ISO) created an adaptation task force to develop standards for vulnerability assessment, adaptation planning, and adaptation monitoring and evaluation (M&E) (ISO 2015).

Quality control and enforcement of construction codes is particularly important. Miyamoto International (2019) points out that enforcing construction codes and standards is costly and more challenging than defining them. Enforcement in the infrastructure sector requires a robust legal framework and strong regulatory agencies to monitor construction and service quality and performance and reward and penalize service providers based on their performance. Many regulators lack the resources and capacity to enforce existing construction codes. As a result, expensive infrastructure systems may be designed with inappropriate materials or technologies, leading to high long-term costs.

ACTION 2.3 >>

Revise land use and urban plans to make them risk-informed

LEAD MINISTRY: *Interior, planning, investment, infrastructure, or environment*

Land markets are powerful tools for driving new construction in a way that efficiently meets population needs. However, they are also imperfect, and often fail to fully internalize climate change and natural hazards (Bin and Polasky 2004; Holway and Burby 1990). In some countries, dysfunctional land markets mean that most of the population lives in informal dwellings with no land use or urban planning.

So, developments often spring up in risky areas, especially when developers do not carry the cost of future climate change impacts. Agglomeration externalities and long building and urban infrastructure lifetimes mean that new developments are also largely irreversible. When a neighborhood is urbanized, it is likely to remain so forever, even if it requires massive protection or adaptation investment.

Land use regulations can help by ensuring that new development occurs in places that are safe or can be easily and cheaply protected. They can also avoid unchecked urban development that leaves too little porous green space, further increasing runoff and flood risk (Lall and Deichmann 2012).

But implementing risk-based land use plans remains challenging and countries need strong institutions that can ensure these plans are enforced. In most of the world today, risk-sensitive land use plans face strong political economy obstacles and are rarely enforced (World Bank 2013). Where land rights are mostly informal, introducing climate and disaster risks in land use planning would require the government to first build the right institution, legal framework, and information systems.

Mandate land use and urban planning to accounts for long-term risks

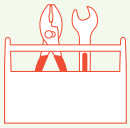
In areas with rapid urban growth, smart risk-informed planning is crucial to reduce long-term risks and adaptation costs. Land use plans need to account for climate risk and avoid guiding urban growth into high-risk zones. Designating high-risk zones as unsuitable for human settlement can avoid costly and politically challenging relocation decisions. Using simple geographic information system approaches, governments can identify "good" land for infrastructure development that is safe and close to opportunities, jobs, and existing network infrastructure (*toolbox E)*.

One option for government is to mandate local authorities to revise their land use and urbanization plans, based on hazard maps that take climate change into

TAKING ACTION >>

Toolbox E

Using geospatial information to identify priority land for urbanization



Risk-informed urbanization planning can help accommodate Fiji's growing urban population while limiting the increase in natural risks.

In 2016, Nadi Town, Fiji's third-largest urban center, had a population of around 52,800 and was growing at the relatively rapid rate of 2.5 percent a year, driven by tourism, transportation, and high-value real estate developments. So, it sought to identify areas for future settlement and infrastructure investment that would minimize exposure to natural risks and development costs (Government of Fiji and World Bank 2017).

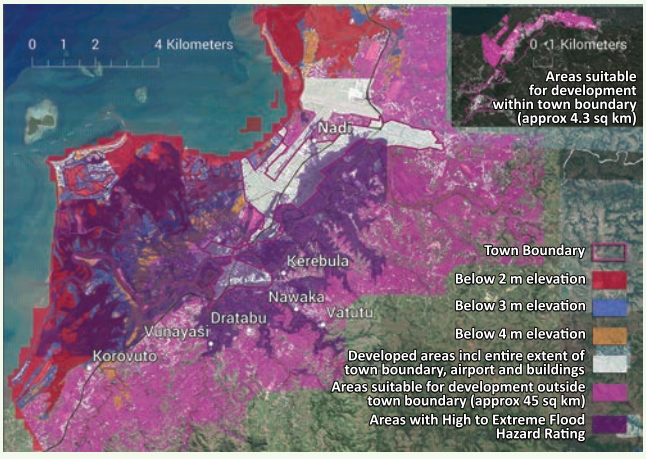
Planners used digital elevation models and flood maps as a first screen to identify areas that might be suitable for further development. ***Figure E.1*** shows the areas of Nadi that are highly exposed to coastal and river floods in red, blue, and orange; those that are at high or extreme risk of flood in a 100-year return-period flood risk map are purple; developed areas are gray; and areas with steep slopes are white. The light pink areas are potentially suitable for future development, although further studies are required to confirm this simple assessment, and more investment in drainage could make some of the flood-prone, low-lying areas suitable for development.

The exercise identified about 4.3 square kilometers that were not developed within the town boundary (see inset). With additional investment to improve drainage, this land could be a priority for future development. With future densities of 10–15 dwellings per hectare (based on today's values), this area could host 4,300–6,500 households. In view of Nadi's backlog of about 2,000 units and its growth rate of 300 new households a year, this land could accommodate the town's urban growth for 8–15 years.

Over the longer term, town planners should consider areas beyond the town boundary. This could be combined with expanding the boundary. More than 45 square kilometers are available close to Nadi, but outside the town boundary. This area could accommodate 45,000–70,000 households, enough to manage rural-urban migration for several decades. Using this land, however, would require addressing issues of land tenure and ownership and expanding networks, especially for water and sanitation.

FIGURE E.1 >>

Digital elevation and flood maps help identify areas with development potential in Nadi Town, Fiji



Source: Government of Fiji and World Bank 2017.

account. Colombia's framework law, for example, requires regional, municipal and district authorities to incorporate climate change management into their development and land management plans.[16]

Governments can also create financial incentives for local authorities to consider climate change, by linking the revision of plans with financial support for risk reduction projects or other initiatives. In France, the PPP for natural disaster insurance (the CatNat system) offers different deductibles for municipalities that have designed and implemented a flood management plan and consider flood risk in the building permit approval process (Przyluski and Hallegatte 2012).

Risk-sensitive land use and urbanization plans must also abide by construction norms and building regulations. The quality of construction and the role played by building regulations are key determinants of climate resilience. Behavioral and market failures—for example, a lack of awareness of risks or the challenge of verifying whether a building is built to standard—affect the resilience of buildings and justify public action in creating and enforcing standards.

The world will see the construction of one billion new dwelling units by 2050. With current practices, this may lead to a rapid increase in risk. And yet this growth creates an opportunity for inexpensive reductions in risk through appropriate building regulations. Appropriately designed new buildings can be made disaster-resistant for a small fraction (5–10 percent) of the cost of construction. However, retrofitting vulnerable structures may require major expenditure, in the range of 10–50 percent of building value.

Infrastructure localization decisions drive urbanization patterns and expose populations and assets to risks (Baum-Snow 2007a, 2007b); they should therefore be coordinated with land use and urban plans. Planners can use infrastructure master plans and new investments to guide urban growth towards safe zones. Choices

TAKING ACTION >>

Sample targets and indicators

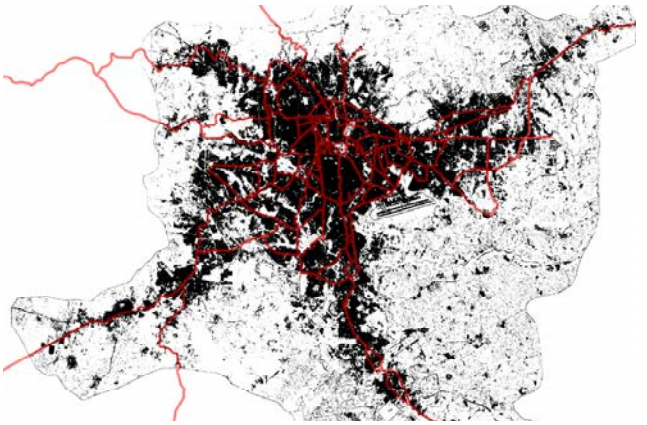
- Percentage of country/municipalities with revised land use or urbanization plans that include current and projected hazards
- Share of population living in (or relocated from) high-risk areas, fragile buildings or retrofitted fragile buildings
- Strategy for or specific regulations on the use of nature-based solutions approved
- Areas impossible or too costly to protect against climate change impacts identified and communicated to the public
- Regulation mandating the provision of climate and hazard information to buyer in real estate markets

around the localization of power, water, sanitation, and transit infrastructure guides spatial development and influences land use, land use intensity, land values, and employment and population densities (*figure 9*). Typically, transit-oriented development investments have a unique ability to influence community resilience because they inherently lead to concentrations of people and businesses around transit stops (Salat and Ollivier 2017). For example, the location of a new road corridor will probably determine where new settlements are built. If these investments are not made strategically, considering information on an area's exposure to natural hazards, the outcome could be an increase in vulnerability to disasters.

FIGURE 9 >>

Urbanization in Addis Ababa, Ethiopia, closely follows the major public transport lines

Source: NASA MODIS Imagery 2002–2013 for built-up area and OpenStreetMap for primary and trunk roads.



With land use, early action is more efficient. Once a neighborhood has reached a critical mass, relocating households becomes difficult. Once high-risk areas are developed and inhabited, they may require costly protection investments, which are often unaffordable in lower-income economies. The estimated cost of the Netherlands' fifth Delta Program, which aims to improve national flood safety and fresh water supply, is €20 billion. The cost of the new flood protection system in New Orleans—a city of fewer than one million inhabitants—is about $15 billion. The reason these protection systems are so costly is partly due to having to meet rigorous design and construction standards and undergo perfect maintenance. Defense failure can lead to much larger losses than would have occurred in the absence of protection (Hallegatte et al. 2013).

In places with little capacity to create and enforce risk-sensitive land use and urban plans, other approaches may be mobilized, such as allocating the riskiest land to non-residential use. In many places, flood zones or wetlands can be transformed into urban parks, to minimize the risk of encroachment.

Explore the implications of climate change for internal migrations and regional economic impacts

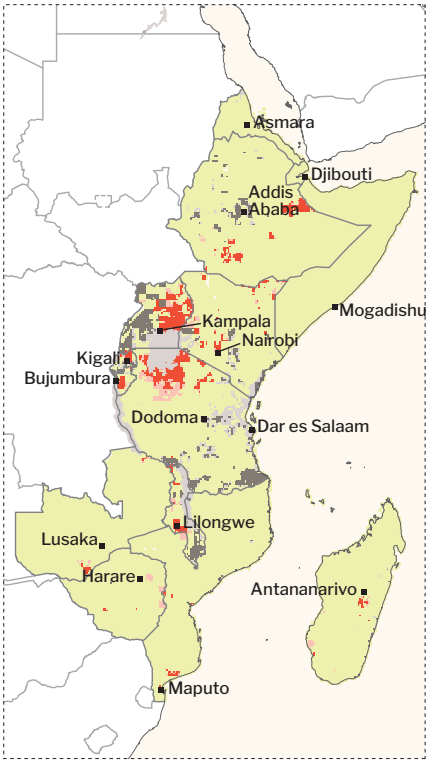
Not all regions or areas of a country will be affected in the same way. Some will be affected more than others, and some—such as higher elevation areas in hot countries—may gain at least a comparative advantage.

The *Groundswell* report explores this question, focusing on three regions—Sub-Saharan Africa, South Asia, and Latin America—that together represent 55 percent of the developing world's population (Rigaud et al. 2018). It projects that, without concrete climate and development action, just over 143 million people (around 2.8 percent of these regions' population) could be forced to move within their own countries by 2050 to escape the slow-onset impacts of climate change. They will migrate from less viable areas with lower water availability and crop productivity and from areas affected by rising sea level and storm surges.

These trends, alongside the emergence of "hotspots" of climate in- and out-migration (*figure 10*), will have major implications for climate-sensitive sectors and the adequacy of infrastructure and social support systems. In particular, they may need to increase cross-regional financial support to help negatively affected regions cope with and adapt to the impacts, and reallocate infrastructure investments toward the places that are least affected and most likely to attract populations in the future.

FIGURE 10 >>

Areas projected to have high climate in- and out-migration in East Africa in 2050



- High certainty in high levels of climate in-migration
- Moderate certainty in high levels of climate in-migration
- High certainty in high levels of climate out-migration
- Moderate certainty in high levels of climate out-migration

Source: Rigaud et al. 2018.

Systematically consider nature-based solutions

Land use planning must also account for the important role ecosystems play in protecting people and livelihoods against risks. Trees on steep slopes protect rural villages from landslides when heavy rains fall, mangroves protect coastal livelihoods during storm surges (Badola and Hussain 2005; Das and Vincent 2009), and forest cover helps reduce the occurrence of drought

(Bagley et al. 2014). Protecting ecosystems can therefore help countries reduce exposure to natural disasters.

In 2015, a flood risk assessment in Colombo, Sri Lanka, considered the deep uncertainty around the city's hydrological conditions and vulnerabilities to compare the economic consequences of floods with and without local wetlands (Hallegatte et al. 2019). While it is impossible to predict future flood risks in the city with any certainty, the study revealed that the economic consequences of floods would exceed 1 percent of Colombo's GDP every year—a level of risk the authorities consider intolerable—in the scenarios where all the city's wetlands disappear.

As well as offering protection, ecosystems also provide income sources. To protect these incomes from the impacts of climate change, the main option is reducing non-climate stresses on ecosystems to make them better able to cope with changes in environmental conditions. Conservation and ecosystem-based strategies are critical for making ecosystems more resilient and protecting the resources on which many poor people in rural areas depend. Healthy ecosystems are generally quite resilient, so protecting them and restoring degraded lands can increase their ability to withstand climate-related disturbances.

Consider strategic retreat when risk reduction is impossible or unaffordable

As the impacts of climate change intensify—through rising sea levels or increasingly frequent flooding—authorities should consider a managed retreat or relocation of people. While some areas can afford to invest in costly physical protection infrastructure such as extensive sea dike systems, the risks involved can also make such an approach unviable or unaffordable in the long run.

Adaptation and resilience investments that are efficient over the short term can also prove costly over the long term by promoting maladaptation through the creation of new or higher risks. For example, although incremental coastal protection investments may offer short-term relief, they also lock future urban, economic, and population growth into high-risk areas, requiring multiple follow-up protection investments, which may one day become unaffordable.

Lower-income areas and economies may prefer a well-managed retreat from areas with excessive risk over cycles of continuously increasing risk and expenditure. People have long used temporary migration as part of their coping mechanisms to manage natural disasters and climate variability (Rigaud et al. 2018). But long-term permanent migrations can be more difficult to manage, have much larger financial, cultural and psychological costs, and pose unprecedented ethical questions. Retreat and relocation strategies require careful consultation, planning, and compensation, in line with social safeguards—and relocating large populations while preserving livelihoods is costly. Decisions regarding retreat and relocation

are always complex, and rely on more than economics. Fairness, the political context, and a government's ability to manage the negative impact of relocation and support affected populations are all important considerations.

In some extreme cases, the long-term viability of entire countries has been questioned. This is especially so for small, low-lying, highly vulnerable islands facing sea level rise. However, there is no definitive answer to whether adaptation to long-term climate change is technically, economically, and politically possible in all countries, and what is possible will often depend on the instruments the international community provides to support highly vulnerable countries. Nevertheless, an adaptation intervention or strategy has to be sustainable over the long term. Interventions that simply postpone the negative consequences of climate change for a few decades may lead to maladaptation and higher costs in the long run.

Priority Area 3:

Help firms and people manage residual risks and natural disasters

LEAD MINISTRY:
Interior or environment

No matter how much private actors and governments try to reduce people's exposure or make their assets more resistant to natural hazards and climate change, they cannot reduce risk to zero. Disasters will continue to inflict damage, so it is vital to supplement actions on exposure and vulnerability with improvements in people's ability to cope with unavoidable shocks. A government's first function is ensuring disaster management instruments are available to all firms and households—for example, through insurance regulations. And since ensuring safety and security and managing emergencies and crises is one of their main functions, governments also have an important role to play in ensuring that all private actors cope with and recover from disasters and climate impacts, using tools ranging from social protection to emergency response and humanitarian interventions.

TAKING ACTION >>

Screening questions

Identify actions to cope with and recover from unavoidable shocks

While effective risk mitigation can go a long way in reducing loss and damage, some natural shocks are too extreme and intense to be prevented. Governments need strategies to ensure that when disasters do occur, people and firms can cope without devastating long-term consequences and recover quickly. The following questions can help decision makers identify shortcomings and guide them towards the actions needed to manage residual risks.

ACTION 3.1 >>

Early warning systems

Do people have universal access to effective early warning systems for natural hazards?

Should include: *effective communication channels; warnings with clear recommended actions*

Is the country prepared to manage large-scale evacuations?

Should include: *adequate and inclusive shelters; evacuation plans*

ACTION 3.2 >>

Strategy to manage residual risks

Does the country have a comprehensive strategy for managing residual climate and natural risks?

Should include: *economy-wide strategy to manage residual risks and disasters; households and firms have access to necessary financial instruments to manage small and big shocks*

ACTION 3.3 >>

Insurance and other financial instruments

Are financial services equipped to provide people with accessible services in postdisaster situations?

Could include: *readiness of financial sector to provide access to savings, loans, and remittances in a disaster aftermath*

Do households and firms have access to disaster insurance? Are these services affordable?

Could include: *penetration rate of disaster insurance among households and firms; ratio of premium to expected claim amounts*

ACTION 3.4 >>

Adaptive social protection

Are households covered by a social protection scheme that can provide postdisaster support?

Should include: *stress-tested systems that can deliver payments in a postdisaster context—for example, if power is interrupted*

Does the country have a registry of potential beneficiaries, in case of major disasters, and the ability to make quick transfers to them?

For example: *in Kenya, all householders in the regions covered by the Hunger Safety Net Programme are registered and have a bank account on file to ensure quick transfers*

ACTION 3.5 >>

Business continuity plans

Are firms required to prepare business continuity and contingency planning?

Could include: *regulation, tax incentives, or technical support available to develop such plans*

Does the government have contingency plans to support affected firms?

Could include: *tax relief, reconstruction subsidies, or emergency loans*

ACTION 3.6 >>

Capacity to build back better

Are postdisaster recovery and reconstruction plans designed to avoid long-term lock-in of risk?

Could include: *not developing areas that may be prohibitively expensive to protect in the long term*

Are plans in place to build back stronger, faster, and fairer after large-scale disasters?

Could include: *pre-contracting debris removal tasks; procurement agreements for essential services*

ACTION 3.1 >>

Save lives (and money) with hydromet, early warning, and emergency management systems

LEAD MINISTRIES: *Interior and environment*

Weather forecasts enable the anticipation of and preparation for extreme events, and timely evacuation can save thousands of lives. The value of preparedness was illustrated by two intense cyclones in the Bay of Bengal that occurred 14 years apart. Cyclone 05B in 1999 caused massive devastation, killing more than 10,000 people, and destroying housing and public infrastructure in the state of Odisha, India. Fourteen years later, Cyclone Phailin, with wind speeds of 200 kilometers an hour, made landfall in Odisha on October 12, 2013. This time, the story unfolded differently. After 72 hours, the official death toll was 38 persons, less than 0.4 percent of the death toll in 1999, and close to one million people had been evacuated to cyclone shelters, safe houses, and inland locations in Odisha and Andhra Pradesh.

This success was the result of years of effort by the Odisha State Disaster Management Authority and the government of Odisha, which built disaster risk mitigation infrastructure, established evacuation protocols, identified potential safe buildings to house communities, and, most importantly, worked with communities and local organizations to set up volunteer teams and local champions who knew what needed to be done when the time came to act.

Early warning systems can save lives when they effectively communicate information, using simple messages and practical advice on how to react to warnings. The European Meteoalarm system provides an example of a simple information system to warn people and inform them of required actions.[17] Reaching the people who need to act before a disaster can be done using mobile phones or internet, but also with volunteers who are well connected and trusted in their communities. Other important recommendations include ensuring shelter designs meet the needs of communities, taking into account gender issues and access for people with disability.[18]

Preparation also reduces physical damage and economic loss. Preparing a house before a hurricane (by shuttering windows, for example) can reduce damage by up to 50 percent (Williams 2002). In the case of floods, households can prepare by moving goods to the second floor of buildings, moving vehicles outside the flood zone, protecting important documents and valuables, disconnecting electricity and gas supplies, unplugging electric appliances, and installing water pumps. Studies show that when the Elbe and Danube flooded in Europe in 2002, 31 percent of the population in flooded areas implemented such preventive measures

(Kreibich et al. 2005; Thieken et al. 2007). The timing of the flood warning was critical: the businesses that were able to protect their equipment or inventories were those that received the warning early enough. One study estimates that a warning issued 48 hours before a flood can reduce overall damage by more than 50 percent (Carsell et al. 2004).

The benefits of providing universal access to early warning systems globally have been repeatedly found to largely exceed costs (GCA 2019; World Meteorological Organization et al. 2015; Hallegatte 2012; Hallegatte et al. 2016b). One study estimated that investing in early warning systems could generate about $13 billion a year in avoided asset losses and well-being gains equivalent to $22 billion (Hallegatte et al. 2016b). Despite considering only asset losses and not human lives that could have been saved, this estimate is much larger than previous assessments. Although no solid estimate exists for the cost of providing such a service globally, a back-of-the-envelope calculation is about $1 billion a year (Hallegatte 2012). This confirms that investing in an early warning system makes economic sense, even without considering its main benefit: the lives that can be saved (World Bank 2013).

Although early warning and prevention systems cannot avert all damages, they can help ensure that emergency services are ready to act, and possibly pre-positioned so that they can act more quickly and efficiently. Early warning systems must be interconnected with emergency management systems, including health care, fire, police, civil protection, and the army, who can support a response to major disasters.

TAKING ACTION >>

Sample targets and indicators

- Daily weather forecasts are produced by the hydromet agency and an easy-to-communicate alert system is in place
- Communication channels are in place to efficiently communicate early warnings to the population and emergency services
- Average error in early warning (both missed events and false alarms)
- Share of population with access to early warning systems or covered by evacuation plans
- Average distance to closest shelter
- Capacity of shelters or emergency services—for example, number of emergency medical service units, and trained health emergency professionals
- Duration communities can operate safely and independently—for example, water and food storage and medical supplies
- Number of disaster drills performed per year

ACTION 3.2 >>

Provide all firms and households with risk management instruments

LEAD MINISTRY: *Economy or finance, with social affairs or protection*

Helping households cope with and recover from shocks requires a holistic and flexible risk management strategy with a range of policy instruments appropriate for different disasters and affected populations. Poorer and richer households have different needs and can be supported with different instruments (*figure 11*).

Revenue diversification and basic social protection can help households at all income levels cope with small shocks, while remittances make people less vulnerable to income shocks. Financial inclusion helps poor people save in ways that are less vulnerable to natural hazards than in-kind savings, such as livestock and housing; it also diversifies risk.

But when shocks are larger, these instruments will not be enough, and additional tools will be needed. For relatively wealthier households, financial savings will help, and access to borrowing can help them rebuild quickly. But there are limits to what savings and access to borrowing can achieve, and borrowing can create a debt trap that poor households struggle to escape.

Insurance products can provide protection against rare shocks at a lower cost than savings or borrowing. A study of the Christchurch earthquake in New Zealand in 2011 shows that insurance helps firms bounce back after a shock (Poontirakul et al. 2017). Over the medium term, a firm with business interruption insurance is significantly more likely (by some 15 percentage points) to have enhanced productivity and improved performance after a disaster.

Social protection systems, which are usually implemented to reduce poverty and help people manage idiosyncratic shocks such as accident and health issues, can also provide support in postdisaster situations. To increase their efficiency in postdisaster situations, some countries have implemented adaptive social protection systems that respond to shocks by either expanding the list of beneficiaries (Ethiopia or Kenya) or increasing transfers to existing beneficiaries (Fiji).

TAKING ACTION >>

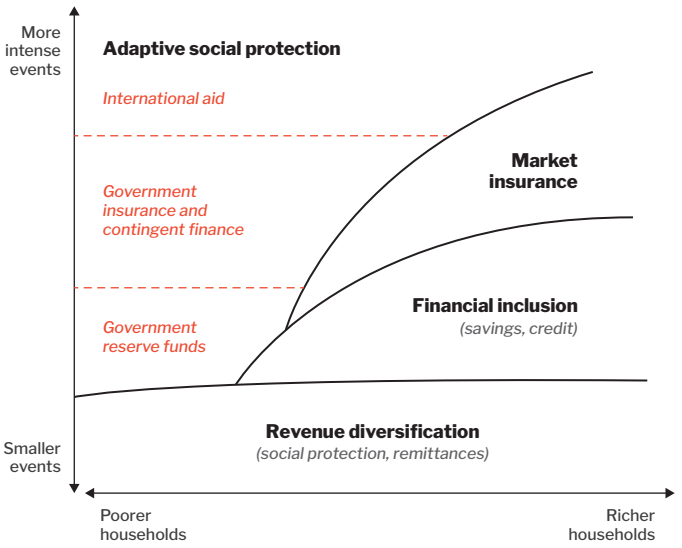
Sample targets and indicators

- Overall strategy to manage residual risks and disasters is prepared and approved
- Coordination mechanisms between the various preparedness actors are in place—for example, ministries or agencies for crisis management, social protection, food security and agriculture, finance
- Fraction of the population covered by at least one financial instrument to cope with shocks—for example, insurance, social protection, or access to emergency borrowing

FIGURE 11 >>

Risk finance strategies for households and governments

Source: Hallegatte et al. 2016b.
Note: Instruments targeting households are in black; instruments for governments or local authorities, in red.



ACTION 3.3 >>

Develop the insurance sector, building on public-private partnerships

LEAD MINISTRY: *Finance*

Domestic disaster insurance markets have proven to be an effective channel for developing the resilience of disaster-exposed households and businesses. The Turkish Catastrophe Insurance Pool and the Mongolian Livestock Insurance Pool are good examples of PPPs. Both the Turkish and Mongolian governments use their domestic insurance markets to reach households and businesses with insurance products, realizing their policy goals of expanding the population's financial resilience to disasters. Both partnerships have substantially increased insurance penetration at the local level.

TAKING ACTION >>

Sample targets and indicators

- Share of population with disaster insurance
- Share of population with access to emergency loans from financial institutions
- Share of population receiving remittances
- Share of population with financial savings in a bank account

But developing insurance markets is challenging, particularly in low-income environments. Where insurance is not compulsory, pick-up rates remain low. Even in the US and Italy—high-income countries with subsidized insurance against floods or earthquakes—less than 30 percent of homeowners are covered. The Mongolian Livestock Insurance Pool scheme started in 2005 and covers more than 10,000 herders. But despite its success, pick-up rates remain relatively low, at less than 15 percent of herders in covered areas. There are many reasons for low pick-up, including high costs, affordability issues and behavioral biases (Kunreuther et al. 2013). But while affordability issues, magnified by large transaction costs, are a problem in developing countries, weak institutions and a lack of trust also play a role. A lack of robust data—which insurers need to assess potential risks—is another frequent problem in developing countries.

Index-based insurance refers to products for which payments are not based on observed losses. Instead, they are based on when a physical variable—for example, a rainfall deficit, wind speed, or area-based yield—or another index exceeds a predetermined threshold, regardless of the existence of loss. For example, a farmer will receive a predefined insurance payment if rainfall falls below a minimum threshold over a one-month period. Index-based insurance schemes have major advantages over traditional contracts, including:

- Reduced transaction costs because losses do not need to be measured

- Encouraging individuals to still take preventive measures because the payout does not depend on losses or actions taken to reduce risks—in other words, reducing moral hazard

- Simple and objective payment decisions, which make it easier to enforce contracts.

But index-based insurance also suffers from basis risk—the difference between payments contract holders receive and the losses they suffer. This means that they may receive a payment and lose nothing; but they could also receive nothing and have large losses, which would be catastrophic for those close to subsistence level. So, when exploring index-based insurance products, it is important to:

- Invest in high-quality indices that aim to minimize basis risk

- Ensure the contract holder fully understands the limitations of the index

- Explore the possibility of covering large groups—for example, a community or an agriculture cooperative—which makes the basis risk smaller and easier to manage.

ACTION 3.4 >>

Build a social protection system that is responsive to shocks

LEAD MINISTRY: *Social affairs or social protection*

Ensure that social protection systems can be scaled up in case of disaster

For the poorest households, savings are often not an option, and high transaction costs and affordability issues make access to private insurance challenging. These households need well-targeted and easily scalable social safety nets.

Adaptive social protection systems have proven to be critical for channeling resources to those who are most in need due to climate stresses. As shown in *Figure 12*, adaptive systems can respond quickly to disasters or slow-onset climate crises through:

- **Vertical expansion:** Scaling up or providing additional resources to regular beneficiaries—for example, all beneficiaries of Fiji's Poverty Benefit Scheme received exceptional transfers after Tropical Cyclone Winston in 2016.
- **Horizontal expansion:** Scaling out or providing support to additional beneficiaries during bad times or years—for example, the number of beneficiaries of Ethiopia's Productive Safety Net Program depends on rainfall.

TAKING ACTION >>

Sample targets and indicators

- Stress test of existing systems completed, including delivery mechanisms
- Contingency plan to scale up social protection systems developed and approved
- Delivery mechanism in place, such as bank accounts for all households in registry
- Share of population covered by social protection or in social registry, including potential beneficiaries in case of scale-up

Some systems combine scaling up and out. Kenya's shock-responsive cash transfer Hunger Safety Net Programme, for example, has disbursed about $8 million to some 180,000 households (900,000 people) in response to drought. The government also used the program to provide aid before a drought hit in 2015, when El Niño increased the likelihood of lower rainfall. As well as raising awareness of the impending shock, this gave people the resources they needed to prepare for it.

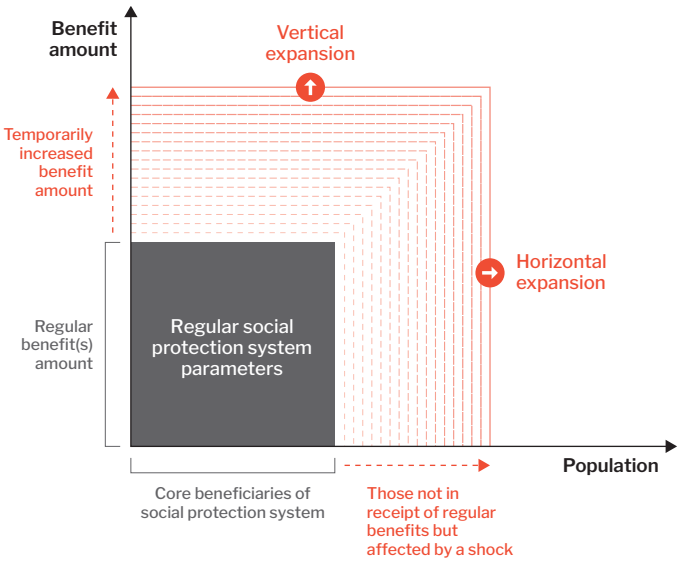
Ethiopia's innovative adaptive Productive Safety Net Programme has been found to reduce the impact of drought in rural households. A study measuring the impact of drought on farmers' consumption in 2005 and 2011 found that a 10 percent loss of crops through drought led to a 2 percent reduction in consumption. But people

covered by the program only experienced a 1.5 percent reduction, suggesting that the safety net reduces the impact by a quarter on average (Porter and White 2016).

FIGURE 12 >>

Adaptive social protection: horizontal and vertical expansion

Source: Bowen et al. 2020.



Strengthen social protection systems, especially delivery systems and pre-arranged finance

Adaptive social protection requires more administrative and financial resources than regular social protection systems. A recent World Bank report (Bowen et al. 2020) identifies several priorities and investments that go above and beyond business as usual for regular social protection. Generated by the unique demands of building household resilience to systemic shocks, these priorities fall into four building blocks:

» **Programs:** To be adaptive, social protection systems need to build resilience by supporting preparedness, coping, and adaptation. This includes actions before and in the immediate aftermath of disasters or environmental shocks.

» **Data and information:** The design and implementation of social protection systems must be underpinned by data and information. This also needs to be easily available to respond quickly after a disaster, when timeliness is critical and data collection is difficult.

» **Finance:** To be scaled up when required, social protection systems must have resources available—both of their own and in coordination with the Ministry of Finance. For a timely and effective delivery, these resources must be pre-arranged.

» **Institutional arrangements and partnerships:** Multisectoral institutional arrangements and partnerships—especially between government and humanitarian crisis management agencies—are critical for an efficient response.

The use of modern tools and systems can make delivery systems more flexible, able to react quicker, and more resilient to shock, ensuring their reliability during a crisis. To make adaptative social protection systems possible, governments must ensure that:

» The social registry is sufficiently inclusive and includes more than the "regular" social protection beneficiaries. These registries can build on unique and universal identification systems (with appropriate oversight and accountability to make sure it is used for the correct purpose).

» Electronic/digital payment mechanisms are robust enough to get cash to households even during a crisis, when power may be out for extended periods and roads may be cut for even longer.

Investing in such systems will raise the adaptation potential of social safety nets, and may facilitate the delivery of international aid and humanitarian support, as seen in the Philippines (Hallegatte et al. 2016b). An adaptation and resilience strategy can include provision to ensure that new and existing social protection systems are designed or retrofitted to do more to boost resilience. *Spotlight 3* discusses the opportunity to design social protection investments to respond to pandemics such as COVID-19 so they build long-term resilience in affected countries.

Ensure resilience measures support long-term adaptation and do not lock people into a place or activity

Support to people after shocks or disasters should be designed in a way that does not disincentivize adaptation to long-term trends. For example, support to areas that are increasingly affected by drought should not lock people in place, especially if the trend is expected to worsen over time. Instead, postdisaster support should help people change activity or migrate if that will improve their prospects.

Social protection schemes need to maintain incentives to invest in long-term adaptation to economic and environmental changes. Poorly designed social safety nets can reduce the incentive for people to quickly adapt and change occupation or activity when the first effects of climate change appear (Chambwera et al. 2014).

This problem is not new or specific to climate change, and efforts are already under way to ensure that social protection is a facilitator of, and not an obstacle to, long-term change and adaptation. This includes facilitating migration (Brown et al. 2013; Bryan et al. 2012) or making benefits more portable if recipients decide to move to capture better opportunities (World Bank Group 2015).

SPOTLIGHT 3 >>

COVID-19

Exiting the COVID-19 crisis more resilient than before?

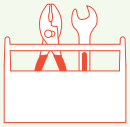
A few months into the COVID-19 crisis, almost all countries have boosted their social protection systems to help their population manage the pandemic and the consequences of needed containment measures (Gentilini et al. 2020). However, this experience has shown that existing systems are not always designed to quickly increase the number of beneficiaries or deliver exceptional transfers to usual beneficiaries. Interventions in most countries include determining which additional beneficiaries need to be covered; executing the transfers through existing or new delivery mechanisms; and financing the cost of these transfers.

If designed and implemented sustainably, and if efforts are maintained over the long term, any improvements made during the COVID-19 crisis could improve all social protection systems' capacity to scale up quickly and efficiently next time countries are affected by a major shock, including a climate-related one. This includes, for example, creating and maintaining household registries and electronic payment mechanisms.[19]

TAKING ACTION >>

Toolbox F

Assessing the benefits of higher resilience and designing resilience-building instruments



One challenge in designing and advocating for resilience-building tools like adaptive social protection is that they do not yield measurable benefits in terms of reduced asset or economic losses. But although insurance, social protection, and remittances do not reduce direct damage from a disaster, they can significantly reduce impacts on societal well-being (Hallegatte et al. 2016b).

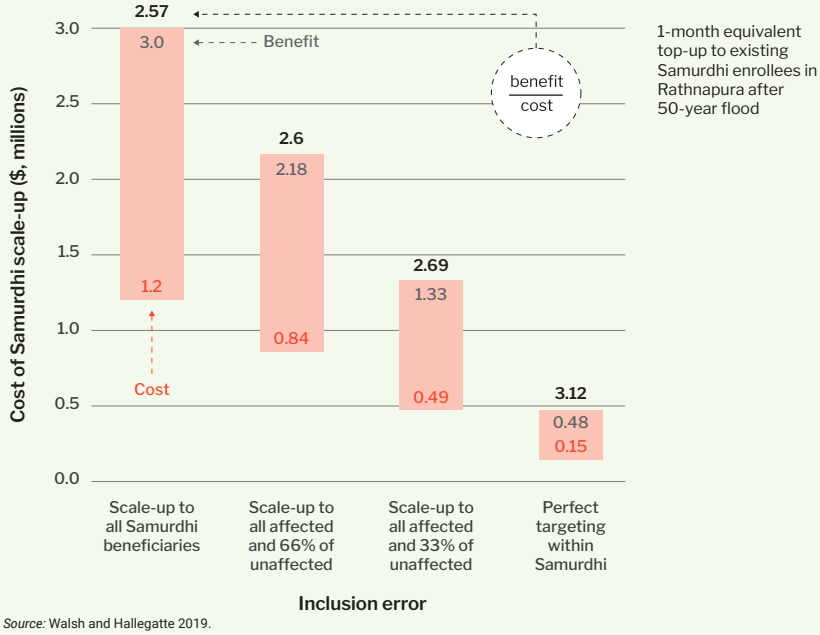
It is possible to use alternative metrics—such as the number of people falling into poverty, full recovery time, or well-being losses—to assess and compare initiatives that reduce asset losses or increase socioeconomic resilience. These include building dikes and providing insurance to at-risk populations. By expanding the range of policies they consider to reduce disaster impacts, decision makers can create cheaper, more efficient, and more equitable policy packages.

An analysis of Sri Lanka's social protection system found that—in the case of a 1-in-50-year flood in Rathnapura—a top-up equivalent to one month of regular transfers to all recipients of the *Samurdhi* cash transfer program would have a benefit-cost ratio of 2.6, and would cost $1.2 million (Walsh and Hallegatte 2019). More targeted approaches reduce the budgetary cost of the top-up and increase the benefit-cost ratio, mostly by reducing the inclusion error (***figure F.1***).

The same study also investigated using a new proxy means testing (PMT) score to support poor households affected by floods, calculating benefits and costs across the range of PMT scores. The analysis suggested that the marginal benefit of adding recipients exceeds the marginal cost, up to a PMT score around 950 (***figure F.2***). This type of analysis can help guide the design of postdisaster support systems and ensure the most efficient use of limited resources after a shock.

FIGURE F.1 >>

Cost-benefit analysis of different implementations of a Samurdhi scaleup in response to a 1-in-50-year flood in Rathnapura, Sri Lanka

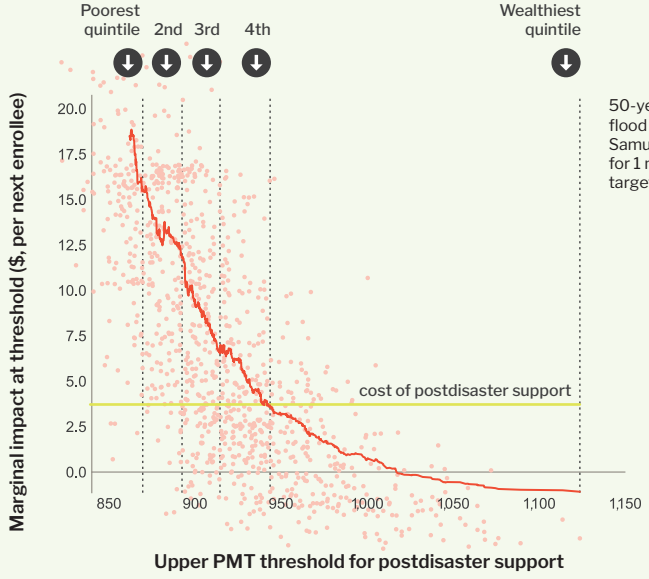


1-month equivalent top-up to existing Samurdhi enrollees in Rathnapura after 50-year flood

Source: Walsh and Hallegatte 2019.

FIGURE F.2 >>

Marginal cost and benefit of increasing the PMT threshold for postdisaster support following a 1-in-50-year flood in Rathnapura



50-year precipitation flood in Rathnapura Samurdhi to affected for 1 month (perfect targeting)

Source: Walsh and Hallegatte 2019.

ACTION 3.5 >>

Help firms develop business continuity plans and financial preparedness

LEAD MINISTRY: *Economy*

Individual firms' ability to cope with a shock and continue to produce in the aftermath of a disaster depends on many factors; still firms can do a lot to become more resilient (Rose 2009). The general recommendation is to identify threats, assess risks, and consider mitigation options. This allows them to invest in prevention—for example, by adding a generator in case of power outage, investing in movable flood protection, or even elevating critical equipment. It also helps them prepare for residual risk.

TAKING ACTION >>

Sample targets and indicators

» Fraction of firms with BCPs or disaster insurance coverage

» Number of area-based BCPs

Preparing a BCP can ensure a firm's management and workers know what to do in case of disaster to maintain or restore production as fast as possible. For example, Japan's policy and institutional framework for industry resilience, the Basic Disaster Response Plan, requires companies to recognize the role they are expected to play when disaster strikes, understand their own risk from a natural disaster, implement risk management and develop a BCP to minimize the consequences of shocks. The 2012 Japan Revitalization Strategy sets BCP establishment targets for 100 percent of large firms and 50 percent of small and medium enterprises by 2020.

BCPs usually include operational recommendations on:

» How to proceed if critical supplies cannot be procured

» How to maintain activity if people have to work from home due to damages to the firm facility

» What to do if there is no internet or other form of telecommunication

» How to manage the needs of workers personally affected by the disaster through injury, loss of friends or relatives, or loss of home.

BCPs should also consider the full supply chain and include issues that may affect suppliers (or suppliers' suppliers) and clients. They can also consider financial issues, such as how to manage a drop in sales, increased supply prices, or the

urgent need to replace expensive equipment. Access to contingent credit lines and appropriate insurance are among the many tools that firms can include in their BCP.

Firms or facilities may find it easier to establish an area-based BCP to manage disaster impacts by collaborating and pooling their resources to reduce costs—for example, by sharing emergency power generation. Since the 2011 earthquake in Japan, which caused large production disruptions, several firms have come together to redesign their evacuation protocols and emergency communication procedures and develop new shared backup solutions for critical utilities. This can require an authorizing legal and regulatory environment, so government, competition regulators and other authorities may need to support such efforts.

BCPs can be designed by performing stress tests and exploring "what if" scenarios to identify bottlenecks and vulnerable points (Chopra and Sodhi 2004). Firms should update plans regularly, incorporating lessons from any new disasters or disruptions (Hamel and Valikangas 2003). They also need sophisticated data management. After the 2011 earthquake, Toyota created a new database, *Rescue*, for the inventories held by 650,000 suppliers worldwide. It uses this information to locate available resources and prevent bottlenecks in production processes when suppliers are affected by a shock.

ACTION 3.6 >>

Be prepared to build back better after disasters, with contingency plans and financing

LEAD MINISTRY: *Economy, planning, environment, investment, or infrastructure*

Public assets—from energy and transport infrastructure to schools and hospitals—are highly exposed to disasters, so contingency plans and financing are required to ensure the rapid and efficient reconstruction or repair of these systems after a disaster. And since schools are often used as shelters in case of evacuation, they usually need modifying before they can accommodate students again, which also requires preparation and finance. One common recommendation is for each sector to prepare the equivalent of a business continuity and reconstruction plan to follow in a disaster aftermath. Such plans are also important inputs into the financial component of the response, since they should provide an estimate of required resources. See *Action 4.1* for a discussion on contingent liability.

TAKING ACTION >>

Sample targets and indicators

- Resilient recovery and reconstruction plans ready for implementation, with revised land use and standards
- Pre-approved contracts for emergency interventions (such as debris removal) or reconstruction (such as road repairs) approved, with enhanced standards

When a disaster hits and old or low-quality assets are destroyed, public and private sector reconstruction can help countries build back better under improved building norms, thereby improving their productivity and resilience postdisaster. Often, this does not happen—usually because the urgency to rebuild leaves little time and resources to rethink the design or spatial footprint of cities and infrastructure. Building back better depends on a country's ability to plan and implement the reconstruction process efficiently; having pre-prepared plans, developed ahead of a crisis, is extremely useful.

There are some encouraging cases. After the 2009 Victoria bushfires in Australia, the authorities successfully implemented measures to build back better, with improved land use planning and structural design (Mannakkara et al. 2014). In Mexico, the government has initiated innovative financing arrangements under its natural disasters fund, Fondo de Desastres Naturales (FONDEN), to incentivize investment, build back better, and relocate housing to lower-risk areas (Tanner and Rentschler 2015).

Replacements for destroyed capital can be more resilient and better adapted to current and future needs, and use the most recent technologies, which have higher productivity. Upgrading capital can involve:

- **For households**, rebuilding houses with better insulation and heating systems, allowing for energy conservation and savings

- **For companies**, replacing old production technologies with new ones—for example, computer-based management files instead of paper-based systems

- **For government and public agencies**, adapting public infrastructure to new needs—for example, replacing destroyed schools with larger or smaller buildings according to demographic evolutions.

A more productive economy can compensate for capital losses in an event aftermath, increasing the pace of technical change and representing a positive consequence of disasters. Several studies mention this "productivity effect" (Albala Bertrand 1993; Benson and Clay 2004; Hornbeck and Keniston 2017). Although it cannot turn natural disasters into desirable events (Hallegatte and Dumas 2009), the productivity effect can reduce overall impacts on economic growth and well-being.

The potential benefits of building back stronger and using more recent and productive technologies provide a strong incentive for introducing policies and tools that help ensure the highest quality reconstruction. For both private and public sectors, useful policies and tools—which must be in place before disaster hits for their benefits to be realized—include:

- Contingency plans and a clear allocation of reconstruction responsibilities

- Financial protection through insurance or social protection systems

- Financial inclusion with access to credit to finance the reconstruction

- Updated construction norms and performance standards to apply to the reconstruction

- Access to information and knowledge on how to implement modern solutions and technologies.

Building back better does not only depend on financial resources; countries must also have the ability to efficiently plan and rebuild. The experiences in Haiti after the 2010 earthquake revealed that a lack of technical expertise and raw materials in the disaster location can make building back better difficult in practice (Kijewski-Correa and Taflanidis 2012). However, with good advance planning and preparation, recovery efforts can build back not only stronger, but also faster and more inclusively (Hallegatte et al. 2018).

Priority Area 4:

Manage financial and macrofiscal issues

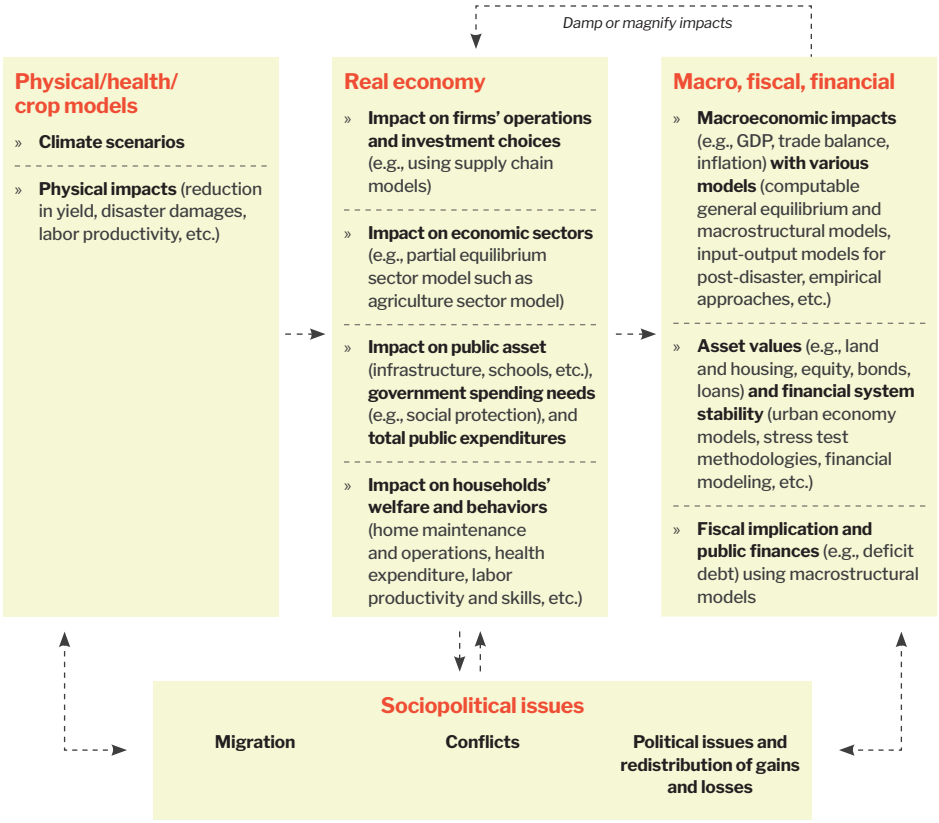
LEAD MINISTRY: Finance

Climate change impacts—whether through slow changes or shocks—and the adaptation actions that households, firms, and investors take can influence macroeconomic aggregates such as GDP, trade balance, inflation, or public debt (*figure 13*). They may also lead to changes in asset values or financial risks that are large enough to threaten the stability of the financial system (Carney 2015; Campiglio et al. 2018). Because they have macro-level implications, climate and disaster risks cannot be managed by individual households, firms, or investors alone. There also needs to be public action, especially in assessing, monitoring, and regulating financial and macrofiscal risks.

This is particularly challenging due to the massive uncertainty around how to measure or model the macroeconomic impacts of natural disasters and climate change. Decision makers should therefore consider uncertainty when designing adaptation and resilience strategies, which need to be both robust, so they deliver benefits in the wide range of possible futures, and flexible, so they can be adjusted as new information becomes available.

FIGURE 13 >>

The channels through which climate change can affect macrofiscal and financial aggregates



TAKING ACTION >>

Screening questions

Identify actions to mitigate financial and macrofiscal risks

Through its impacts on people and firms, climate change has the potential to cause system-wide impacts on economies. Are countries and governments well prepared to manage the fiscal and financial shocks alongside the long-term structural changes that climate change could bring? The following questions can help decision makers identify shortcomings and guide them towards the actions needed to mitigate financial and macrofiscal risks.

ACTION 4.1 >>

Financial protection strategy

Does the government have an assessment of contingent liabilities associated with different natural hazards?

Does the government have contingency plans and financing instruments that can mobilize the resources needed to respond to a shock?

Could include: *postdisaster public finance management (PFM) assessment; clear earmarking; defined accountabilities; targeting*

ACTION 4.2 >>

Mitigating macroeconomic impacts

Are the possible long-term macroeconomic impacts of disasters and climate change assessed and planned for? Is the uncertainty properly considered?

Should include: *implications for GDP and long-term debt sustainability, in multiple scenarios*

ACTION 4.3 >>

A resilient financial system

Have climate stress tests of the financial system been conducted, and potential shortcomings addressed?

Should include: *publicly disclosed stress tests of banks, insurers, institutional investors, and pension funds; regulations to mitigate financial sector risks*

Have regulators and financial supervisory authorities assessed the vulnerability of the financial system and introduced specific recommendations or regulations?

Could include: *large firms and investors reporting annually on their exposure to climate and disaster risks*

ACTION 4.1 >>

Include contingent liabilities from natural disasters and environmental shocks in the planning and budgeting process

LEAD MINISTRY: *Finance*

Contingent liabilities only materialize if a certain event occurs. For example, if the roads are damaged by flood, the government is responsible for repairing them. There are two types of contingent liability:

- **Explicit contingent liabilities** are relatively easy to estimate, based on public asset and infrastructure inventories—for example, if the state owns the public roads, it is responsible for fixing them.
- **Implicit liabilities** are linked to other expectations or forms of commitment and are more difficult to estimate—for example, governments are expected to support populations affected by disaster and provide humanitarian and financial resources.

TAKING ACTION >>

Sample targets and indicators

- Risk to public assets and corresponding contingent liabilities assessed
- Emergency and social protection spending needs and corresponding contingent liabilities assessed
- Explicit and implicit contingent liabilities quantified and included in budget documents
- Risk to GDP and tax revenues estimated and included in budget documents

The first step, then, is to include these contingent liabilities in the budget planning process and make them part of the deliberation (World Bank 2013; OECD and World Bank 2019). This ensures that climate and disaster risks cannot be ignored. The Bhutanese budget process, for example, includes natural disasters (Nu 225 million/0.1 percent of GDP) and climate change impact (Nu 20 million/0.01 percent of GDP) in its fiscal risk assessment matrix (implicit contingent liabilities). Sweden's Climate Act explicitly states that climate and national budgetary policies should be aligned and requires investment-related impacts to be explicitly considered in the four-year climate plan.[20] It also requires the annual government report on climate action to be connected to the budget bill, strengthening the link between them. France also requires its annual report on climate change policies to be connected with the budget bill.[21] The report contains information on public and private funds dedicated to climate change policies and calculates the gap to the necessary volumes required.

One major challenge, dramatically illustrated by the COVID-19 crisis, is the need to consider the possibility of multiple simultaneous crises—for example, when

a hurricane affects a region already struggling with an epidemic—and cascading crises, which occur when one crisis, such as a long drought, triggers another crisis, magnifies social tensions or leads to conflict and violence. While a fully probabilistic assessment of compounding risks may be excessively complex, using a few scenarios with multiple crises may highlight some vulnerabilities and liabilities that are not apparent if each possible threat is considered independently.

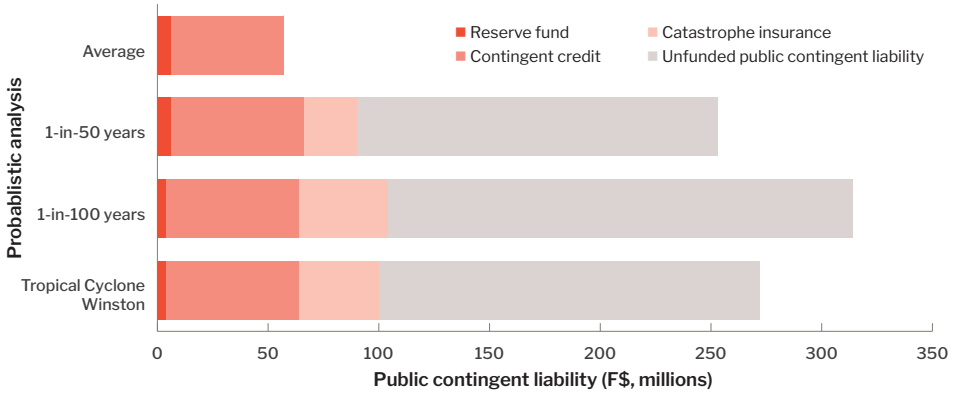
First dimension: public and private asset reconstruction costs

Facing these liabilities when they materialize, governments need to bridge the funding gap to cover both the immediate response—providing emergency food, water, blankets, tents, medical care—and the recovery and reconstruction stage, which includes repairing roads, buildings and so on (*toolbox G*). These two funding needs have different constraints and priorities: for the emergency response, timeliness is critical, but amounts are relatively limited, and the cost of capital is less important. For reconstruction needs, amounts are often large, and the cost of capital becomes a critical consideration.

Figures 14 and 15 illustrate the Fiji government's explicit contingent liability from public asset and infrastructure reconstruction, and its additional financing needs for social expenditure in response to tropical cyclones. *Figure 15* shows the costs of providing social protection at various return periods and two levels: similar to the government's response to the 2016 Tropical Cyclone Winston and another, wider and stronger response. Governments can use analysis like this to calculate the finances needed to respond to future disasters and decide on the best source of financing for various needs.

FIGURE 14 >>

Funding of the government of Fiji's explicit contingent liability (from public assets and infrastructure)

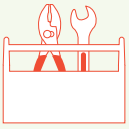


Source: Government of Fiji and World Bank 2017.
Note: F$ = Fiji dollars.

TAKING ACTION >>

Toolbox G

Assessing potential (direct) damages from natural hazards



There are a few databases with records of past disasters and their human and economic consequences. The most used is *EM-DAT*,[22] curated by the Centre for Research on the Epidemiology of Disasters at Belgium's Université catholique de Louvain. Other institutions have created similar datasets, including the UN-DRR's *DesInventar*,[23] reinsurer MunichRe's *NatCatSERVICE*,[24] and reinsurer SwissRe's *Sigma*.[25]

These datasets allow quick estimates of current country-level risk levels. But it is important to use historical and economic datasets with care. They tend to be incomplete, especially for low-income countries and moderate intensity disasters. They also use different definitions and thresholds—for example, for what is considered a disaster—and provide economic estimates based on different methodologies and covering different scopes. Some cover only direct costs, while others cover direct and indirect costs. Also, socioeconomic and climate trends make natural hazards non-stationary, and risk assessments based on historical data cannot provide precise estimates of future risks (McCarl et al. 2008). Governments should create their own monitoring system and keep records of every disaster. These should cover the nature and location of each event as well as all available information on its consequences, with harmonized methodologies and scopes if possible. There are recommendations on how to set up such a system elsewhere (see, for example, OECD 2016).

To assess future disaster risks and their economic implications, governments should use simulation modeling to estimate the direct risk to assets and economic activity (usually expressed as average annual losses). A range of approaches are available for this, from simple, cheap options to complicated and expensive ones, including:

Relying on global estimates: For example, the United Nations Disaster Office for Disaster Risk Reduction's *2015 Global Assessment Report* (UNISDR 2015) and its risk and disaster data platforms[26] provide country-level assessment for earthquake, storms, and floods.

Making relatively simple assessments using existing data, combining:

- Global hazards maps, such as those recorded in the ThinkHazard platform[3]
- Remote sensing-based estimates of exposure, such as the approach proposed in Gunasekera et al. (2015)
- Vulnerability curves, which are available from various sources, including academic papers and engineering documents.

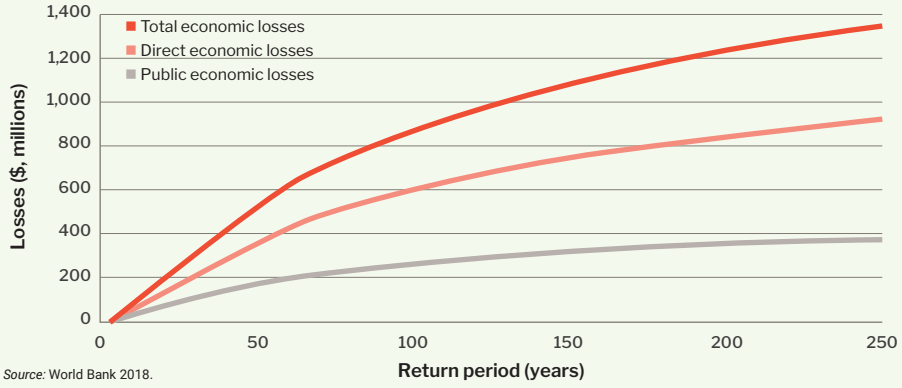
The GFDRR country profiles provide examples of simple risk assessments, with estimates of direct damages for different hazards and reporting periods in many countries.[6] ***Figure G.1*** illustrates the risk assessment for Saint Lucia.

Developing a full country catastrophe model: This is a longer and more expensive exercise involving primary data collection—for example, on the exposure and vulnerability of buildings and infrastructure. Commercial modeling firms have developed such models in countries with developed insurance markets, but low-income countries do not usually use them.

With each of these approaches, it is possible to restrict the assessments to public assets, either by using a public asset inventory or a simple rule of thumb on the fraction of assets that are government-owned. This would allow governments to assess the risk to public assets, which will correspond to the reconstruction needs they will be directly exposed to. This work can build on ***Action 1.1***, which recommends creating hazard maps and datasets, and ***Action 2.1***, which recommends creating an inventory of public assets, including their value and exposure to natural hazards and climate change impacts.

FIGURE G.1 >>

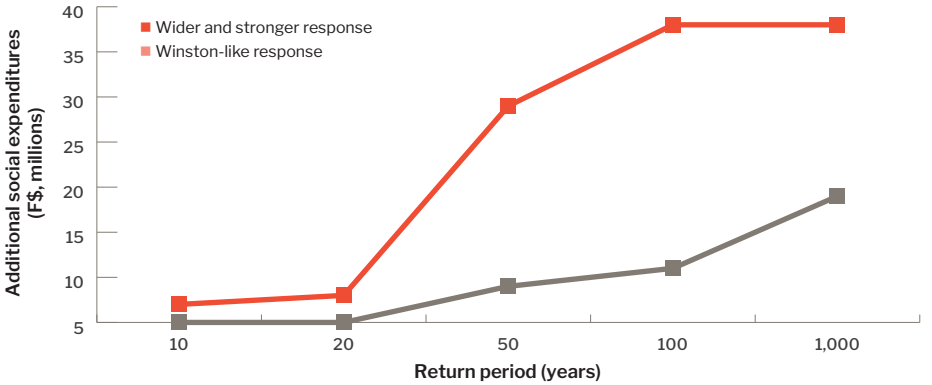
Saint Lucia hydrometeorological risk profile



Source: World Bank 2018.

FIGURE 15 >>

The government of Fiji's implicit contingent liability, based on social protection financing needs in response to tropical cyclones



Source: Government of Fiji and World Bank 2017.
Note: F$ = Fiji dollars.

Second dimension: impact on tax revenues

As well as affecting spending needs, disasters cause tax revenues to fall, increasing the funding gap. For example, following a severe drought in 2017, Argentina lost an estimated $1.5 billion in tax revenue in 2018, mostly due to reduced exports (Secretaria de Ingresos Publicos, 2019). The impact on tax revenues depends on the indirect effects on GDP and economic activities, so it is much more challenging to assess than spending needs and contingent liabilities. *Toolbox H* discusses tools for estimating the GDP impact of natural disasters, ranging from simple rules of thumb to full modeling options. Governments can use these estimates as inputs when designing appropriate policy response strategies. They can then mobilize traditional instruments and approaches to link the potential impact on GDP to a drop in tax revenues.

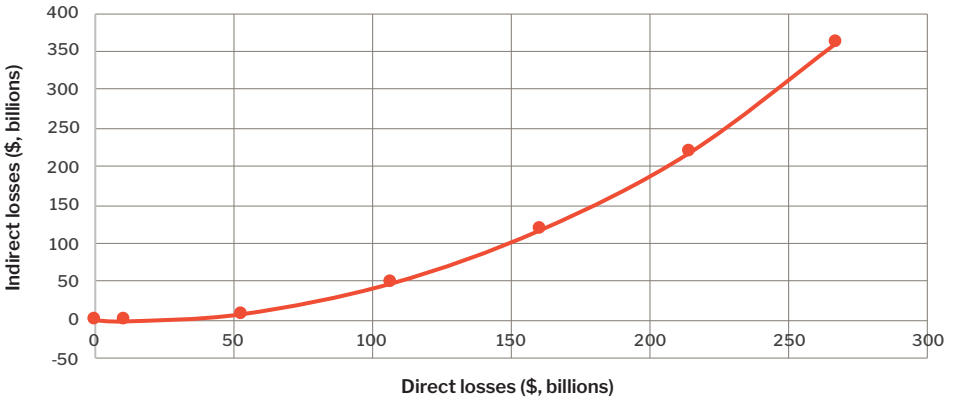
The impact of a disaster on GDP can differ enormously from its direct impacts—that is, the cost of repairing or replacing damaged assets. Impact on GDP will depend on how damage to assets and interruptions to economic activity translate into reduced output and value added. It will also depend on the stimulus effect generated by reconstruction and government responses. Because GDP includes components that cannot be directly observed through a transaction—such as the value of services provided by owner-occupied dwellings or public roads—measuring the GDP impact of disasters is difficult and subject to large uncertainties.

One important finding in both empirical and theoretical literature is that the impacts of natural disasters on GDP are nonlinear—in other words, doubling the direct damages does more than doubling the GDP impact. They are also context-dependent, particularly in respect to the pre-existing macroeconomic situation. *Figure 16* illustrates the GDP losses caused by hurricanes of increasing intensity in the US state of Louisiana, based on a modeling study. GDP losses due to hurricanes

are almost null until direct losses reach a certain threshold—in this case, around $50 billion—because the lost output due to damages is compensated by the increased demand from post-shock reconstruction. But GDP losses increase rapidly beyond this threshold.

FIGURE 16 >>

Relationship between direct asset losses from hurricanes of increasing intensity and resulting losses in output



Source: Hallegatte 2008.

This nonlinearity in the impact of disasters on GDP is largely explained by constraints on reconstruction: the loss of output at one point in time increases more or less linearly with capital losses, but reconstruction takes longer for bigger shocks (*toolbox H*). This increases the cumulative loss of production nonlinearly with the amount of capital losses, while the benefit from reconstruction increases only linearly with asset losses. Such nonlinearity is fully consistent with empirical studies showing that the impact of disasters on GDP is only detectable for the largest ones.

Modeling the duration of reconstruction is therefore critical. In a simple model with no financial and technical constraints on reconstruction, damages can be repaired within weeks or months. The capital losses from Hurricane Katrina in the US state of Louisiana in 2005, for example, only represent a couple of weeks of investment in the US. But reconstruction takes much longer, for financial, regulatory, and technical reasons:

» **Financial:** In many countries, local infrastructure reconstruction is paid for by central government but carried out by local authorities. Budgetary processes can take months to transfer the resources, slowing down reconstruction. Private actors—firms and households—may also be unable to mobilize enough resources to rebuild straight away, often deciding to repair their homes and factories in phases, spreading the cost over years.

» **Regulatory:** After a large shock, reconstruction requires long-term planning, particularly if the goal is to build back better. For example, governments or local authorities may decide not to rebuild in the most at-risk areas, but this would require a political process that can take several months. In the absence of pre-approved contracts and specific PFM arrangements (see *Action 4.2*), procurement can also delay reconstruction by months or more.

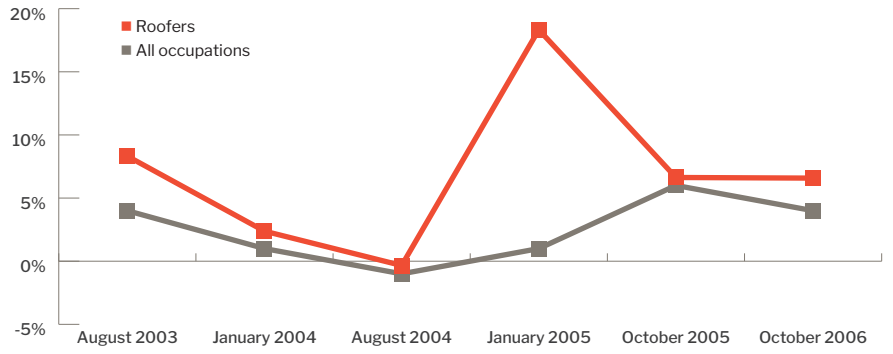
» **Technical:** Reconstruction increases demand in specific sectors that have capacity constraints. For example, removing debris after a hurricane can take a long time because heavy equipment is scarce, and repairing houses can take years because skilled workers—such as roofers or carpenters—are missing. Supply constraints are often visible through sectoral inflation in the construction sector's wages and prices. This is referred to as "demand surge" in the insurance industry (*figure 17*).

These three types of constraint explain why reconstruction after major disasters can last 5 to 10 years, magnifying the impacts of a shock on total GDP and consumption. If disaster impact analyses do not consider these constraints, they will underestimate the effect on macroeconomic aggregates.

Similarly, the impact of disasters on GDP is magnified if the shock occurs during a phase of rapid growth, when all production capacities are already used. Disasters that happen during a recession, however, tend to have a smaller impact on GDP, because it is easier to mobilize resources that were idle before the shock to fund the reconstruction process (Hallegatte and Ghil 2008). For example, Hurricane Andrew's impact on Florida in 1992 was damped by the low level of activity at the time of the shock: half the workers in the construction industry were out of the work and could be mobilized for the reconstruction effort, creating jobs and income with little crowding out effect (West and Lenze 1994).

FIGURE 17 >>

Wages for qualified roofers in Miami, US, rose significantly after the 2004 hurricane season

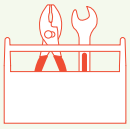


Source: Hallegatte and Vogt-Schilb 2019.

TAKING ACTION >>

Toolbox H

Measuring the macroeconomic impact of disasters and implications for public finances



This toolbox explores some of the tools governments can use to estimate the possible impact of a disaster, based on the direct damages it causes. These include: empirical estimates, based on past disasters; a simple modeling approach linking direct damages to GDP impacts; and multisector models representing the full impact and linkages across sectors.

Empirical estimates

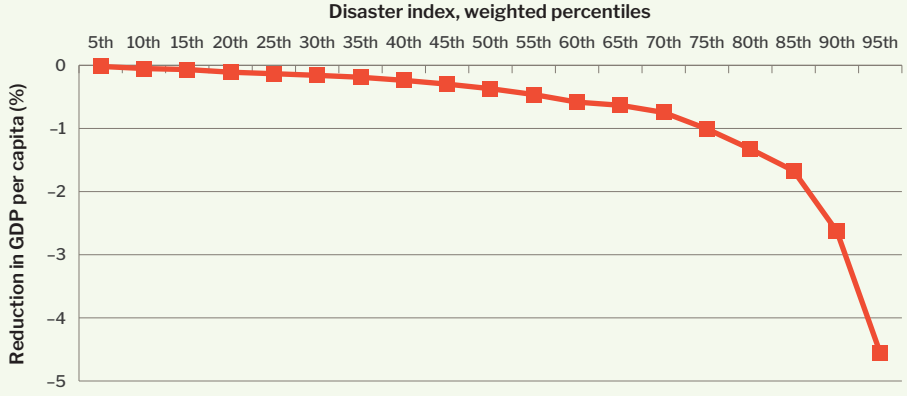
A first option is relying on past disasters and using econometric techniques. For example, a Central American study found that a one standard deviation increase in a hurricane's intensity leads to a 0.9–1.6 percent decrease in total per capita GDP growth and a 3 percent decrease in total income (Ishizawa and Miranda 2016). Governments can use such estimates to anticipate the possible impact of future disasters, including their nonlinearity. A global study found that disasters in the top decile of magnitude result on average in an almost 3 percent reduction in GDP per capita; but this goes down to 0.8 percent for those in the top 20 percent (*figure H.1*) (Felbermayr and Gröschl 2014).

The long-term impacts of natural disasters on growth remain controversial. Some studies have suggested that natural disasters have a positive influence on long-term economic growth (Albala Bertrand 1993; Skidmore and Toya 2002), while a meta-analysis of more than 750 estimates found that the impact is short-term, and long-term per capita GDP returns to its original growth path (Klomp and Valckx 2014).

However, other studies have found that the negative impacts of natural disasters can exceed 10 percent of GDP. For example, von Peter et al. (2012) found that a typical natural disaster causes a 0.6–1.0 percent drop in long-term economic growth and results in a permanent output loss of two to three times this magnitude, with higher estimates for

FIGURE H.1 >>

Growth effects of natural disasters as a function of disaster intensity



Source: Felbermayr and Gröschl 2014.

larger natural disasters. Hsiang and Jina (2014) found that a 90th percentile event reduces per capita income by more than 7 percent after two decades, "effectively undoing 3.7 years of average development". Comparing the situation of Kauai island after Hurricane Iniki with the situation of unaffected Hawaiian islands, (Coffman and Noy 2012) found that, 18 years after the event, Kauai's population was 12 percent smaller than it would have been without the hurricane, and its aggregate per capita income and employment were proportionally lower. Cavallo et al. (2013) found that, while the largest disasters—those in the 99th percentile—have some long-term impacts on growth, this disappears entirely when controlling for political change. In other words, the long-term impact only happens when the disaster is followed by political instability. This suggests that the secondary impacts of natural disasters through political instability and conflicts could play a major role in determining their long-term effects.

Limits in measuring the impact of natural disasters on GDP: One important note of caution on using empirical studies based on historical GDP timeseries is that they are likely to underestimate the impact of disasters on economic output. Statistical agencies measure GDP based on many data sources, but they mostly rely on actual economic transactions—such as the sales of goods and services. To calculate real GDP, however, they have to also include economic outputs that cannot be measured through transactions—such as the value of public education, public road use, and housing services provided by owner-occupied dwellings.

Most developing countries use household surveys to estimate the economic value of the services provided by owner-occupied dwellings, even if there is no transaction associated with them. But these surveys are undertaken unregularly. When a hurricane damages a large share of the housing stock, the quantity of housing services drops, but there is no updated household survey to measure this impact. In parallel, the value of housing services may increase—reflecting scarcity—but this effect is not always measured, or can blocked by regulation on rents or other factors.

Caribbean Central Bank data estimate that services from owner-occupied dwellings in Dominica dropped by 21 percent in 2017. Even accounting for possible changes in prices, it is unclear whether this is a good measure for the impacts of hurricane Maria: of the 31,348 homes comprising the Dominican housing stock, approximately 4,700 (15 percent) were identified as destroyed, some 23,500 (75 percent) were estimated to have incurred partial damage, and 3,135 (10 percent) were considered unaffected by the event. Similarly, road transport outputs were estimated to have remained stable (rising from EC$78 to EC$79 million), in spite of EC$380 million in damage to roads and bridges (Government of the Commonwealth of Dominica 2017).

Modeling the impacts of a disaster on GDP

Looking beyond past events, governments need to rely on modeling. It is not possible to estimate the impact of a natural disaster on GDP or economic growth by simply reducing the stock of capital in an unchanged growth, dynamic stochastic general equilibrium (DSGE), or macrostructural model. These models have been developed to explore shocks that are different from natural disasters and will underestimate GDP losses, unless they are specifically adapted for this task.

Channels of impact and rule-of-thumb estimates: Most models assume that capital is one homogeneous commodity that can be instantaneously reallocated toward its most productive use, hence the decreasing returns with the last unit of capital being the least productive.[27] But in reality, the remaining stock of capital after a disaster is not optimally allocated. For example, the roads that remain usable are not the most important roads with the most traffic, the buildings that are still habitable are not the ones hosting the most important businesses, and so on. It is possible to reallocate a large share of capital over the medium term—for example, with the most productive firms moving to the habitable buildings. But it is almost impossible to reallocate most of the capital in the short term. The result is a drop in capital productivity, on top of the decrease in capital stock. Empirical studies confirm that disasters reduce both the stock of capital and total

factor productivity (TFP) (Bakkensen and Barrage 2018; Dieppe et al. forthcoming).

To capture these effects, Hallegatte and Vogt-Schilb (2019) propose a modeling approach in which output losses are estimated as the product of capital losses by the average (not the marginal) productivity of capital. This is the expected loss if disaster impacts are purely random and there is no reallocation of capital after the disaster (an assumption that is valid over the short term, at least). It is equivalent to a situation in which the disaster reduces the stock of productive capital by the cost of damages and leads to capital misallocation, which reduces TFP, with an impact on output that is twice as large as the impact from the capital stock decrease. In an intermediate case, with some reallocation of capital after the disaster—for example, where production equipment is moved to non-affected facilities—the impact on TFP would be lower.

This approach leads to the following rules of thumb for making a quick assessment of potential GDP impacts. With discounting at a rate ρ, μ the average productivity of capital in the country, T the expected reconstruction time, and ΔK the monetary value of asset losses, the net present value (NPV) of output losses can be estimated as:

$$\widetilde{\Delta Y} = \frac{\mu \Delta K}{\rho + 1/T}$$

And the NPV of consumption losses is equal to:

$$\widetilde{\Delta C} = \Delta K \frac{\mu + 1/T}{\rho + 1/T}$$

The average productivity of capital μ can be estimated as the ratio of GDP and the value of the capital stock (as measured, for example, in the Penn Table using a permanent inventory method). With standard model calibration, the average productivity of capital is approximately three times the marginal productivity of capital.

Duration of recovery and reconstruction: The duration of reconstruction (the variable T) plays a key role in these estimates. Consider first a case where all losses are repaired instantaneously by reducing consumption and directing all unconsumed goods and services to reconstruction investments. This is a scenario where reconstruction capacity is infinite, and T is equal to zero. In this case, there is no output loss because all asset damages are instantaneously repaired. There are, however, consumption losses, since consumption has to be reduced to rebuild, and this reduction is equal to the reconstruction value—that is, the replacement cost of damaged capital. In that case, the NPV of consumption losses ($\widetilde{\Delta C}$) is simply equal to the reconstruction cost. With unchanged prices, this is equal to the pre-disaster value of damaged assets ΔK.

Consider now another case with no reconstruction, in which output losses are permanent and all output losses are absorbed by reduced consumption, but no share of income is used for reconstruction. In that case, consumption losses are equal to output losses (with no reconstruction), and T is equal to infinity. The loss in consumption at T_θ is equal to $\mu \Delta K$, and the NPV (discounted at the rate ρ) of consumption losses is $(\mu/\rho)\Delta K$. Consumption and well-being losses are thus larger (by a factor around 3) than the value of lost assets in a no-reconstruction case.

Multisector modeling of GDP impacts

There are also more sophisticated approaches that better capture the interplay between sectors or regions (for a recent review, see Okuyama and Rose 2019). Some models are based on the input-output (IO) linear assumption, in which producing one unit in one sector requires a fixed amount of inputs from other sectors, and prices do not play any role (see, for example, Brookshire et al. 1997; Haimes and Jiang 2001; Okuyama and Rose 2019). Even though the IO model is originally demand-driven (see, for example, Oosterhaven 1988; Cochrane 2004), it is commonly used to model disasters that are largely supply-side shocks. Extensions of IO models have been used to include supply constraints and production dynamics within IO-model disaster assessments (for example, Okuyama and Rose 2019; Hallegatte 2008; Hallegatte 2013). The IO approach is based on the idea that the production system is fixed in the short term, and local production capacity is constrained by existing capacities, equipment, and infrastructure.

Other models are based on the CGE framework, which

assumes that changes in relative prices balance supply and demand (Rose and Liao 2005; Rose et al. 2007). In this framework, there is no rationing in the economic system and markets remain at equilibrium. In CGE models based on the Cobb-Douglas or constant elasticity of substitution function, production technology is not fixed and there is short-term input substitution. In other words, when one input is scarce, production can continue, using less of this input and more of others.

Economic losses caused by a disaster are smaller in a CGE than an IO setting. In reality, it is likely that IO models are pessimistic in their assessment of disaster output losses, because the economy is flexible even over the short term—for example, maintenance can be postponed, workers can do more hours to cope with the shock or production can be rescheduled (Rose et al. 2007). It is also likely that CGE models are optimistic, even in the long run, because prices have stickiness and cannot adjust perfectly,[28] because substitution has technical limits that are not always adequately represented in production functions, and because their aggregation at sector level makes it difficult to capture the impact of supply chain effects (Hallegatte 2013).

These models remain limited and cannot capture all relevant mechanisms. In particular, they lack an explicit representation of network-shaped industries, such as electricity, water and transport. Hallegatte et al. (2019) provide estimates and methodologies to assess the consequences of disruptions in networked infrastructure, including electricity, water and sanitation, and transportation, and find that the indirect losses linked to infrastructure disruptions can be significant.

The models described here also underestimate economic impacts due to their aggregation level, representing economic sectors—that is, thousands of businesses located in different places—as unique producers. Such a framework assumes that all businesses from one sector suffer the same direct impacts from disasters; in other words, that impacts are homogeneously distributed among the businesses from each sector. Considering the multiplicity of producing units, their locations and explicit supply chains would allow for a much more realistic representation of natural disaster consequences. Modeling exercises suggest this approach would lead to higher estimates of disaster output losses, not least because they would take into account indirect impacts in locations that are not directly hit by the disaster (Henriet et al. 2012; Colon et al. 2019; Inoue and Todo 2019).

Firm-level studies also suggest that the vulnerability of firms can vary significantly depending on their position in the supply chain (Barrot and Sauvagnat 2016; Colon et al. 2019; Kashiwagi et al. 2018). Overall, modeling supply chains and their role in propagating shocks can be complex and data intensive. However, even if simplifying assumptions need to be made, acknowledging and quantifying their roles can be crucial to understanding the true economic cost of climatic shocks.

ACTION 4.2 >>

Develop a financial strategy to manage contingent liabilities, combining multiple instruments

LEAD MINISTRY: *Finance*

When a disaster or another environmental shock hits, there are immediate financial needs related to emergency response and humanitarian support for affected populations (*Priority Area 3*) and longer-term recovery and reconstruction costs, which can have a strong impact on public finance. In parallel, tax revenues often drop during the crisis and recovery phase. As a result, governments and local authorities often struggle to finance postdisaster response and reconstruction, while liquidity constraints can also affect their short-term response. Noy and Nualsri (2011) found that developing countries conduct pro-cyclical fiscal policy as a result of natural disasters, thereby decreasing debt but increasing the negative economic impacts of disasters.

The resource mobilization challenge in a postdisaster situation therefore requires specific financial solutions, which need to be arranged in advance to be readily available when a disaster hits (*figure 18*). These financial solutions must obey four core principles:

- **Timeliness of funding:** Some funds are necessary right away, but not all resources are needed at once
- **Appropriate delivery mechanism:** How funds are disbursed and how they reach beneficiaries is as important as where the money comes from
- **Disaster risk layering:** No single financial instrument can address all risks
- **Based on data and analytics:** As described in *toolboxes G and H*, it is important to quantify risk to build a sound risk financing strategy.

Disaster risk financing and insurance bring together disaster risk management, fiscal risk and budget management, public finance, private sector development, and social

TAKING ACTION >>

Sample targets and indicators

- Percentage of explicit and implicit contingent liabilities covered by reserve funds, contingent credit lines, insurance products or similar instrument
- Disaster escape clause in budget processes approved
- Process for managing inflow of international aid in place in case of major disasters, including using existing financial instruments to coordinate delivery
- Post-Disaster Public Financial Management and Engagement Framework (PD-PFM Review) conducted and approved
- PD-PFM principles and processes approved

protection. While the private sector is an important partner to provide analytics and financing solutions, strong stewardship by the ministry of finance in coordination with other public agencies is crucial to successfully advance this agenda.

The World Bank Group's operational framework for risk financing (*figure 18*) starts with thorough risk assessments like those described in *toolboxes G and H* to quantify a government's contingent liabilities. Based on these assessments, governments can build a financial strategy by following the risk layering approach. The urgency and chaos of a postdisaster situation also create specific challenges on the expenditure side, which need to be considered through a disaster-sensitive PFM system.

Revenue and resource mobilization solutions

Most countries have budget contingencies of 2–5 percent of government expenditure to contend with all shocks, not only natural hazards. However, this is often not enough for responding to natural hazards and many governments—especially small island states—cannot afford the reserves they need to respond to major events (IMF and World Bank 2018). Vietnam, for example, has been hit several times by cyclones in November, when the year's contingency budget had already been fully exhausted (Mahul and Ghesquiere 2010).

Various instruments are available to cover the contingent liabilities created by natural hazards and other environmental risks (Mahul and Ghesquiere 2010; Clarke and Poulter 2014; Clarke and Dercon 2016). They include:

» **Fiscal space, diversified and resilient tax collection, and reserve funds:** Regardless of their origin, the most robust way to manage unexpected shocks is maintaining fiscal space in normal conditions, with manageable structural deficit and debt levels. It is also preferable for the tax collection system to be reasonably diversified and resilient. For example, a government funded primarily by export duty on a small set of agricultural commodities is exposed in case of drought.

  A strong macrofiscal situation makes it easier to manage surprises and access external financing in case of liquidity constraint. However, in countries with automatic fiscal adjustment systems—for example, where deficits cannot exceed a certain threshold—governments can add specific escape clauses in case of disaster, allowing them to respond quickly to emergency needs.

  It is also useful to have reserve funds in case of shocks, to enable an immediate response to an event. In the Philippines, the National Disaster Risk Reduction and Management Fund finances a range of disaster-related expenditures but cannot disburse rapidly in response to

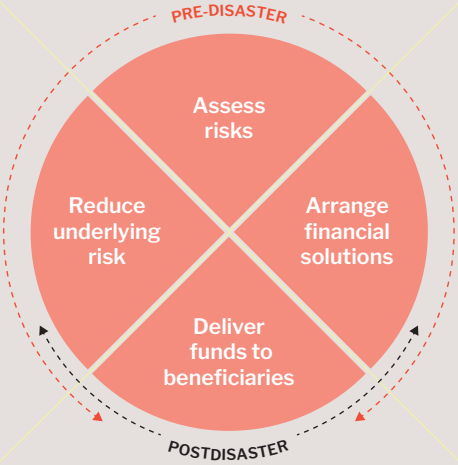
FIGURE 18 >>

Operational Disaster Risk Financing and Insurance Framework: core technical steps

Risk assessments for financial protection quantify potential diaster impacts based on historical and simulated data. This often requires investments in the necessary underlying hazard, exposure, and vulnerability data. It also includes building an effective interface between the policy maker and underlying technical models.

Sustainable financial protection requires reducing underlying drivers of this risk.

It complements risk reduction by manging residual risk which is not feasible or not cost-effective to mitigate. It also creates incentives to invest in risk reduction and prevention by putting a price on risk and clarifying risk ownership.



Effective postdisaster response and recovery rely on access to sufficient and timely resources. This includes:

- Arranging the required financial resources for the government to meet its contingent liabilities
- Developing catastrophe risk and agricultural insurance markets, building on public-private partnerships
- Developing rules and arranging financing instruments for scalable social protection

Resources should reach beneficiaries in a timely, transparent, and accountable fashion. This requires effective administrative and legal systems for the appropriation and execution of funds for the government budget, insurance distribution and settlement (often through private channels), as well as social protection programs.

Source: World Bank Group 2014.

a crisis. So, the government created the Quick Response Fund to focus on emergency response. However, Typhoon Yolanda raised questions about the adequacy of the Quick Response Fund volume and the process for replenishing it if it is emptied by a major event or a series of smaller disasters. The country has since developed additional instruments to protect its public finances. Mexico created FONDEN as a budgetary tool to rapidly allocate federal funds for rehabilitating public infrastructure affected by disasters. Evidence shows that FONDEN has significant benefits, increasing local GDP postdisaster by 2–4 percent, with a benefit-cost ratio estimated conservatively between 1.52 and 2.89 (de Janvry et al. 2016). However, its reserve funds have limited capacities and are not designed to cope with rarer, more extreme events.

» **Contingent credit lines:** In 2007, the World Bank introduced Catastrophe Deferred Drawdown Options (Cat-DDOs), a new financing instrument that gives countries that are eligible to borrow from the International Bank for Reconstruction and Development (IBRD) access to budget support in the immediate aftermath of a disaster. Compared to private sector alternatives, this instrument is financially attractive for middle-income countries, even in the absence of subsidy, because it builds on the size of the IBRD balance sheet and available liquidity. The same instrument is now also available to low-income countries, with a subsidy component, through the World Bank Group's International Development Association. In both cases, the instrument allows low-cost contingency loans to be rapidly disbursed if a state of emergency is declared; so, it can help governments finance emergency interventions and the upscaling of social protection. Other institutions, such as the Inter-American Development Bank and the Japan International Cooperation Agency, have since introduced similar instruments. Cat-DDOs have proven to be an effective instrument for implementing disaster risk management strategies and supporting postdisaster responses.

» **Insurance and catastrophe bonds:** Mexico's FONDEN contingency fund leverages private sector financing as part of a strategy that combines risk retention and risk transfers. In 2006, FONDEN issued a $160 million catastrophe bond to transfer Mexico's earthquake risk to the international capital markets. This was the first parametric catastrophe bond issued by a national government. Even though they are costly, these financial schemes can disburse funds rapidly; more rapidly than would be possible with public budgets. And by predefining payout rules for allocating postdisaster support, formal insurance and financial products can reduce political economy biases (Clarke et al. 2016b).

- **Regional risk-sharing facilities:** The Caribbean Catastrophic Risk Insurance Facility pools disaster risk across 16 countries. The world's first regional catastrophe insurance facility, it uses parametric insurance to give participating governments quick, short-term liquidity to finance responses and early recovery in the case of major earthquakes or hurricanes. The Pacific Catastrophe Risk Assessment and Financing Initiative (PCRAFI), African Risk Capacity, and South Asia Disaster Risk Insurance Facility (SEADRIF) are more recent examples of donor-supported regional mechanisms that offer quick-disbursing, index-based coverage against tropical cyclones and earthquakes. In response to Cyclone Pam in March 2015, PCRAFI rapidly gave Vanuatu $1.9 million to support immediate postdisaster needs. Although this payout was small compared with total losses and reconstruction needs—estimated at $184 million—it was eight times bigger than the government's annual emergency relief fund and seven times bigger than the annual insurance premium, which is largely subsidized by international donors.

- **State contingent debt instruments:** Some countries include disaster clauses in their sovereign bond contracts, to enable changes in debt service payments in the event of an exogenous natural disaster. In Grenada, for example, the hurricane clause is designed to provide cash flow relief at a critical moment after a natural disaster event, enabling the government to redirect funds intended for debt service to more immediate needs. The clause provides for deferred payments for up to two payment periods, and there is no nominal principal or interest rate reduction. The deferred interest payment is capitalized, and the deferred principal payment is distributed equally on top of the scheduled payments until final maturity. Key features of a hurricane clause include a verifiable trigger event measured by an independent entity and a maximum number of triggers. Grenada uses parametric measures for events and the maximum number of triggers is three (Asonuma et al. 2017).

- **International aid:** When a country exceeds its capacity to cope with a disaster, international aid and humanitarian emergency measures can be critical. On average, emergency foreign aid covers only a small percentage of total economic losses stemming from a disaster (Becerra et al. 2013). As well as being slow, it also remains highly unpredictable, making it difficult to include in contingency and reconstruction plans. Nevertheless, it is useful for countries to prepare clear systems for screening and processing international aid offers before disasters occur, so they can quickly channel any offered resources to those in need (for an example of this in the Philippines, see Hallegatte et al. 2016b, chapter 5).

However, none of these instruments can meet all the needs on their own, so a combination of tools is preferable (*Figure 19*). Their value can be assessed in various dimensions (GFDRR and World Bank 2014), including:

- **Financial costs and benefits:** Different instruments have different costs for providing the same post-disaster $1. These often depend on the amounts at stake—for example, transaction costs can make small portfolios expensive—but extremely large contracts are also expensive because the risk taker needs large (and liquid) financial reserves.

- **Volume:** Some instruments, such as reserve funds, are efficient when the amounts covered remain relatively small, but there are limits to the size of these funds and opportunity costs can grow quickly, especially in countries with limited resources and large investment needs.

- **Timeliness:** The speed with which an instrument can deliver postdisaster finance depends on the process and the size of the product. Government reserve funds are the quickest, since the money is readily available, and the use of soft triggers means that contingency funds can be disbursed in a matter of days. Indemnity-based insurance (when the pay-off depends on losses) is the slowest, as it requires lengthy damage assessments.

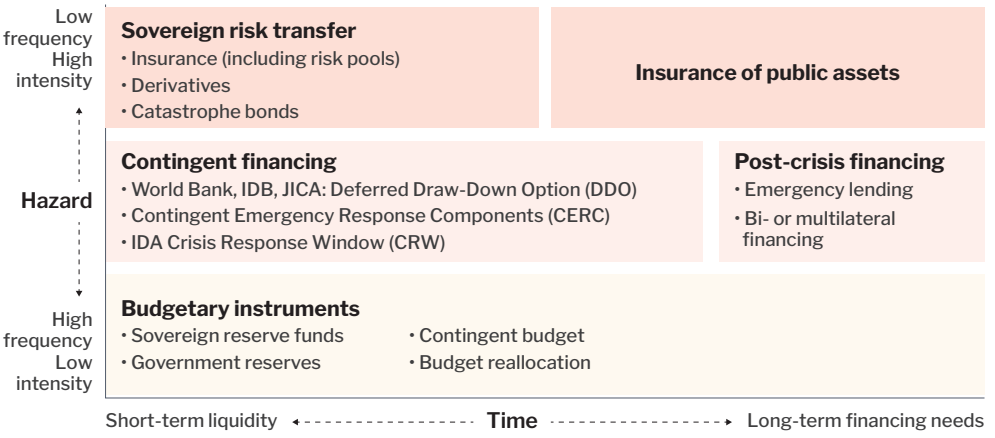
- **Discipline:** Some instruments, like insurance, require strict contracts that provide discipline in terms of when and how resources are available and can be used. Others, like reserve funds, are more difficult to protect from opportunistic behaviors.

The trade-offs in these different dimensions mean that a package of tools is more efficient than a single instrument. Expensive instruments, such as reinsurance, can be a useful component of this package, allowing governments to meet immediate needs after a major event, or providing discipline in the use of the large financial resources needed after a big shock. Some tools are better for covering the (relatively small) short-term liquidity needs for managing a crisis; others are better for larger, longer-term reconstruction needs. Some are better for frequent, low-intensity events, while others are better for managing massive shocks. *Figure 19* provides a schematic view of the adequacy of these instruments for hazards of different magnitudes and probability and for different time horizons.

Clarke et al. (2016a) provide a framework and methodology for designing a multi-instrument strategy. The optimal choice will vary by country. *Figure 20* illustrates how different financial instruments can be combined for financing the shock-responsive scalability component of Ethiopia's Productive Safety Net Programme (Clarke et al. 2016a). More specifically, it shows the average cost of different combinations of instruments as well as the cost for 1-in-5 and 1-in-30-year events.

FIGURE 19 >>

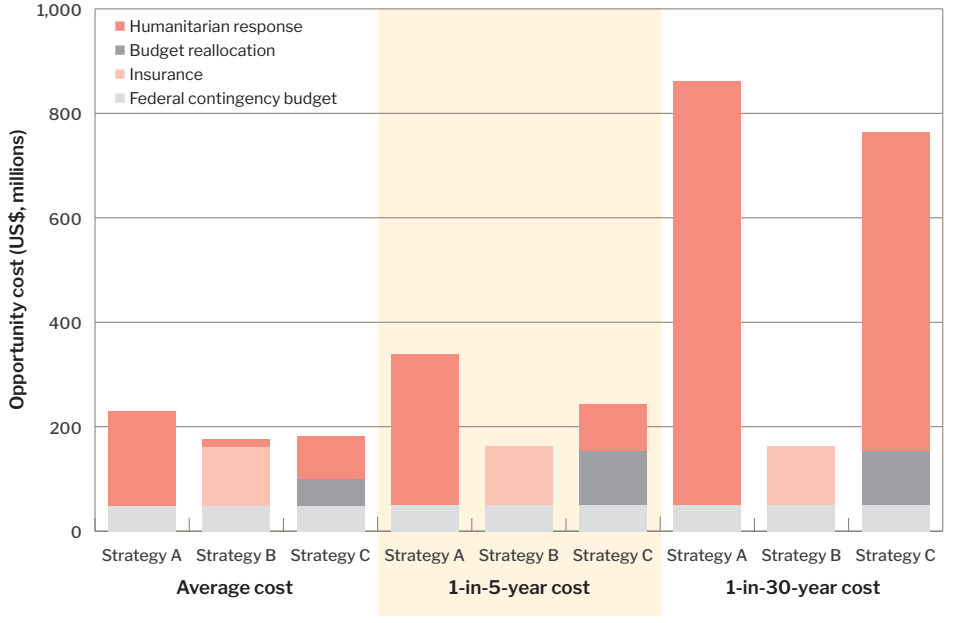
Financing instruments to cover contingent liabilities from natural disasters



Source: World Bank 2017.
Note: IDB = Inter-American Development Bank; JICA = Japan International Development Cooperation Agency; IDA = International Development Association.

FIGURE 20 >>

Comparing risk financing scale-up strategies in Ethiopia at different probabilities of occurrence



Source: Clarke et al. 2016a.
Note: "Humanitarian response" represents costs not covered by government tools that need to be covered by humanitarian actors or foreign aid.

Expenditure-side challenges and solutions

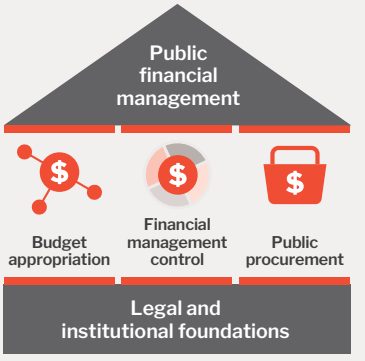
The value of mobilizing financial resources depends on the ability to spend them quickly and efficiently. Adaptive social protection is useful here because it ensures that all the systems and decision-making rules and procedures are in place before a disaster hits. For other emergency spending and reconstruction finance, timeliness requires an adapted PFM system and good contingency plans—for example, with pre-approved contracts to accelerate the procurement of urgent tasks such as debris removal.

Public spending in postdisaster situations faces specific challenges, due to the urgency of needs and the direct effects of disasters on normal government functioning. April and Sutherland (2019) provide an overview of the core principles of the PD-PFM Review.

The PD-PFM Review is an analytical instrument that seeks to help countries build resilient, responsive PFM systems. It does this by pinpointing critical PFM policies, practices, and procedures that governments can strengthen to improve their capability to respond more efficiently and effectively to natural disasters and other catastrophic events, without losing integrity and accountability. The PD-PFM Review focuses on four key elements of the PFM system: legal and institutional foundations, budget appropriation, financial management control, and public procurement (*figure 21*). A short summary of a PFM assessment of Saint Lucia highlights the main barriers to a quick disaster response and opportunities to improve existing systems (World Bank 2018).

FIGURE 21 >>

Core module of the Post-Disaster Public Finance Management Review



Source: April and Sutherland 2019.

One of the values of contingency plans and instruments—including those on the spending side, such as adaptive social protection—is that they allow for careful design before a crisis. This ensures that all due processes can be followed and rapid execution during an emergency (Hallegatte and Rentschler 2018). In the absence of advance preparation, governments—and ministries of finance in particular—face difficult trade-offs between respecting due process and providing swift support provided to the population. This often results in a delay in support provision (see case studies in Hallegatte et al. 2015), which can be very costly for the affected population (Clarke and Dercon 2016).

ACTION 4.3 >>

Anticipate and plan for long-term macroeconomic impacts

LEAD MINISTRY: *Finance*

Action 4.2 focused on the most efficient and cost-effective response to a single disaster as an independent event. But climate change will increase the frequency of such events, affecting the cost and benefits of these financial tools and their impact on public finance and debt. Climate change will also provoke other long-term changes in tax revenues and spending needs, with additional implications for economic growth and public finances. It is important for governments to understand these risks and construct an appropriate response strategy. However, it is also essential to keep in mind that current tools and knowledge do not allow for precise and reliable estimates of future macroeconomic impacts. Different approaches lead to radically different results and all methodologies ignore many possible climate change impacts.

TAKING ACTION >>

Sample targets and indicators

- Sector-level adaptation plans collected, harmonized, and costed, and an estimate of public adaptation spending needs produced
- Long-term plan to diversify tax revenues away from vulnerable sectors approved
- Climate and disaster impacts included in debt sustainability assessment or financial sector assessment program
- Share of tax revenues originating from high-vulnerability sectors

Macrofiscal risk assessment can be a standalone analysis (such as with the World Bank–IMF Climate Change Policy Assessments) or embedded into other long-term, macro-level assessments. At least two such assessments—both joint World Bank-IMF initiatives—have already started to include climate considerations, such as disaster and climate risks:

- **Debt Sustainability Analysis**,[29] which can include macrofiscal risks of climate change impacts, and mitigation and adaptation plans
- **Financial Sector Assessment Program**,[30] which can include climate and disaster risks in the financial sector assessment, especially in stress testing exercises.

Whichever approach governments choose to use, looking at these long-term effects will mean exploring long-term growth impacts and their consequences on public finances.

Explore the possible impact on long-term GDP growth

Building on sector-level assessment and analyses of physical risks, modeling

exercises can aggregate the possible impacts of climate change to estimate total impacts on macroeconomic variables, such as GDP, debt level, or trade balance, allowing governments to consider and plan for these longer-term effects (*toolbox I*).

The use of macroeconomic models, which are necessarily simpler in their representation of sectoral impacts, should be reserved for informing macroeconomic decisions, such as long-term debt sustainability. Considering the complexity of the issue and the many channels through which climate change can affect macroeconomic variables, results will always be highly uncertain. Many factors that can affect macroeconomic variables are difficult to model, and there is often little consensus on how best to do it (Bolton et al. 2020; Stern 2013; Pindyck 2013). Results should therefore be treated with a lot of caution and never be used as forecasts.

When it is possible to work at sector level and with simpler models—for example, to design a government-wide financial protection strategy—it is preferable to use the simpler models, even if they do not include all possible feedbacks. For macroeconomic issues that require aggregation at macroeconomic level, it is recommended to use multiple scenarios, to cover uncertainty in climate change impacts as much as possible.

It is also important to consider that GDP impacts do not fully capture the severity of climate change impacts and cannot be used directly in a cost-benefit analysis of climate policies (IPCC 2014; Dennig et al. 2015; Hallegatte and Rozenberg 2017; Hallegatte at al. 2016a). There are several issues around using usual economic aggregates—and GDP in particular—as the unique metric for climate change damages:

- GDP does not measure consumption or societal well-being. Disasters—hurricanes in particular—can increase GDP growth and reduce well-being, if increased risk leads to more precautionary savings (Bakkensen and Barrage 2018). Increasing investment in and consumption of defensive expenditure—for example, by building dikes and using air conditioning—may increase GDP without increasing societal well-being.

- Long-term averages are not a good measure of the impact of repeated shocks. In the US, a small decrease in productivity across all regions and sectors or one Katrina-like disaster per year can lead to the same 1 percent loss of GDP. But the latter has a bigger impact on well-being, as losses are concentrated on a small population.

- National or regional aggregates can miss impact on the poorest. A major impact on poor people is compatible with small impacts on GDP (Hallegatte et al. 2015, 2016b; Hallegatte and Rozenberg 2017) because in

most countries, poor people represent a tiny share of income and wealth. If climate change impacts are concentrated on the poor, then GDP may not be an appropriate measure, and other metrics may be preferable (see also *toolbox K*).

Evaluate impacts on tax revenues, spending needs, and public debt sustainability

Tax revenues: By impacting economic growth in some sectors, climate change will impact tax revenues. These risks are particularly large if the tax base is very narrow—if, for example, it is concentrated on a few commodity exports.

Governments can simplistically estimate the impact of changes in GDP, trade, and employment on tax revenues by assuming a linear relationship between value added and tax revenues. Or they can use a more realistic representation of the tax system, applying different rates onto different income sources and sectors. For local communities, tax revenues are partly linked to land values, either because a tax is raised when there is a transaction or because property taxes are indexed on home values. Estimating the impact of climate change on these taxes would require a detailed spatial analysis of expected local-level climate change impacts.

Based on expected impact on tax revenues, a government may want to explore options to diversify the tax base. For example, introducing value-added, income or capital gain taxes can make tax collection less sensitive to the impacts of disaster and climate change on one major sector. Since adjusting the tax system takes time and is always sensitive, it is preferable for governments to explore and act on these issues before their revenues start to decline due to climate change impacts.

Additional expenditure and adaptation needs: Climate and disaster impacts affect public expenditure in two ways. When sudden shocks—for example, a major natural disaster—destroy capital and production, governments need to spend significant amounts on supporting the population and funding reconstruction. They also need to make additional public investments to adapt infrastructure and other public assets and help private actors adapt.

It is difficult to estimate the amount needed to adapt to climate change (often referred to "adaptation needs"). This is partly down to definitional issues, as there is no easy way to separate development needs—such as providing universal access to improved water and sanitation—from adaptation needs.

Some studies have focused on the incremental costs that result from climate change, accounting for the fact that natural disasters and climate change make some investments more expensive. Hallegatte et al. (2019) estimate that low- and middle-income countries will need to invest $11–65 billion a year to increase the resilience of their infrastructure systems (water and sanitation, power, transport).

At least two-thirds of these costs are for infrastructure assets that are typically funded by the public sector. This represents only 3 percent of total infrastructure investment needs in these countries.

Other estimates lump development and adaptation needs together. Fiji, for example, will need up to F$9.3 billion (almost 100 percent of GDP) in investments over the next 10 years to strengthen its resilience to climate change and natural hazards for decades to come (*table 4*), but many of these investments would have been required even in the absence of climate change.

TABLE 4 >>

Summary of investment needs and recurrent costs for Fiji's full adaptation plan

	INVESTMENT NEEDS (F$, MILLIONS)			RECURRENT COSTS (F$, MILLIONS)		
Sector	**Planned**	**New**	**Total**	**Planned**	**New**	**Total**
Housing/land use	63	152	215			
Hazard management	n/a	2,106	2,106			
Transport	3,098	1,591	4,689			
Energy	271	175	446			
Water	685	447	1,132			175–440
Health/education	5	568	573			
Environment	55	22	77			
Agriculture	11	3	14			
Fisheries	6	14	20			
Social protection				47	4	51
Grand Total	**4,194**	**5,078**	**9,272**			**226–491**

Source: Government of Fiji and World Bank 2017.

Many countries have included adaptation actions in their nationally determined contribution (NDC) to the Paris Agreement (Hallegatte et al. 2018). Fifty countries (totaling 2.4 billion people) have provided an estimate of the cost of the adaptation component of their NDC, with a time horizon going from today to 2050, depending on the country. However, NDC adaptation components are generally poor and, as such, do not form a rigorous basis for estimating national adaptation needs and priorities. Total adaptation costs in the 50 available NDCs add up to $39 billion a year, with annual per capita costs ranging from $0.29 (Burundi) to $594 (Namibia). This huge difference across countries arises from the NDC design process rather than any difference in vulnerability or adaptation needs. The average per capita cost is $16 a year. Assuming that these estimates are consistent with actual needs—a strong assumption, considering how simple and partial most NDCs are, especially in their adaptation component—the global adaptation need would be approximately $115 billion a year.

And while solid estimates have been produced for some sectors (such as coastal protection), there is great uncertainty in others (such as agriculture) (Chambwera et al. 2014). Global estimates are based on methodologies that can provide orders of magnitude but are too simple to provide a solid basis for a country-driven policy response.

Long-term considerations and impact on debt: Reduced revenues and increased expenditure are likely to lead to higher debt levels. There is empirical evidence that debt increases after natural disasters (Lis and Nickel 2010; Melecky and Raddatz 2011). Gerling (2017) also found that the impact of disasters on deficit and debt is driven more by governments' response in terms of spending and tax rates, than by the impact of the disaster. High debt leads to higher interest rates and lower credit scores. This results in higher budget deficits and causes debt to increase further, creating a vicious cycle that threatens debt sustainability (Borensztein et al. 2009; Koetsier 2017). High debt also discourages private investment and constrains fiscal flexibility. More specifically, looking at debt default, Klomp and De Haan (2015) showed that investors see natural disasters as an adverse shock that makes government debt less sustainable and may eventually trigger a sovereign default. And Klomp (2017) shows that the probability of a sovereign debt default increases by about three percentage points after major earthquakes and storms.

Trade balance: When countries depend on climate-sensitive sectors for exports, climate shocks can have negative impacts on their trade balance. In Argentina, the 2017 drought damaged exports, as production in the oilseeds sector—which represents around one-third of Argentina's total exports—fell by 13 percent the following year. The total value of primary exports decreased by 5.4 percent, as the 11.2 percent fall in quantities was partially compensated by an increase in prices (Argentina has such a large market share in the soybean market that it can influence global prices). Sudden shocks in the trade balance can force countries to increase their capital imports, which can damage interest rates and credit scores.

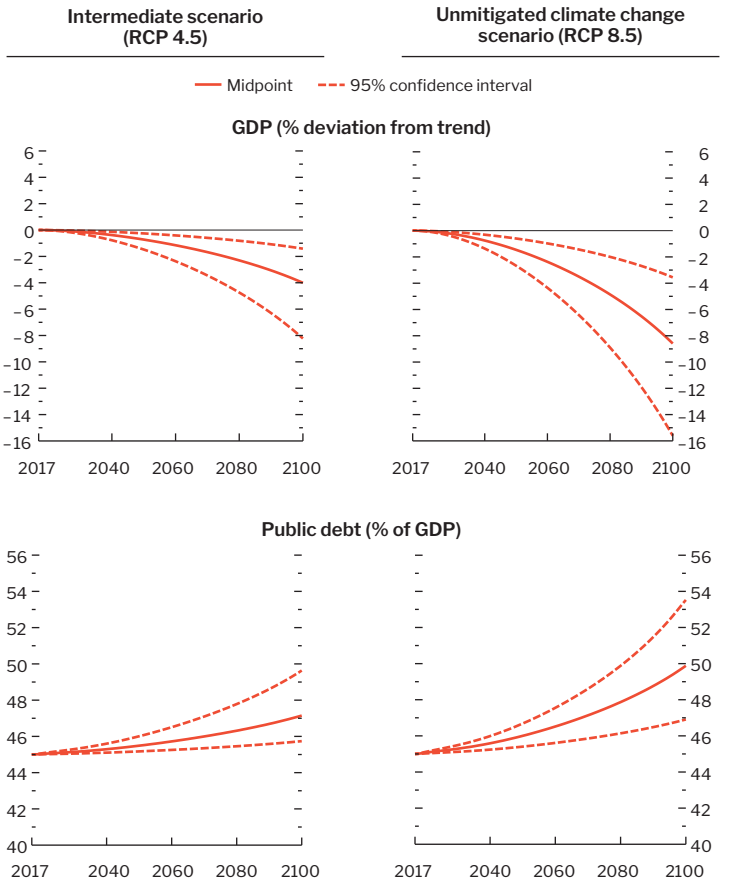
Planners can use different tools to anticipate the implications of the macroeconomic impacts of climate change on deficits and debt levels. This includes simple growth models—as used by the IMF to investigate long-term impacts on GDP and public debt in various climate change scenarios (*figure 22*)—or the World Bank's Macro-Fiscal Model. This macrostructural model is widely used by central banks and ministries of finance to explore long-term scenarios including climate change impacts and help include climate considerations into long-term debt sustainability assessments.

Based on these findings and acknowledging the uncertainty around GDP and debt projections, governments can start identifying long-term strategies to minimize risks. Such strategies can range from making changes in tax revenues or government spending to ensure long-term sustainability or developing or supporting sectoral targeted action plans to reduce the sources of these risks.

This includes the policies described in *Priority Areas 1–3*, such as changes in agricultural production, land use and building regulations.

FIGURE 22 >>

Impact of climate change on GDP and public debt in two emission scenarios

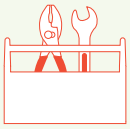


Source: IMF 2017.
Note: RCP = representative concentration pathway.

TAKING ACTION >>

Toolbox I

Identifying the impacts of climate change on GDP



Although many assessments look at sectoral impacts of and adaptation options for climate change, few are economy-wide. This is directly due to the challenges of modeling all sectors and then aggregating results into an economy-wide model without losing the complexity of the sector-level results. The literature proposes two main approaches.

Integrated assessment models

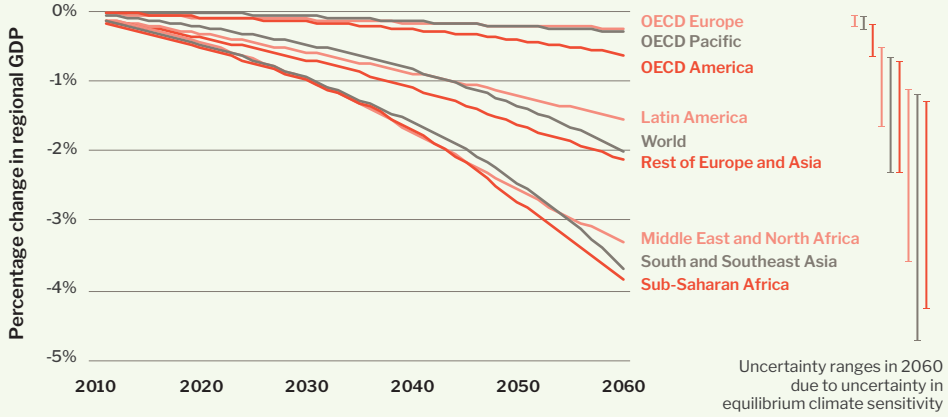
Following up on initial work (Nordhaus 1994; Tol 2002), a few integrated assessment models estimate the impact of climate change on economic growth, GDP, and other economic variables. For example, Dellink et al. 2019, use models based on simple damage functions, calibrated on sectoral studies to provide estimates in large regions to 2060 (*figure I.1*).

While these models provide useful benchmarks and can identify the channels through which climate change can affect GDP growth—for example, by comparing impacts through agriculture and impacts through labor productivity—they also have limitations (as also shown in *toolbox B* with a focus on poverty).

First, integrated assessment models do not represent all important mechanisms. They are missing many important channels through which climate change can affect growth. For example, climate change may affect access to micronutrients, which would have implications on children's physical and cognitive development and future labor productivity. There is also evidence that disasters have most impact on economic growth when they create political instability or conflicts (Cavallo et al. 2013). However, neither of these are included in any current model.

FIGURE I.1 >>

Projected impact of climate change on regional GDP, 2010–2060



Source: Dellink et al. 2019.

Second, and most importantly, their results depend on strong assumptions about sector and country adaptation capacity. Indeed, a physical change—say, a rise in sea level—may or may not lead to more floods, depending on whether a city regularly upgrades its flood defenses. While it is possible to model physical impacts based on physical laws, the ability of institutions, agencies, firms, and households to respond to changes in environmental conditions is more difficult to predict over the long term. So economic outcomes often depend more on hypotheses of adaptation capacity and performance than on physical climate change impacts.[31]

Finally, several papers have flagged that the response in terms of savings and investments can be as important as direct climate change impacts in determining effects on growth (Fankhauser and Tol 2005; Bakkensen and Barrage 2018). The cumulative effect of individual disasters can also lead to tipping points in the economic system, especially when disasters wreak more damage than the economy can efficiently cope with (Hallegatte et al. 2007b). As a result, the way the models endogenize economic growth (for example, with exogenous or endogenous technical change) and represent behaviors (for example, with optimal investment responses and perfect foresight or myopic behaviors) is critical in determining final results. The macroeconomic modeling debates are therefore also relevant for assessing the macroeconomic cost of climate change.

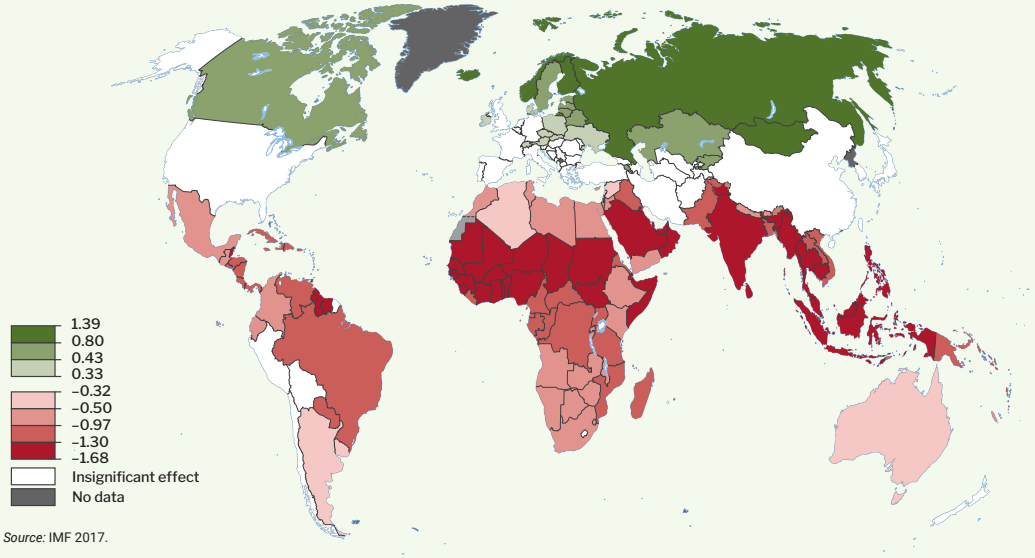
Empirical studies

Other approaches are based on empirical studies (see, for example, IMF 2017; Burke et al. 2015; Hsiang et al. 2017; Kahn et al. 2019). These analyses use past changes in temperature and precipitation such as year-to-year changes in average temperature or more granular indices and their measured impacts on GDP or GDP growth to anticipate future impacts of climate change. ***Figure I.2*** shows the effect a 1°C increase in temperature has on GDP, using such an approach.

The strengths and weaknesses of this approach are different from those of modeling approaches. One advantage is that, being based on historical data, it includes all channels of interaction between temperature and precipitation changes and GDP. But it has other limitations (Kolstad and Moore 2020). Because it uses year-to-year changes to extrapolate decadal changes, it can overestimate or underestimate impacts.

FIGURE I.2 >>

Effect of a 1°C increase in temperature on real per capita output (percent)



Source: IMF 2017.

Overestimating happens because adaptation options like upgrading infrastructure systems are available in the long term, but not the short term. The difference between short- and long-term impacts and the role of adaptation to evolving climate conditions has been a topic of intense debate (Kolstad and Moore 2020). Deryugina and Hsiang (2017) have shown conditions under which the economic impact of a marginal change in short-term weather is equal (at the first order) to the impact of a marginal change in long-term climate (in which case, adaptation is a second-order mechanism). However, these conditions are very restrictive: adaptation options need to be defined over a continuum (no discrete options) and local economies need to be optimally adapted to their current climate, at each point in time used for calibration.

These assumptions appear unrealistic in the context of rapidly evolving climate, so there may be a significant gap between short- and long-term impacts. In efforts to explore the impacts of longer-term changes in climate conditions, other authors have applied econometric techniques to past changes in climate over decades (15 years in the case of Dell et al. 2012), finding impacts that are relatively similar to short-term impacts.

Underestimating happens because some activities, ecosystems or economic sectors may be able to cope with one bad year but will not be able to adjust to permanent change. Most studies also only consider temperature and precipitation, so this approach does not capture correlated or more complicated changes such as shifts in extreme event frequency and intensity. Nor do they include other types of impact, such as long-term sea level rise. Finally, simultaneous changes in multiple climate variables may lead to impacts that are different from the sum of independent changes.

By definition, this approach cannot include any impacts that did not already occur in the past, which means that it does not consider some of the most worrisome climate change impacts. Work in climate sciences to identify climate analogues—or find a climate today that is similar to the climate expected tomorrow in Location X—has concluded that many of the future climates simply do not exist today. For example, even if one can find a place that has in 2020 the temperature one will find in Barcelona in 2100, it will not have the same precipitation patterns (Hallegatte et al. 2007a). Also, empirical studies cannot include the effect of unprecedented temperature levels, a possible collapse in local biodiversity and ecosystems, or reaching physiological limits when temperatures exceed certain thresholds. ***Figure I.2*** suggests that there will be significant benefits in high latitudes, but it is unclear whether the analysis captures the negative impacts—such as wildfires and new forest pests in Canada and Russia, the need to retrofit infrastructure built on melting permafrost and extreme heat waves in cities—that are also expected there.

Finally, the approach remains sensitive to the specification, which explains why different analyses have led to different results. Whether studies assume that climate change will affect GDP levels (temporary shocks) or GDP growth (permanent shocks that will accumulate over time) is particularly important. Burke et al. (2015), for example, assume that the effect of climate change on GDP is permanent and cumulative, affecting growth rates and not GDP levels, which largely explains the large magnitude of the impact they project for the end of the century.

Overall, using empirical analyses to assess climate change impacts beyond the next few decades, when changes are no longer expected to be marginal, should be done with great care.

ACTION 4.4 >>

Communicate and mitigate disaster and climate risk exposure of the financial sector and pension systems

LEAD MINISTRY: *Finance*

One role of the financial system is to help the economy manage risks. But a history of financial crises has shown that it can also magnify the impact of a shock, if this shock exceeds the financial sector's capacity (World Bank 2013). Countries must therefore assess their financial system's ability to absorb climate shocks, to ensure it can play the role of adaptation facilitator and not create a crisis.

Climate change and natural disasters can impact the financial sector balance sheets through four overlapping channels (Feyen et al. 2020).

- **Operational risk:** This includes damages to financial infrastructure, branches, and office buildings.
- **Market and liquidity risk:** Re-assessing financial projections and risk premiums will impact asset valuations. This could trigger pro-cyclical materialization of losses and tighter funding and liquidity conditions, particularly when it is due to a disaster. Droughts and other natural disasters can also drive up commodity and energy prices.
- **Credit risk:** Damage to infrastructure, higher prices, lower productivity and so on can adversely affect borrower repayment capacity. Lower collateral prices amplify credit risk, particularly when uninsured. In natural disaster-prone economies, sovereign credit risks could adversely interact with financial sector risks.
- **Underwriting risk:** Physical risks can impede the pricing accuracy of (re) insurance liabilities. This can cause losses to insurers, raise premiums, or even render some activities or geographies uninsurable, raising fiscal costs as governments are forced to backstop losses. Lower availability of insurance can have important repercussions on investments and loans.

TAKING ACTION >>

Sample targets and indicators

- Regulations of banks, insurers, and large investors include specific disaster and climate risk requirements
- All banks, insurers, and large investors conduct stress tests for climate and disaster risks, including at least two climate scenarios
- All banks, insurers, and large investors provide a quantified estimate of their exposure to natural hazards

Countries can manage these impacts by investing in data, knowledge and modeling capacity, planning and budgeting for disasters, and improving coordination between sectors. They may also need to issue specific regulations to incentivize their financial systems to assess climate-related risks.

Banks: Climate change impacts can increase operational, credit, market, and liquidity risks for banks. Weather-related shocks could trigger losses due to higher defaults and lower collateral valuations, particularly if people are uninsured. Weather-related shocks can also damage payment systems and bank branches.

Institutional investors: Pension funds, life insurance companies and other institutional investors could be disproportionately affected by climate change, given their longer-term investment horizons. Climate change can trigger non-linear impacts such as food security crises, social and political unrest, biodiversity loss and the sudden reevaluation of assets located in risky areas, so investors must design investment strategies that can manage these (uncertain) long-term risks.

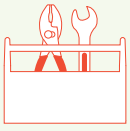
Insurers: Climate change has implications for insurance companies on both sides of the balance sheet: as investors and as underwriters. As investors, they face similar risks as other asset managers. Like institutional investors, insurers may be disproportionally affected by the long-term nature of their equity and infrastructure investments. As underwriters, pricing risks may arise from the changing risk profiles of insured assets (Feyen et al. 2020). Climate change introduces deep uncertainty in catastrophe models, so it is harder to make valid predictions about expected losses and therefore price some insurance products. Some risks may become impossible to insure. At the same time, some insurers might find opportunities for innovative insurance offerings. Insurance companies may also be affected by increased liability risks due to climate change, as part of negligence policies or through litigation—for example, related to inadequate disclosure of climate risks (IAIS/SIF 2018).

Real estate and housing values: Risks related to real estate and housing are included in credit risks and mostly borne by the banking system. But it is worth assessing them separately due to their importance (especially in banks' balance sheets) and exposure to climate change risks. Because natural risks are at least partly included in housing values (Beltrán et al. 2018; Hallstrom and Smith 2005; Erman et al. 2018), a rapid reevaluation of risks from natural hazards—which has happened after big disasters (see, for example, Hallstrom and Smith 2005)—could lead to brutal changes in housing values, significantly impacting banks' portfolios and risk profiles.

TAKING ACTION >>

Toolbox J

Stress testing financial institutions for disaster and climate risks



Stress testing is common in the financial sector. In practice, it is possible to estimate the effect of some negative but plausible socioeconomic scenarios—for example, a 3 percent drop in GDP—on individual financial firms' portfolios or across the sector, providing insights on vulnerability in the firm or sector. Some regulations mandate that financial firms demonstrate their ability to weather an economic crisis or shock through such a stress test.

Stress testing is now also used to investigate climate change-related risks, though this is mostly for so-called "transition risks", which are those associated with policies enacted to reduce greenhouse gas emissions. For example, Battiston et al. (2017) link global macroeconomic scenarios to major commercial banks' portfolios to estimate their exposure to rapid decarbonization.

Stress testing the financial system to the physical risks of climate change, however, is more challenging, because the impacts of climate change are more spatially heterogenous than the impacts of climate policies. Estimating a company's vulnerability would require considering the localization of every production unit. But this information is not enough, as a well-designed asset in a high-risk area can be very resilient. And information on how assets are designed—for example, whether a factory can cope with heavy rain—is simply not available, even to companies themselves. A firm's or a sector's vulnerability also depends on its suppliers, clients, and the transport and communication networks that their relationships depend on (Colon et al. 2019). And while firms usually know their direct suppliers, only the biggest ones have the resources and capacity to understand their full supply chain and its vulnerability. Finally, uncertainty around future impacts is so large that any single scenario is unlikely to capture a firm's or a sector's full vulnerability to climate change.

In this context, government and financial system regulators have two (complementary) options:

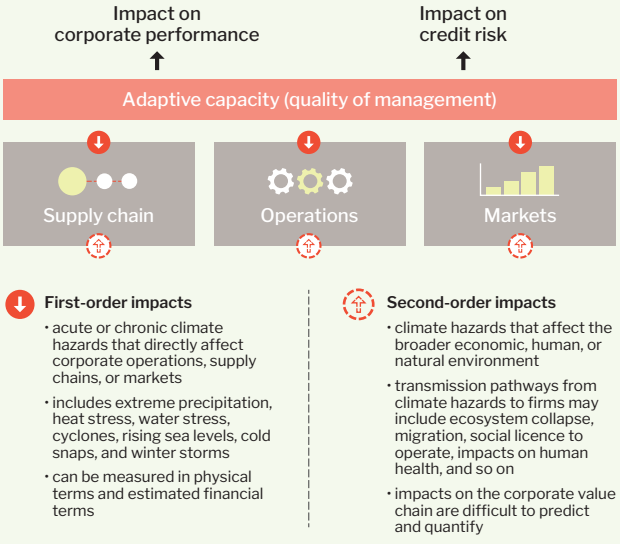
- **Top-down stress tests:** First-order assessments based on sector-level vulnerability to climate change—for example, vulnerability of Uganda's coffee production—assuming that all firms within a sector have a similar vulnerability. This approach provides insight on an economy's vulnerability based on its sectoral structure, disregarding heterogeneity across firms and individual firms' ability to adjust to a shock by diversifying to other activities or developing new technologies.

- **Bottom-up stress tests:** Firms and financial actors conduct their own risk assessments, based on their in-depth knowledge of their production systems and supply chains and publicly available data on climate change and natural hazards, building knowledge from the bottom up that can be aggregated over time.

A firm's or a sector's vulnerability to climate change will depend on its ability to respond to anticipated and non-anticipated impacts of climate change. Top-down and bottom-up stress tests should therefore go beyond the direct physical impacts, to assess various firms' and financial actors' ability to absorb shocks and adapt to change. For example, a firm that is heavily exposed to major hazards but has well-developed contingency plans and is well insured may be less at risk than a firm that is less exposed but not prepared. A European Bank of Reconstruction and Development and Global Center for Adaptation report recommends that all firms and private actors assess how climate risks may affect their value chains and operations, and put in place appropriate risk management systems (EBRD and GCECA 2018, see *figure J.1*).

FIGURE J.1 >>

How climate change affects corporate value chains



Source: EBRD and GCECA 2018.

Information on firms' exposure to disaster and climate risks—including through stress tests (*toolbox J*)—can help investors and decision makers adjust investments and portfolios to reduce exposure and future losses. Transparency on disaster and climate risks, as advocated by the Task Force for Climate-related Financial Disclosure,[1] would also send a strong signal to firms' management that this is a topic of concern for investors and create an incentive for all firms to manage their long-term risks better.

In this domain, governments can lead the action through a law, or regulators who consider that climate change risks are part of their mandate due to their impact on financial stability can lead the action directly. One example of action through law is Article 173-VI of the French Energy Transition for Green Growth Act. Its objective is to influence decision making and directly promote adaptation and resilience while enabling public authorities, NGOs, thinktanks, and civil society more generally to have the information they need to influence investors. However, implementing the law has shown that reporting on exposure to climate and disaster risks is more challenging than reporting on carbon emissions, exposure to carbon pricing, and climate mitigation policies.

But regulators can act even in the absence of such an explicit mandate, on the basis of the impact of physical climate change risks on the financial system (for example, NGFS 2020). They could, for example, consider imposing appropriate requirements to ensure firms' risk management approaches adequately capture the different risk profiles of their investments with regard to natural hazards and other adaptation-relevant climate risks. Authorities can set out regulatory guidance or supervisory expectations to enhance firms' responses to these risks, addressing all aspects of firms' governance, risk management and disclosure practices. They should actively monitor the implementation of these expectations by integrating climate risk into existing regulatory frameworks. The Network for Greening the Financial System provides useful recommendations in its guide to regulators (NGFS 2020), focusing on identifying and quantifying exposures and risks, and managing these risks.

Requiring regulated entities to conduct climate-related stress testing or scenario analysis will enable firms to test their portfolios' resilience to physical climate risk and adaptation-related shocks. Taking a forward-looking approach will provide insights into their assets' longer-term risk profile, exposing potential future vulnerabilities in their business models. Using this to inform their strategic planning and decision making would increase the overall resilience of the financial system.

Over time, regulators may consider imposing additional capital requirements, should supervisory assessments conclude that firms fail to adequately address

climate risk. Shortcomings in risk management practices or a failure to reduce high-risk exposures may lead to a capital add-on under Basel regulations. Integrating climate risk into the direct risk-weighting of assets will require substantial further research to close significant data gaps, in addition to an agreed-upon climate risk-related classification system.

It is important to note that current methodologies for financial climate risk assessment and stress tests are crude, and their limits could have unintended effects. Many assessments are based solely on geographic localization—for example, whether a factory is in a flood zone. They do not consider whether the asset was designed and built to manage local hazards, because these data do not exist. This simplification means that a well-designed asset in a flood zone could be wrongly considered at high risk, despite all the project developer's efforts. This type of error could discourage the proper design of assets in at-risk areas and any form of investment in high-risk regions, including the poorest countries and communities. It could thus complicate efforts to reduce poverty and accelerate development, which should be the priority for reducing climate change vulnerability and impacts (see *Foundations*).

Application:

Prioritization, implementation, and monitoring progress

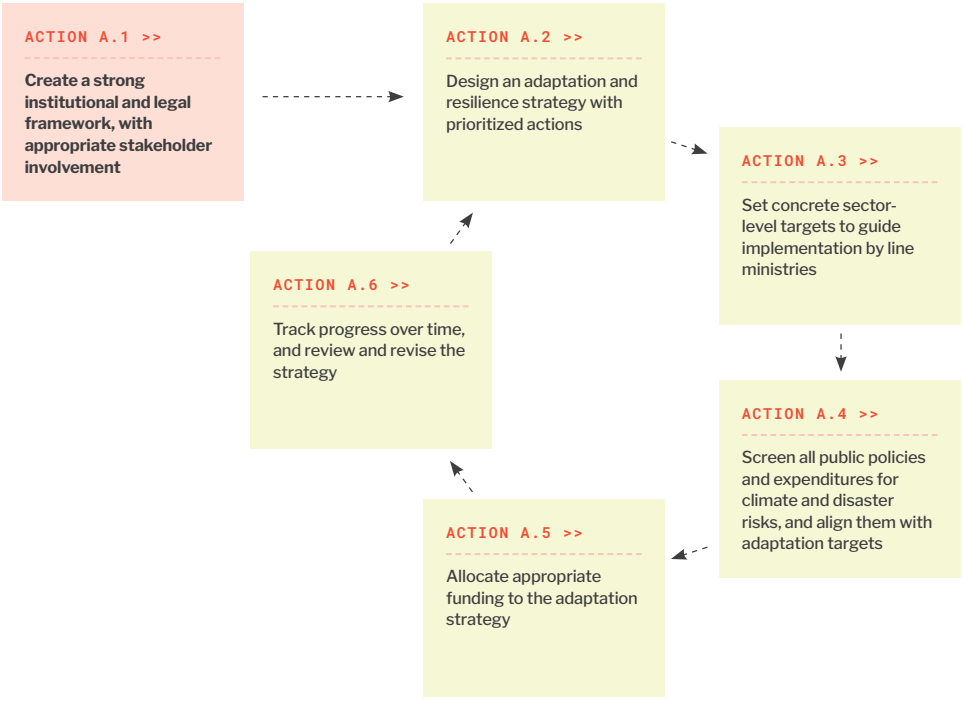
★ LEAD MINISTRIES:
Finance/ economy and ministry or agency in charge of climate change (often environment)

The earlier sections of this guide have argued that an effective climate change adaptation strategy needs to comprise measures to ensure a broad, productive, and inclusive development pathway (*Foundations*), and actions in four priority areas, covering the adaptation of people and firms (*Priority Area 1*); land use plans, public assets and services (*Priority Area 2*); residual risk management (*Priority Area 3*); and macrofiscal risk management (*Priority Area 4*).

To effectively implement these actions, governments must first establish the right institutional and legal framework for robust implementation (*Action A.1*) and then design a concrete multisectoral adaptation and resilience strategy that clearly identifies and prioritizes actions in line with available resources (*Action A.2*). A concrete set of intermediate targets and milestones is essential to implement the strategy in each sector (*Action A.3*). Governments should actively mainstream and integrate resilience in all public policies, rather than limit their consideration of resilience to climate-related actions (*Action A.4*). With priority actions defined, they need to raise, allocate and track adequate financial resources to implement the strategy (*Action A.5*). Finally, once implementation is underway and new information and challenges emerge, they will need to make regular strategy adjustments and course corrections to strengthen the approach (*Action A.6*). Overall, the key to successful implementation is ensuring that all government departments adopt and mainstream the strategy in all their decisions, and that governments continuously monitor and evaluate the impact of their decisions and actions, so they can address any challenges and adjust their actions accordingly. *Figure 23* illustrates how these actions link together.

FIGURE 23 >>

Six actions to effectively implement an adaptation and resilience strategy



ACTION A.1 >>

Create a strong institutional and legal framework, with appropriate stakeholder involvement

The policy actions discussed across this report require an appropriate institutional and legal framework. Such changes are usually introduced through climate change framework laws (see World Bank 2020b). These framework laws have multiple roles, from establishing short- and long-term climate change targets to creating the institutional and legal framework needed to ensure that climate change is properly addressed. There are many required changes, which are discussed in multiple places in this report. For example, most climate change framework laws have a "knowledge" or "data" component, to ensure that climate change-related information is available to public and private decision makers (*Action 1.1*). There are three important components for creating a strong institutional and legal framework:

1. **Adjusting the mandate of existing ministries, agencies or institutions:** Considering resilience and climate and disaster vulnerability must be made part of existing mandates, to ensure these issues become part of good governance. This is particularly important for infrastructure services (*Action 2.2*)—for example, regulating public and private power providers can help increase power systems' resilience to storms and drought (see Hallegatte et al. 2019)—and when developing rules for budget preparation and discussions (*Action 4.1*) and financial or banking regulations (*Action 4.4*) (NGFS 2020). Considering climate and disaster risks in land use planning (*Action 2.3*) should also be included in the mandate of municipalities or authorities in charge of developing land use plans and delivering building permits.

2. **Creating new agencies or committees where needed:** Although it is generally preferable to build on existing institutional design to prevent conflicts and contain costs, governments will sometimes have to create new agencies or institutions to implement an action. But while infrastructure resilience may be coordinated by a small committee placed under the prime minister or minister of economy, the design and implementation of the measures is better left to existing regulators of infrastructure services. Leaving, for example, regulations on the resilience of the power system to the regulator of said power system will prevent cross-agency conflicts and improve consistency in regulations and investments. But where there is an institutional vacuum—for example, an absence of watershed agencies to manage water allocation at the right spatial scale—the challenges around climate change and natural risks provide additional rationale for strengthening institutions, including by creating new agencies.

3. **Establishing an overarching coordinating body:** Designing and implementing an adaptation and resilience strategy often requires a coordination mechanism to ensure consistency in actions across sectors and ministries (horizontal coordination) and across national, regional and local tiers of government (vertical coordination) (World Bank 2020b). Ensuring coordinated action across entities can help capture synergies and take care of important roles like M&E and progress tracking. To be effective, the mechanism must include representation at a senior (typically agency head) level, to give it the necessary authority and access to the required resources. Since adaptation and resilience are highly cross-sectoral, the mechanism is also best placed at the center of government—for example, with a committee chaired by the presidency or prime minister's office, or the head of a planning or central finance agency. Several proposals exist, including the creation of a national risk board or chief risk officers (World Bank 2013).

The UK's Committee on Climate Change, in charge of maintaining political commitment to climate goals and adherence to the Climate Change Act, comprises eight experts from academia, business, civil society, and politics. Its Adaptation Sub-Committee has six members. The Climate Change Act requires Parliament to have access to the committee's advice and obliges the government to respond to the committee's recommendations—in other words, the government cannot ignore the committee's advice. The committee has an effective public communications function and its advice is regularly referred to in the media.

Kenya's Climate Change Act 2016 establishes a National Climate Change Council chaired by the president as an overarching national climate change coordination mechanism and the lead agency in charge of climate change plans and actions.[33] The act outlines duties for all state ministries, departments and agencies, establishes a climate change unit and appoints a senior official to coordinate mainstreaming climate change into sectoral strategies. The council reports annually on the implementation of climate change duties and functions.

Stakeholder involvement is an important dimension of any institutional setup. It is critical at each stage of the adaptation and resilience process, including:

- **Strategy design**, identifying available options and contributing to assessment and prioritization, making sure that the concerns and priorities of various groups are given due consideration

- **Implementation**, since the adaptation and resilience strategy will be largely implemented by private actors

» **M&E**, particularly by flagging unintended side-effects that the established set of indicators would miss—for example, an adaptation and resilience strategy may have unintended negative impacts on housing affordability, and if the M&E framework does not include the right indicator to identify this problem, it would need stakeholders to raise it.

Countries have used different approaches for stakeholder involvement, depending on their political system and context. Some—like the recent citizens' convention for ecological transition in France—have punctual stakeholder consultations when plans are designed.[34] Others have created permanent bodies, such as Colombia's National Council for Climate Change, which ensures effective coordination between the government and unions, civil society, Congress and academia,[35] Ireland's Citizens' Assembly on Climate Change,[36] and Costa Rica's Citizen Advisory Council and Citizen Consultative Council on Climate Change.[37] Peru's Framework Law on Climate Change includes specific provision on the rights and participation of indigenous stakeholders.[38]

ACTION A.2 >>

Design an adaptation and resilience strategy with prioritized actions

After establishing the appropriate institutional and legal framework for adaptation and resilience, governments can design their adaptation and resilience strategy—with details of interventions, investments, and policies—building on the agencies and participatory instruments available.

Since no country has the capacity to implement in parallel all desirable measures and interventions for increasing resilience and reducing future disaster and climate change losses, one of the strategy's (and the finance ministry's) main roles is prioritizing interventions, to ensure limited resources go to the best opportunities. Even projects that are economically beneficial—with a positive NPV—may be impossible to fund with available resources.

Ministries can use multiple tools to prioritize investments in climate change adaptation, from traditional methods for appraising investments to more holistic approaches that account for societal benefits and uncertainty (*toolbox K*). Indeed, tools for prioritizing and selecting investments are crucial for a robust adaptation strategy. For example, some interventions may not be justified on the basis of pure economics, but are essential for protecting populations and communities from unacceptable impacts.

Prioritization methodologies allow decision makers to identify a small subset of interventions that are most likely to deliver large net benefits. But when selecting short-term priorities, they should also consider the long term. Resilience-boosting interventions implemented over the lifetime of an adaptation plan (say, five years) should be considered as the first steps within a decades-long strategy. Selected short-term interventions need to:

- **Build the foundation for future interventions**—for example, by establishing the right institutions and governance systems
- **Demonstrate the value of investing in resilience**—for example, by supporting pilot and demonstration projects that can then be scaled up and generalized
- **Prevent irreversible impacts**—for example, by implementing interventions that cannot wait.

This last consideration is crucial in rapidly growing countries. As they build new infrastructure and buildings, they have an opportunity to build right in the first place and prevent large retrofit costs in a few decades. The World Bank's *Lifelines* report estimates that delaying action in improving the resilience of new

infrastructure by one year would cost low- and middle-income countries around $100 billion (Hallegatte et al. 2019).

A cascade of uncertainties characterizes all decisions that relate to climate change and long-term socioeconomic trends. Uncertainty about sea level rise, temperature, precipitation, and other climate factors—as well as socioeconomic change, political factors, disruptive new technologies, and behavioral change—all have tremendous implications for decision makers' short-term choices. Past evidence shows that our ability to predict the future is limited (Kahneman 2011; Silver 2012). Parties to a decision often also have competing priorities, beliefs, and preferences. And when parties do not know or cannot agree on the models that describe the key processes that shape the future, the probability distribution of key variables and parameters in these models, or the value of alternative outcomes, it leads to deep uncertainty (Lempert et al. 2003).

Traditional investment appraisal methods can be ill-suited for prioritizing adaptation investments in this context, especially when the uncertainties cannot be translated into probabilities of occurrence. Conventional cost-benefit analysis is particularly challenging in the presence of deep uncertainty, diverging worldviews, or disagreement among experts.

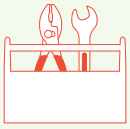
Against this context, new decision-making tools—such as decision trees and adaptive pathways—have been developed to make robust decisions that perform well across a wide range of future scenarios, preferences, and worldviews (*Toolbox K*). They are designed to deliver acceptable outcomes in the largest range of possible futures, instead of optimizing for one particular scenario (Haasnoot et al. 2013; Lempert and Groves 2010; Ray and Brown 2015).

Governments also need to consider the context of the COVID-19 crisis when prioritizing and financing an adaptation and resilience strategy. On the one hand, governments managing a health emergency have reduced capacity to design and implement complex policy changes or investments, their tax revenues have dropped, and they may want to focus on simpler and cheaper actions in the short term. On the other hand, their COVID-19 response may allow them to build long-term resilience to other shocks. For example, all countries have scaled up their social protection systems to protect their populations against the negative side-effects of COVID-19 containment measures. Ensuring the infrastructure for scaling up their social protection system stays in place after this crisis would build a country's resilience, by improving their ability to respond to the next emergency.

As the COVID-19 crisis gets under control, over a timeline that remains highly uncertain, countries may also implement recovery and stimulus packages to help restart the economy. *Spotlight 4* outlines a simple methodology for identifying measures that create an effective stimulus while also building long-term resilience.

TAKING ACTION >>
Toolbox K

Tools to prioritize adaptation and resilience interventions



Cost-benefit analysis, NPV, and rate of return

One traditional approach to selecting projects is using a cost-benefit analysis to calculate the NPV, benefit-cost ratio, or internal rate of return of various options, to select the best ones. A standard cost-benefit analysis would simply take the discounted sums of the costs and benefits over the project's lifetime and calculate either the NPV (as the benefits minus the costs) or the benefit-cost ratio (as the benefits divided by the costs).[39]

If the *NPV* is larger than zero, then the project delivers net benefits and is economically beneficial. The choice of the discount rate ρ and the pricing of non-market impacts—for example, when a project reduces mortality or morbidity—are complex questions that are well treated elsewhere (see, for example, Tan et al. 2001). Following World Bank guidance on the discount rate, we recommend that the discount rate ρ is based on normative considerations, while the opportunity cost of funds or financing costs should be considered directly as a project cost, not indirectly through the discount rate. This means that there may be more projects with a positive NPV than available resources to invest in them, and a positive NPV is a necessary—but not sufficient—criterion for implementing a project. Additional prioritization—for example, based on ranking benefit-cost ratios or NPV—is required.

In the case of adaptation and resilience, however, there are four additional complexities that traditional approaches are often ill-equipped to address:

- The benefits of increased resilience are not only avoided losses; higher resilience can also enable investments and development, creating more value than avoided losses alone (Tanner et al. 2015). Cost-benefit analyses too often consider only avoided losses, and thus underestimate the value of risk reduction interventions.
- Adaptation and resilience projects tend to have broad consequences at the system level, and focusing on the project level is likely to oversee such aspects (Hallegatte et al. 2019).
- Future climate change impacts are highly uncertain, as different models tend to provide different projections, making it difficult to calculate a single expected NPV (Kalra et al. 2014).
- Decisions on resilience and climate change adaptation cannot be driven by economic considerations alone (Hallegatte et al.

NPV calculation

$$NPV = \sum_{\text{starting date}}^{\text{asset lifetime}} \frac{1}{(1+\rho)^{y}} \left[\text{Benefit}(y) - \text{Cost}(y)\right]$$

2016b). Concentrating interventions on where the return on investment is highest would focus on richer areas and populations by protecting the areas that have most to lose.

This toolbox discusses alternative approaches to dealing with these specificities.

System-level and criticality analysis

In a networked and interconnected system, the resilience of each asset depends on the resilience of the whole system. Even perfectly functional power plants can stop producing if the transmission system is damaged, for example. So, the resilience of each asset in a system must be determined from the system's needs and depends on its importance within the system.

A simple approach to prioritizing interventions is assigning a level of criticality to assets based on their capacity. For example, construction standards are often higher for primary roads such as highways and freeways than for tertiary roads that have much lower volumes of traffic. Similarly, strengthening or retrofitting actions can be prioritized by focusing on the largest assets in a system.

However, this approach is limited in that it does not include information on the type of service the asset provides (for example, a freeway that provides access to a camping area is less critical than one that leads to the main port or hospital) or the role that the asset plays in overall network functionality. Sophisticated approaches to prioritizing infrastructure assets model infrastructure systems as a network of nodes and links. A criticality analysis can identify the bridges and road segments that are most important for the whole system, so that resources can be focused on them. ***Figure C.1*** (***toolbox C***) is an example from Tanzania.

Approaches based on criticality analysis can provide similar outcomes as a cost-benefit analysis: they can help decision makers estimate the costs and benefits of investing in different parts of a network, and calculate an NPV or benefit-cost ratio for each asset, making it possible to prioritize highest returns. ***Figure K.1*** shows the losses from a four-week disruption of different roads in Tanzania, ranked from the most to the least important road. With a given budget for retrofitting and strengthening, such an analysis can provide a prioritized list of roads that should be reinforced.

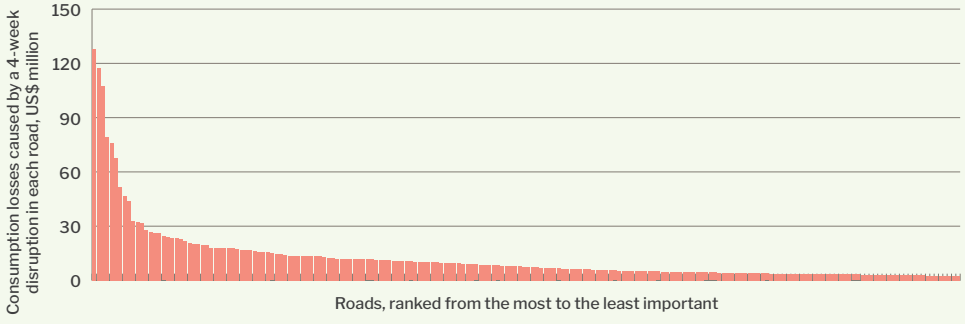
Scenario analysis and decision making under uncertainty

Regardless of the quality of data and models available, long asset lifetimes and deep uncertainty about the future exacerbate the challenges of sound decision making in risk management. Scenario analysis and tools for decision making under uncertainty have been designed to deliver acceptable outcomes in the largest range of possible futures, instead of optimizing for a single future scenario.

The first step is stress testing available options under a range of plausible conditions, without requiring a decision or

FIGURE K.1 >>

Benefits from strengthening different road segments in Tanzania considering their criticality



Source: Based on Colon et al. 2019.

agreement on how likely these conditions are. The methods then repeatedly evaluate decision options under different sets of assumptions, including low-likelihood but high-consequence events. This process promotes consensus around decisions, which can help decision makers manage deep uncertainty. By performing analyses in this way, decision makers can debate important questions, such as:

- What trade-offs should be made between robustness and, for example, cost?
- Is it possible to add safety margins to a project to hedge against surprises?
- Which options offer the most flexibility for responding to unexpected changes in the future?
- What should be done in case of failure?

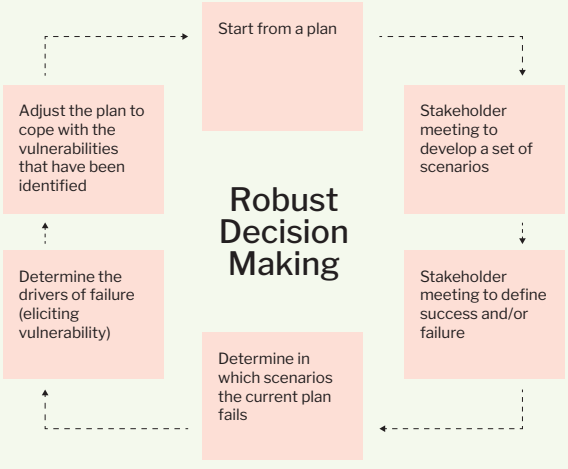
Robust solutions can usually be achieved by selecting options that minimize the potential for regret. Here, regret is defined as the difference between what a given decision would achieve and what the best decision could have achieved. For example, there is a regret from having strengthened a bridge to resist a strong earthquake, if no such earthquake occurs during the lifetime of the bridge. Similarly, there is a regret from not having strengthened the bridge if a strong earthquake does happen and the bridge is destroyed.

Figure K.2 represents this approach, which is based on the Robust Decision Making (RDM) methodology. It suggests starting from existing plans and working with decision makers and stakeholders to define what would be considered a failure or unacceptable outcome. These can be defined in pure economic terms (for example, the NPV is negative) or in more complex ways (the NPV is negative or the project creates unsustainable debt or bad health consequences for the population). It is then possible to identify scenarios in which the existing plan would fail. The vulnerabilities identified through this process can help identify options and opportunities to reduce or manage them, and to make the considered system less vulnerable.

This approach does not usually provide a ranking of projects or a single metric to measure project returns. But it does identify vulnerabilities and options to minimize them. It is then up to decision makers to decide whether the vulnerabilities are too big to be accepted and whether investing in the identified options is worthwhile.

FIGURE K.2 >>

RDM methodology to identify vulnerabilities and options to mitigate them



Defining a target level of residual risk

Risk cannot be brought to zero. The appropriate approach to manage risk is always a combination of prevention to avoid disasters and impacts and preparedness to manage the risks and impacts that cannot be prevented at an acceptable cost. The right balance between these two pillars depends on whether we are dealing with frequent or rare events.

For changes in average conditions, and small and frequent shocks, it is usually best to focus on preventing the impacts—for example, by retrofitting housing and infrastructure to manage higher temperatures or by building dikes to prevent frequent floods. But for more

extreme and infrequent events, or places with low population and asset density and more limited economic value, the cost of prevention may quickly become unaffordable. In these cases, preparedness becomes an increasingly important option. For many assets—including electricity distribution infrastructure, some roads and other transport infrastructure—it may be cheaper to accept and be ready to repair damage quickly after disasters, than to try to strengthen them (Nicolas et al. 2019; Colon et al 2019).

Figure K.3 illustrates how, when shocks are more intense and less frequent, prevention becomes less affordable and preparedness more important. Not all countries can aspire to the same level of resilience over the short term. Defining risk levels should also consider ethical issues, poverty reduction and inequality objectives.

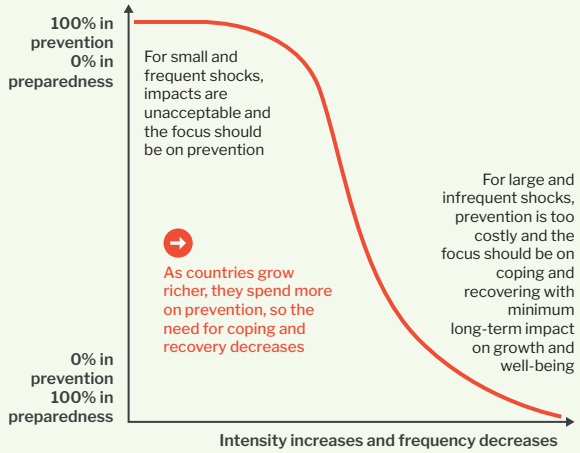
Countries with different institutional and technical capacities and levels of wealth will not select the same level of acceptable risk. So, while the Netherlands has invested massively in coastal protection to reduce flood risks to almost zero, this solution may remain unaffordable for many developing countries in the next decades. Poor countries often experience repeated shocks. For example, urban floods affect Dar es Salaam in Tanzania almost every year and drought-related crop losses occur every few years across Eastern Africa. The frequency of disaster- and climate-related impacts in these countries means that preparedness, through early warning systems and other mechanisms, has to play a bigger role than it does in richer countries (*figure K.3*).

Once an acceptable level of risk has been defined, it can guide investment decisions, funding the required actions to maintain residual risk below this acceptable level. This is the approach the Netherlands government uses to manage flooding: it commits to maintain risk below certain levels, depending on population density, and then translates these commitments into investment plans.

In the presence of significant interdependencies across systems, applying a consistent level of resilience to various components of the infrastructure system is more cost-effective than making independent decisions. It would not make sense for a government to invest major resources in making the power system highly resilient if the water supply or transport system cannot cope with frequent hazards. For systems that interact, it is more practical and efficient to use a target level of resilience to allocate investments across sectors than trying to equalize the rate of return of various investments.

FIGURE K.3 >>

Prevention and preparedness efforts, and how they depend on income levels



Dedicated metrics to capture distributional impacts

Economic losses hide the impact of disasters on poor people (Hallegatte et al. 2016b). Because the wealthy have more assets and income to lose, their interests dominate economic loss assessments. If informed only by potential economic losses, decisions about the resilience of infrastructure or investments to reduce natural risks will tend to favor a country's or a city's richest areas. Although the poor often have little to lose, they lack the resources and tools to cope with infrastructure

disruptions or income shocks without reducing essential consumption. So, they are more likely than the wealthy to forgo food, health services, and education after a disaster.

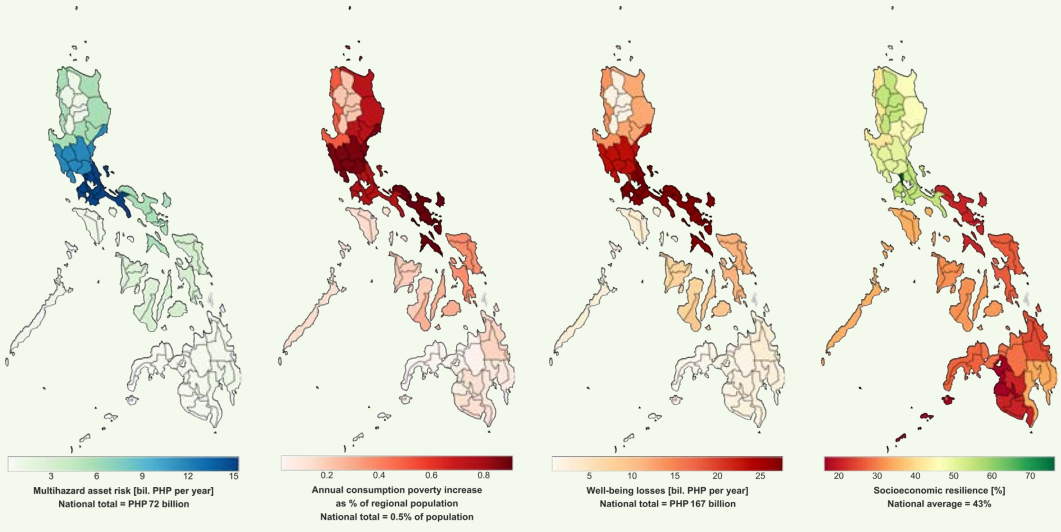
To ensure resilience is distributed fairly across the population, governments can use a metric that accounts for the socioeconomic status of affected populations to measure the impacts of disasters and infrastructure disruptions. A recent analysis in the Philippines employed a multimetric regional-level assessment of disaster risks using traditional asset losses, poverty-related measures such as poverty headcount, well-being losses for a balanced estimate of the impact on poor and rich households, and socioeconomic resilience to measure the population's ability to cope with and recover from asset losses (Walsh and Hallegatte 2020).

In both spatial (where to act?) and sectoral (how to act?) terms, priority interventions depend on the metric used for disaster severity. Focusing on physical asset risks prioritizes adaptation action in areas with high asset values and strong economic activity, while concentrating on well-being losses prioritizes action in poorer and vulnerable areas.

In the Philippines, for example, if asset losses are the main measure of disaster impacts, the most important interventions will take place in the Manila area. If the government expresses its policy objectives in terms of poverty incidence and well-being losses, then other regions become priorities (***figure K.4***). But countries need to account for multiple policy objectives when assessing national risks. As such, they should use a set of metrics that goes beyond asset losses.

FIGURE K.4 >>

Using different metrics to measure natural risks in the Philippines highlights different intervention priorities



Source: Walsh and Hallegatte 2020.

SPOTLIGHT 4 >>

COVID-19

Developing a stimulus and recovery package that builds resilience

To accelerate recovery once the COVID-19 health emergency is under control, many governments are planning to introduce massive stimulus packages to help restart the economy. Governments can improve these packages by considering not only the short-term needs for jobs and economic activity, but also actions to boost the potential, resilience, and sustainability of future development paths.

Governments can use a sustainability checklist to screen potential projects (Hammer and Hallegatte 2020), policies, and measures for inclusion in a stimulus package, looking both at the short term *(How many jobs will be created? Over which timeline?)* and the long term *(Does the intervention improve long-term growth prospects, for instance by improving the population's skillset? Does it increase resilience? Does it facilitate the transition to a zero-carbon economy?)*. The key is to maximize short- and long-term gains through a careful selection of interventions.

If stimulus packages simply get countries to where they were before the pandemic, they will face the same problems tomorrow that they faced yesterday, with low productivity, high pollution, and lock-in of carbon-intensive economic structures. The most efficient stimulus packages will be the ones that are designed to create many jobs and support economic activity over the short term, but also get economies on track for rapid sustainable growth. As well as using this spending to make their countries 21st-century-ready by investing in skills, governments can invest in building modern, resilient, zero carbon infrastructure systems and a healthy environment.

This spotlight demonstrates how governments can transform the sustainability checklist into a screening, scoring, and prioritization tool, using Fiji's Climate Vulnerability Assessment (CVA) resilience-enhancing plan as an example (Fargher and Hallegatte 2020). Fiji's starting point was the list of 124 interventions identified as part of the CVA. This list was created through an in-depth multisectoral collaboration between the government of Fiji and the World Bank, based on an assessment of the threat that climate change and natural disasters create for Fiji's own development goals, as stated in its national development plan. Although the list includes some pure adaptation or disaster risk reduction interventions, such as building dikes, most of the measures and interventions combine development and resilience-building objectives. Indeed, the CVA plan was designed to support the achievement of the country's 5- and 20-year national development plans, despite disaster and climate risks.

Not all the measures listed in the CVA plan are useful stimulus actions. For example, creating drought management plans is essential to minimize future economic costs from climate change, but it is not likely to create many jobs. To select the right set of interventions for the short term, governments need to look at many dimensions, as suggested in the sustainability checklist.

Assessment methodology

To identify interventions that should be included in a stimulus package, each of the criteria listed in the sustainability checklist was applied to each intervention, with a score given based on expected performance, using simple classification to categorize performance:

- 1 for "good"—for example, this measure generates short-term jobs
- 0 for "not relevant" or "requires more information"
- -1 for "bad"—for example, this measure does not generate short-term jobs.

To transform the 35 scores of the full checklist into a small set of priority interventions, the first step was removing any interventions that failed to achieve short-term objectives or were likely to create significant issues over the long term. Next, using a "do no harm" approach, any interventions that received a score of -1 for the following dimensions were also removed:

- **Short-term job creation:** Does the measure create new jobs in the short term? Do the new jobs make use of skills that already exist in the local population? Can the intervention create jobs in 12 months after a decision is made, including intervention design, consultation processes, budget mobilization, and procurement?
- **Long-term financial sustainability:** Is the risk for local/national debt sustainability manageable? Are induced costs—for example, for maintaining and operating a new asset—manageable?
- **Irreversible environmental impacts or lock-in to risky or carbon-intensive patterns:** Can the intervention be designed to prevent irreversible environmental or cultural losses, such as increased deforestation, developing on wetlands or damage to cultural heritage sites? Has it been screened for exposure and vulnerability to disaster and climate risk, considering future changes in climate conditions? Can it prevent magnifying (or creating new) lock-in to carbon- or energy-intensive development patterns?

Interventions that do not perform well along these dimensions have no place in a stimulus package. This first screening removed 50 percent of the interventions. Since the CVA plan carefully considered long-term implications, the screening removed measures that were not expected to generate many jobs over the short term. The plan included two massive interventions related to the retrofit of schools and hospitals, with a total cost of F$560 million that was considered unrealistic for a stimulus package. These were reduced instead to F$60 billion, making short-term implementation more realistic.

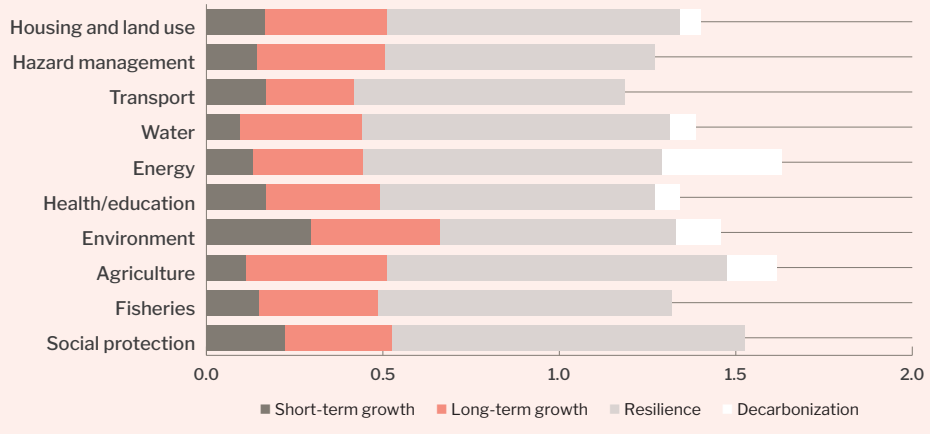
The next step was using a classical multicriteria approach to identify the most promising of the remaining interventions. This involved aggregating the scores into four core categories of interest—short-term stimulus, long-term growth, resilience, and decarbonization—and weighting each of the category scores to calculate an overall score. Governments need to select the weights that best represent their priorities and policy goals. The example here simply illustrates the approach by selecting a set of weights in an ad-hoc manner.

Results

Figure B4.1 demonstrates how each sectoral group performed against each category for the

FIGURE B4.1 >>

How different categories of interventions perform along different dimensions



Note: Score weight used for illustrative purposes: ST=1, LT=0.5, R=0.5, D=0.5

63 remaining interventions. As expected, they were all strong on resilience—this was, after all, a resilience plan—but they also performed well on long-term growth. This was to be expected, since the plan was developed to support long-term sustainable growth. Short-term growth was more selective, but since the worst measures were removed during initial screening, the 63 remaining actions provided some short-term stimulus benefits. The decarbonization dimension produced the most different results across sectors, with only the energy and agriculture interventions generating significant benefits in this domain.

To package these measures into a suitable stimulus plan, a budget cut-off was applied at 3 percent GDP, reducing the list to 10 core interventions (*table B4.1*). As expected, they all perform well against the four core categories. In particular, they are expected to boost long-term productivity and growth, by improving agricultural productivity or the reliability of infrastructure, or by reducing energy use or wastewater. Some, but not all of them, also contribute to decarbonization.

Conclusion

This exercise does not pretend to identify the best stimulus package for Fiji. Designing a stimulus package would require further exploration of options and interventions that are not part of the CVA resilience plan. For example, the tourism sector is heavily affected by COVID-19 and identifying measures that target this sector will be crucial. Direct cash transfers or public work programs targeting the unemployed and the poorest are also a cornerstone of a stimulus program. Finally, the weights used to prioritize interventions need to reflect the priorities of both government and population, instead of being fixed arbitrarily as they were here for illustrative purposes.

But this exercise shows how governments can use existing investment plans as an input into a stimulus program design, if properly screened to ensure selected interventions are appropriate in the current context. It also demonstrates how a simple tool that allows governments to discard measures that are inappropriate today and prioritize others based on simple weights can support the design of a recovery plan.

Using existing development plans as an initial menu of options for screening has its advantages. It would ensure that selected interventions meet short-term needs by immediately creating appropriate jobs. At the same time, the fact that all considered measures were already included in long-term plans—whether national development plans, NDCs, or resilience plans—would ensure that the stimulus package generates long-term benefits that go beyond immediate needs.

Source: Fargher and Hallegatte (2020).

TABLE B4.1 >>

Budget cut-off analysis of interventions in Fiji CVA

Intervention title	Category	Cost (F$m)	ST	LT	R	D
Improving resilience of rural mini-grids and solar home systems	Energy	4				
Sustainable agricultural practices	Agriculture	2				
Housing microfinance (5-year loans) to retrofit existing houses and construct new houses to approved designs and standards	Housing and land use	2				
Community-level investments for improved ecosystem resilience, Phase I	Environment	30				
Diversifying renewable energy generation	Energy	30				
Expanding underground distribution lines	Energy	90				
Progressive structural upgrading of all remaining schools and health facilities not affected by Tropical Cyclone Winston, Phase I	Health and education	60*				
Expanding solar generation	Energy	79.2				
Promoting alternative income sources not dependent on fisheries	Social protection	10				
Reduction of physical water losses	Water	50				

Notes: ST= short term, LT= long term, R= resilience, D= decarbonization
Score weight used for illustrative purposes: ST=1, LT=0.5, R=0.5, D=0.5
* represents 20% of total intervention costs

■ = Top 10%
■ = Middle (10%–90%)
□ = Bottom 10%
□ = Decarbonization interventions with 0%

ACTION A.3 >>

Set concrete sector-level targets to guide implementation by line ministries

The transport, energy, water, environment, social protection, and other ministries will implement and fund most adaptation and risk reduction interventions, and local authorities will also be important players. For example, a national adaptation and resilience strategy can aim to revise 50 percent of all land use plans to account for climate change by 2025, and 100 percent by 2030. But it would be down to local authorities to implement these targets, under the supervision of the ministry in charge of land use.

Governments can identify sector-level targets for 2025 or 2030 for each of the actions outlined in this guide, and include these in their strategy, leaving detailed policy implementation for achieving the targets to the relevant ministries. These targets are also often introduced through a climate change framework law (see World Bank 2020b).

Targets already set include Singapore's long-term adaptation target of a tenfold increase in desalination capacity to meet 30 percent of long-term water needs by 2060,[40] Vietnam's objective of at least 90 percent of socioeconomic development plans having integrated disaster risk management and climate change adaptation by 2030, and Samoa's requirement that 100 percent of new buildings be climate-resilient by 2020.

Having a representative body such as parliament approve a list of indicators and targets could significantly improve ownership and accountability and strengthen the strategy's authority. It could also help institutionalize a formal and regular reporting process. Such an open process can ensure transparency and may facilitate public acceptance of less popular measures. For illustration, *Annex 1* offers a list of concrete indicators that could help track the actions identified in this note.

ACTION A.4 >>

Screen all public policies and expenditures for disaster and climate risks, and align them with adaptation targets

Adaptation measures can only be cost-effective if all investments and planning decisions consider climate-related risks in their design. To mainstream adaptation measures in this way, governments must systematically screen relevant policies and expenditures—even those without an explicit adaptation or climate rationale—to avoid any negative effects on adaptation objectives. If they find that a policy or expenditure has a negative impact on adaptation objectives, then decision makers should ensure that the benefits exceed the costs and account for any negative climate change impacts.

The value of mainstreaming explains why countries implement wide-ranging laws to support climate change and disaster management (World Bank 2020b). For example, the Philippines' Climate Change Act 2009 puts in place a comprehensive framework for integrating climate change with disaster risk reduction, in policy formulation, development plans, poverty reduction strategies and other development tools.[41]

The priority is improving public investment management (PIM) to include specific actions and controls that will ensure public investments are consistent with adaptation strategy objectives and consider disaster and climate risks. To help governments do this, multilateral institutions are adapting their assessments of PIM systems that inform the design of institutional reforms and capacity building initiatives. The World Bank assesses critical features of PIM systems across the project cycle. The IMF's PIM assessment follows a similar approach, with the addition of planning and monitoring financial assets. But these assessments do not explicitly address the institutional arrangements needed to support integrating climate change into PIM.

The World Bank is currently testing a simple assessment tool that integrates disaster resilience features. Further work is needed to integrate the features described above, thus putting greater emphasis on climate in investment policy and planning, land use planning, regulation use, screening for environmental and transition risks, climate-responsive economic appraisal, asset management and results reporting. The ultimate goal is mainstreaming climate change considerations in PIM across all institutions.

Multiple tools are in place to help governments conduct such a screening process. These include the World Bank-International Finance Corporation's climate

risk screening tools,[42] which governments can use systematically when making decisions. These tools help project development teams assess possible climate change or natural disaster-linked threats to their projects and identify possible interventions and options for reducing risks and increasing resilience.

Many institutions have produced guidance notes for different sectors. USAID's Sector Environment Guidelines and Resources include information on how to reduce project vulnerability to climate change in 21 sectors.[43] The International Hydropower Association—with financial support from the European Bank for Reconstruction and Development, the World Bank Group and its Korea Green Growth Trust Fund—has also produced a guide to help investors, owners and developers make informed decisions about how to plan, build, upgrade and operate hydropower systems in the face of increasingly variable climatic and hydrological conditions.[44] One option for governments is mandating the use of such screening tools or guidance for all investment projects, to ensure project design and appraisal considers disaster and climate risks.

As one of the pillars of its Adaptation and Resilience Action Plan, the World Bank Group is developing a resilience rating system, which aims to ensure investors, government officials, World Bank Group teams and other decision makers are aware of the risks associated with projects and can make informed decisions on whether a project's expected benefits exceed the risks it creates or is exposed to. The rating asks whether the project is likely to underperform compared with expectations. Here, "underperforming" is used in relative, rather than absolute, terms. As part of this process, the World Bank Group is producing a series of guidance notes on necessary screening and risk assessments for different categories of projects.

Over the next years and decades, the tools available for mainstreaming climate change adaptation and resilience into all areas of government intervention will be improved and simplified. However, there is no time to lose. Governments should start using the available tools today, updating them as learning about climate change risks improves.

ACTION A.5 >>

Allocate appropriate funding to the adaptation strategy

After preparing an adaptation and resilience strategy, the next step is ensuring it is appropriately funded. A small budget for an adaptation and resilience plan may be necessary, especially for monitoring and evaluating progress. But most funding needs are in sectoral interventions—for example, more resilient roads, investments in irrigation, financial protection instruments, and so on. There are two ways of funding these interventions: through dedicated funds or sectoral budgets.

Some countries have created **dedicated funds**, with the mandate of funding investment in resilience or climate change (adaptation and/or mitigation). Such funds draw on various sources, including state budget and foreign aid, to finance resilience projects. Bangladesh's Climate Change Trust Act 2010, for example, created a Climate Change Trust Fund as the designated mechanism to fund actions to address the adverse impacts of climate change.[45] Tuvalu's Climate Change and Disaster Survival Fund Act 2015 also created a fund to provide vital services to reduce climate change and natural disasters risks.[46] And Guatemala's 2013 Climate Change Framework Law created the National Fund for Climate Change to support natural risk management plans, programs and projects for climate change adaptation, mitigation, capacity building, payment for ecosystem services for carbon sinks, and others.

To simplify processes, promote synergies within each sector, and ensure consistent action, however, it may be preferable for most adaptation and resilience funding to come from **sectoral budgets** rather than a specific budget or fund. For example, if transport system resilience investments can be funded by the transport infrastructure budget without relying on a dedicated resilience fund, it would help ensure that investments in the transport system and investments in the resilience of the transport system are as consistent and synergetic as possible. And rather than having to establish new institutions or funds, governments would only need to ensure that existing ministries have the mandates (*Action A.2*) and budgets they need.

When adaptation and resilience spending is funded by the general budget, rather than a specific fund, assessing the resources spent can be challenging. One way of monitoring and reporting on this spending is through budget tagging or expenditure reviews (*toolbox L*). Such tools can help track resources invested and ensure consistency across the different areas of government intervention, and thus also across budget expenditures.

These tools can also help identify disincentives for resilience created by the tax system and thus support the reallocation of resources to ensure adaptation

and resilience needs can be financed. This could include agriculture, water consumption, or fossil fuels subsidies, which tend to reduce populations' resilience by increasing water scarcity, damaging ecosystems and their services, and increasing local air and water pollution. While such subsidies have often been implemented to help populations access food, water, and energy, they tend to benefit the richest, who consume more energy and water. Their negative side-effects also mean that populations would likely benefit more if resources were directly distributed through cash transfers or reallocated to resilience—for example, by boosting social protection systems, as done in Indonesia and Jordan, or investing in infrastructure to provide universal access to basic services.

Do sectoral budgets need to be increased to account for climate change and natural risks, and allow for more resilience? Making infrastructure more resilient often increases upfront costs at the investment stage. Looking at transport, energy, and water systems, Hallegatte et al. (2019) estimate this additional cost as being on average around 3 percent of baseline upfront costs for new investments across countries. Where retrofitting is necessary, budgetary needs can be much higher. In extreme cases, where some strategic retreat is required, such as moving away from places where risks are becoming too high or too expensive to reduce, it may be necessary to invest in new infrastructure, which means a cost equivalent to 100 percent of the infrastructure value. In such situations, budgets would need to increase. If they do not, adaptation and resilience investments will take place at the expense of other investments and policy priorities.

But these higher upfront costs will pay off in the long term, and many of the interventions in a national adaptation and resilience strategy would pay for themselves. By definition, adaptation and resilience interventions are designed to reduce the future costs of disaster and climate change. Well-designed interventions should thus have positive NPVs, as the value of reduced disaster and climate change losses will be higher than the costs. An example of such cost-efficiency is the set of options to strengthen and increase the resilience of infrastructure systems suggested in the World Bank's *Lifelines* report: each $1 invested in these measures is expected to reduce future socioeconomic losses by $4 (Hallegatte et al. 2019).

But even a cost-effective investment in adaptation and resilience can be difficult to fund and to finance. Many countries with high vulnerability to natural hazards and climate change already have high debt levels (Feyen et al. 2020); and government responses to COVID-19 are bound to leave them with even larger debts. High debt makes it challenging for governments to finance investments—for resilience or any other purpose. But constraints on investment capacity also tend to make countries more vulnerable, increasing their debt level every time a disaster forces them to invest heavily in reconstruction. This is one reason why the IMF proposed in a recent staff paper that vulnerable countries develop comprehensive disaster resilience

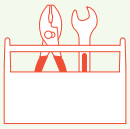
strategies in consultation with development partners and other stakeholders, to facilitate donor coordination and make it easier to decide on the value of various investments in a context of high risk and high vulnerability (IMF 2019).

In addition to general constraints on investments, not all benefits from adaptation and resilience investments can be readily transformed into a financial flow, which could be used to reimburse a loan, for example. First, benefits tend to be far in the future—sometimes farther than the borrowing time horizon. And second, transforming avoided losses into an actual cash flow is complicated. Unlike monetary benefits—for example, from a toll road—it is difficult to monetize avoided losses or gains in well-being from better health or quality of life and transform them into a financial flow that can be used to finance the upfront cost. In such cases, financing adaptation and resilience investments needs to rely on general taxation, rather than the direct benefit of each investment.

TAKING ACTION >>

Toolbox L

Expenditure reviews and budget tagging



Climate change public expenditure and institutional reviews (CPEIRs) use tagging to identify climate change-related activities and expenditures and, in some cases, quantify the funds allocated in support of climate policies. They typically cover climate change mitigation and adaptation, and inclusion of disaster risk management varies by country. In low- and middle-income countries, they are often prepared by international organizations in collaboration with central finance agencies to assess policy alignment, effectiveness, and efficiency in public spending. Early examples include World Bank CPEIRs for Morocco, Philippines and Vietnam and United Nations Development Programme (UNDP) CPEIRs for Bangladesh, Nepal and Cambodia. There is no standardized tagging methodology for CPEIRs; most use variations on the OECD's *Rio Markers*[47] and multilateral development bank (MDB) methodologies.[48] The World Bank's 2013 *CPEIR Sourcebook*[49] provides an overview of the issues and methodology for conducting CPEIRs.

Budget tagging is the practice of identifying climate-relevant activities and expenditures as part of the routine, annual budget process. Developing countries have led the way in budget tagging methodology development, often building on tagging undertaken in CPEIRs. The Philippines, Bangladesh, Indonesia, Nepal, and Cambodia were among the first; they have been joined more recently by Kenya, Pakistan, Ghana, and Uganda. UNDP's 2019 *Knowing What You Spend: A Guidance Note for Governments to Track Climate Finance in their Budgets*[50] summarizes experience from seven developing countries and provides a step-by-step guide.

In parallel, several OECD countries have developed tagging methodologies. The US Congress has required appropriations bills to identify funds addressing climate change since 2010. The European Commission applied EU climate markers—based on the *Rio Markers*—to track climate finance commitments in its 2014–2020 programming period. More recently, Ireland and France have developed budget tagging methodologies.

Defining climate relevance

There are three broad approaches to defining climate-relevant activities and expenditures.

The positive list approach comprises a standardized set of activities that are eligible for tagging regardless of country context. Green bond standards and MDB methodologies use a positive list for defining mitigation activities, but none of the methodologies use it to identify adaptation activities.

The objective approach tags activities where the objective is achieving climate outcomes. Activities that reduce vulnerability of human or natural systems to climate impacts by increasing resilience are tagged as adaptation related. Given that many development activities can increase resilience, adaptation activities must

also identify and state the intent to address specific climate risks, vulnerabilities and impacts, and demonstrate a direct link between these and their proposed activities. The *Rio Markers* methodology for mitigation and adaptation apply this approach, which has also been adopted by the *MDB Joint Methodology* and *EU Taxonomy* for identifying adaptation activities. Most of the CPEIRS and many budgeting tagging methodologies are objective-based and usually use some variation on the *Rio Markers* methodology.

The policy alignment approach tags activities that are aligned with national climate change policy. Some methodologies only tag activities that are identified in climate change policy documents—for example, in Bangladesh, only programs and thematic priorities identified in the Bangladesh Climate Change Strategy and Action Plan are tagged as climate-related, while in the Philippines, expenditures are tagged to policy initiatives under the National Climate Change Action Plan and Risk Resilience Program. Other methodologies allow agencies to self-assess the policy alignment of climate-related activities and expenditures based on sector climate change policy.

The simplest approach assumes that all expenditures related to a tagged activity are climate-related. This is the **measurement approach** used by green bond standards. Budget tagging methodologies can also be used to assess the proportion of expenditures that are climate-relevant. They typically use three or five-step classification ranging from "not relevant" to "strongly relevant" with corresponding weights expressed as percentages of total program or project cost.

It is also possible to estimate the proportion of expenditures that are climate-related, based on the cost of a program or project's climate-related activities. This approach, applied in the MDB methodology and in some World Bank CPEIRs, recognizes that activities with a development purpose can also contribute to achieving climate change objectives. Calculating incremental costs would require comparison with a counterfactual program or project design that does not include climate-related activities.

Tagging approaches

Different tagging approaches have different coverage.

- **The expenditure approach:** The *Rio Marker*, MDB and green bond methodologies were all designed to tag projects. This is relatively straightforward: projects typically have supporting documentation that details objectives, activities, costs, and results. Tagging current expenditures is only feasible if the budget has a program classification, ideally with some breakdown by subprogram, project, activity, and outputs.

- **The tax expenditure approach:** Recent assessments by France and Finland identified tax expenditure as an important instrument for financing climate policy and the main instrument for financing expenditure with adverse climate impacts. Where tax expenditures are reported in budget documentation, they can be tagged following the same principles as expenditures executed through the budget process. This is particularly important to identify tax expenditures— like many agricultural or energy subsidies—that have a negative effect on resilience. However, most low- and middle-income countries do not systematically report on tax expenditures.

- **The off-budget expenditure approach:** Explicit subsidies are direct payments that can be identified as expenditures in budget documents and financial statements and so can be tagged as climate-relevant.

- **The tax revenue approach:** Taxation is an essential tool for climate change policy. It can also help address other market failures such as the degradation of natural landscapes or inappropriate land use in areas that are subject to disaster risk. Tagging can support these policies by identifying taxation that has a climate-change related objective and supporting the notional earmarking of climate-related revenues to climate-related expenditures.

- **The subnational government approach:** These important actors in adaptation and

resilience also account for a substantial share of expenditure in most countries, averaging just over 10 percent of public expenditure in low-income countries to nearly 40 percent in high-income countries. Usually assigned critical land use management, urban services, transport, and water and environmental management functions, they are often the first line of defense in dealing with disasters. Budget tagging can capture climate-related transfers between central and subnational government where these are earmarked for specific purposes or tied to specific programs. In some countries, subnational governments have taken the initiative in launching climate budget tagging. Odisha state, for instance, prepared India's first climate budget for FY2020.

» **The state-owned enterprise approach:** Given their role in strategic industries and the energy, water, and transport sectors, SOEs are key players in climate policy, so central finance and planning agencies will need to integrate them into their mitigation and adaptation policies.

The purposes of tagging

Anecdotal evidence suggests that tagging successfully serves several purposes, including:

» **Awareness raising and communication:** Tagging raises awareness of climate change risks, vulnerabilities, and policies within government and across external stakeholders by forcing government agencies to consider the link between resource allocation choices and climate priorities.

» **Resource allocation:** Tagging informs the allocation of resources in line with climate change policy objectives. This information can influence program and project design if there is a feedback mechanism. Tagging alone is unlikely to influence, much less drive, resource allocation.

» **Resource mobilization:** Tagging supports resource mobilization by channeling finance from ethical investors. Early expectations that budget tagging could be used to mobilize climate-related budget support from sources such as the Green Climate Fund have not materialized.

» **Fiduciary:** Green bond standards provide assurance that funds are applied for the purpose intended by requiring definition of eligible programs and projects, independent verification of eligibility, segregation of funds, independent audit, and impact reporting. Fiduciary concerns would arise in the context of budgeting if there are statutory allocations for climate-related expenditures.

» **Accountability:** Tagging can be used to monitor financial commitments in national policy statements and international treaties. Broader concepts of accountability for results would require the presentation of information on climate-related impacts alongside financial information.

Source: Adrian Fozzard, Xenia Kirchhofer, Wei-Jen Leow and Onur Erdem.

ACTION A.6 >>

Track progress over time, and review and revise the strategy

Tracking progress is key. Without systematic and rigorous M&E, it is impossible to know whether an adaptation strategy is successfully mitigating climate and disaster risks. Continuous tracking of sector-specific progress indicators can highlight any sectors where implementation lags behind (*Action A.3*). Likewise, sectors that consistently meet implementation indicators may yield important lessons that can help strengthen approaches in other sectors. Overall, tracking progress across a range of indicators for each of the actions outlined in this note will enable decision makers to provide regular and consistent progress updates and to communicate residual risks in a transparent manner.

Revising the strategy should be part of the strategy itself. Every strong adaptation and resilience strategy can be further strengthened as new challenges and insights become apparent over time. If targets and milestones are missed, implementation challenges—such capacity or resource constraints, or coordination failures between implementing bodies—may become apparent that were not accounted for in the initial strategy design. In such cases, revising institutional arrangements or prioritizing alternative approaches can help bring implementation back on track. By allowing flexibility, course corrections and adjustments can be programmed as integral elements of the strategy, rather than regarded as admissions of failure.

Such strategy revisions are also likely to become necessary as new challenges and risks arise. For example, the COVID-19 pandemic forced many governments to reevaluate their approach to emergency management, not least in areas such as evacuation planning. Indeed, as this guide emphasizes, there are many uncertainties regarding the future impacts of climate change—especially at macroeconomic level—and the performance and effectiveness of resilience measures. New solutions and technologies are also likely to become available that will allow resilience actions to be implemented in more targeted or cost-effective ways. For example, scientific advances may enable us to anticipate future climate change challenges in more robust ways.

Annex 1

Illustrative list of indicators and actions outlined in this guide

Foundations: rapid, robust, and inclusive development is the first priority
ACTION F.1 >> **Increase economic productivity and growth, while keeping buffers for shocks**
» Average productivity growth
» Economic growth
» Debt/GDP ratio
» Structural deficit
ACTION F.2 >> **Ensure that economic growth is inclusive**
» Poverty headcount
» Change in poverty headcount (last five years)
» Growth in income of bottom 40 percent
» Average income of farmers
» Percentage of farmers with access to fertilizers or improved seeds
» Average share of household budget spent on food and beverages
» Access to modern energy
» Number of power outages per year
» Access to improved water
» Number of water outages per year
» Access to sanitation
» Share of population with a bank account
» Share of population covered by social protection
» Total social protection spending
» Share of population with health care coverage
» Number of conflict-related deaths in the last year
Priority Area 1: Facilitate the adaptation of people and firms
ACTION 1.1 >> **Assess disaster and climate risks, and make the information available**
» Number of weather or hydrological observation stations operational in the country
» Real-time availability of hydromet observations
» Time series of hydromet observations are freely available
» Percentage of country covered by high-resolution digital terrain model
» Percentage of country covered by high-resolution hazard maps for current and future risks, with multiple scenarios
» Risk assessment for main economic sector done and publicly available (including opportunities where competitive advantage may improve)
» Data platform providing easy access to hazard and climate change scenario data
» Guidance materials and methodologies available to users on how to access and include disaster and climate information in decision making

Indicator or target

2020 Baseline → 2025 Short-term target → 2030 Medium-term target

ACTION 1.2 >> **Clarify responsibilities and align incentives with adaptation and resilience objectives**
» Law allocating responsibilities and liabilities for disaster risk management and climate change impacts passed
» Target level of residual risks published and publicly available (for example, through residual flood risk maps)
» Specialized agencies to manage watershed-level water sharing established
ACTION 1.3 >> **Facilitate access to technologies, through R&D investments and trade policies**
» Share of farmers using improved crops and climate-smart practices
» Share of R&D (or percentage of patents) related to climate change adaptation
» Total amount invested in R&D on adaptation- or resilience-related challenges
» Amount invested by the public sector in R&D on adaptation- or resilience-related challenges
» Amount invested by the private sector in R&D on adaptation- or resilience-related challenges
» Average tariff applied to imports of resilience-related technologies
ACTION 1.4 >> **Ensure financing is available to all, and provide support to the poorest and most vulnerable people**
» Number of firms/people accessing dedicated financing instruments (for example, guarantees, subsidized loans)
» Total borrowing for adaptation through dedicated windows
» Most vulnerable populations and communities (occupations, localizations, poverty, ethnicity, and so on) identified and information published
» Share of poor and vulnerable population receiving support for adaptation
» Total subsidy/spending targeting poor and vulnerable populations to support adaptation action
ACTION 1.5 >> **Facilitate structural change in the economic system**
» Strategy to manage the decline of negatively affected sectors published
» Strategy to support the development of nonaffected or positively affected sectors published
» Share of GDP in sectors expected to be negatively affected
» Share of GDP in sectors expected to be positively affected
» Share of employment in sectors expected to be negatively affected
» Share of employment in sectors expected to be positively affected
» Share of exports in sectors expected to be negatively affected
» Share of exports in sectors expected to be positively affected
» Measure of economic diversification (for example, number of exported products) or latent diversification
Priority Area 2: Adapt land use plans and protect critical public assets and services
ACTION 2.1 >> **Identify critical public services and assets**
» Critical infrastructure and services identified
» Inventory of public assets and infrastructure prepared, including hospital, school, and university buildings, their condition, exposure to hazards, and maintenance history
» Gaps in infrastructure and public assets identified
» Investment plans to increase the resilience of public services and infrastructure systems completed
ACTION 2.2 >> **Design and implement a government-wide strategy to increase the resilience of infrastructure and public assets**
» Strategy to manage critical assets and infrastructure approved and published
» Agency in charge of coordinating resilience of critical assets and infrastructure created and operational
» Asset management systems with evidence-based maintenance plans in place
» Construction standards for infrastructure and building updated, accounting for local hazards and criticality, and enforcement mechanism in place

Indicator or target	2020 Baseline	2025 Short-term target	2030 Medium-term target
» Expected recovery time for critical infrastructure systems (power, transport, water) after a major event			
» Revised legal framework to allocate risks across stakeholders (including in PPP and buildings)			
» SOEs have included climate change in their strategy and decision making			
ACTION 2.3 >> **Revise land use and urban plans to make them risk-informed**			
» Percentage of country/municipalities with revised land use or urbanization plans that include current and projected hazards			
» Share of population living in (or relocated from) high-risk areas			
» Share of population living in fragile buildings or retrofitted fragile buildings			
» Strategy or specific regulations regarding the use of nature-based solutions approved			
» Areas impossible or too costly to protect against climate change impacts identified and communicated to the public			
» Regulation mandating provision of climate and hazard information to buyer in real estate markets			
Priority Area 3: Help firms and people manage residual risks and natural disasters			
ACTION 3.1 >> **Save lives (and money) with hydromet, early warning, and emergency management systems**			
» Daily weather forecasts produced by the hydromet agency and easy-to-communicate alert system in place			
» Communication channels to efficiently communicate early warnings to the population and emergency services are in place			
» Average error in early warning (both missed events and false alarms)			
» Share of population with access to early warning systems			
» Share of population covered by evacuation plans			
» Capacity of shelters			
» Average distance to closest shelter			
» Capacity of emergency services (for example, number of emergency medical service units, trained health emergency professionals)			
» Duration communities can operate safely and independently (water and food storage, medicine, and so on)			
» Number of disaster drills performed			
ACTION 3.2 >> **Provide all firms and households with risk management instruments**			
» Overall strategy to manage residual risks and disasters prepared and approved			
» Coordination mechanism in place between the various preparedness actors (for example, ministry of interior for crisis management, social protection, ministry of agriculture for food security and agriculture, ministry of finance)			
» Fraction of population covered by at least one financial instrument to cope with shocks (for example, insurance, social protection, or access to emergency borrowing)			
ACTION 3.3 >> **Develop the insurance sector, building on PPPs**			
» Share of population with disaster insurance			
» Share of population with access to emergency loans from financial institution			
» Share of population receiving remittances			
» Share of population with financial savings (in a bank account)			
ACTION 3.4 >> **Build a social protection system that is responsive to shocks**			
» Share of population covered with social protection			
» Stress test of existing systems completed, including delivery mechanisms			
» Contingent plan to scale up social protection systems developed and approved			
» Share of population in social registry (including potential beneficiaries in case of scale-up)			
» Delivery mechanism in place (for example, bank account for each household in the registry)			

Indicator or target	2020 Baseline	2025 Short-term target	2030 Medium-term target
ACTION 3.5 >> **Help firms develop BCPs and financial preparedness**			
» Fraction of firms with BCPs			
» Number of area-based BCPs			
» Fraction of firms with disaster insurance coverage			
ACTION 3.6 >> **Be prepared to build back better after disasters, with contingency plans and financing**			
» Resilient recovery and reconstruction plans, with revised land use and standards, ready for implementation			
» Pre-approved contracts for emergency interventions (for example, debris removal) or reconstruction (for example, road repairs) approved, with enhanced standards			
Priority Area 4: Manage financial and macrofiscal issues			
ACTION 4.1 >> **Include contingent liabilities from natural disasters and environmental shocks into the planning and budgeting process**			
» Risk to public asset and corresponding contingent liabilities assessed			
» Emergency and social protection spending needs and corresponding contingent liabilities assessed			
» Explicit and implicit contingent liabilities quantified and included in budget documents			
» Risk to GDP and tax revenues estimated and included in budget documents			
ACTION 4.2 >> **Develop a financial strategy to manage contingent liabilities, combining multiple instruments**			
» Percentage of explicit and implicit contingent liabilities covered by an instrument such as reserve funds, contingent credit lines, and insurance products			
» Disaster escape clause in budget processes approved			
» Process in place to manage inflow of international aid in case of major disaster, including using existing financial instruments to coordinate delivery			
» PD-PFM Review conducted and approved			
» PD-PFM principles and processes approved			
ACTION 4.3 >> **Anticipate and plan for long-term macroeconomic impacts**			
» Sector-level adaptation plans collected, harmonized, and costed, and estimate of public adaptation spending needs produced			
» Long-term plan to diversify tax revenues away from vulnerable sectors approved			
» Share of tax revenues originating from high-vulnerability sectors			
» Climate and disaster impacts included in debt sustainability assessment or financial sector assessment program			
ACTION 4.4 >> **Communicate and mitigate the disaster and climate risk exposure of the financial sector and pension systems**			
» All banks, insurers, and large investor regulations include specific disaster and climate risks requirements			
» All banks, insurers, and large investors conduct stress tests for climate and disaster risks, including at least two climate scenarios			
» All banks, insurers, and large investors required to provide a quantified estimate of their exposure to natural hazards			

Annex 2

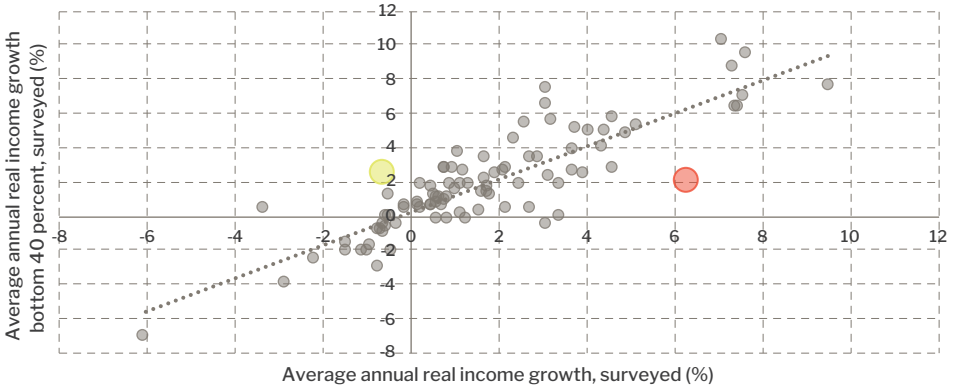
Example of indicator-based identification of policy priorities

This annex illustrates the options discussed in *toolbox A* and shows how to use widely available indicators, such as the World Bank World Development Indicators, to identify priorities for action to build adaptation and resilience.

Not all indicators are available for every country and every year, so the country-level analysis has to adjust to data availability. The figures in this annex highlight specific vulnerabilities for some countries. The gray dots represent the full set of countries for which the indicator is available. The countries that are identified by other colors are discussed in the text and used as illustrations for specific vulnerabilities (or lack thereof).

FIGURE A2.1 >>

Income growth of the bottom 40 percent vs. the whole population



Source: World Bank World Development Indicators.
Notes: Gray dots represent all countries with available data. Red and yellow dots denote Mozambique and Honduras, respectively.

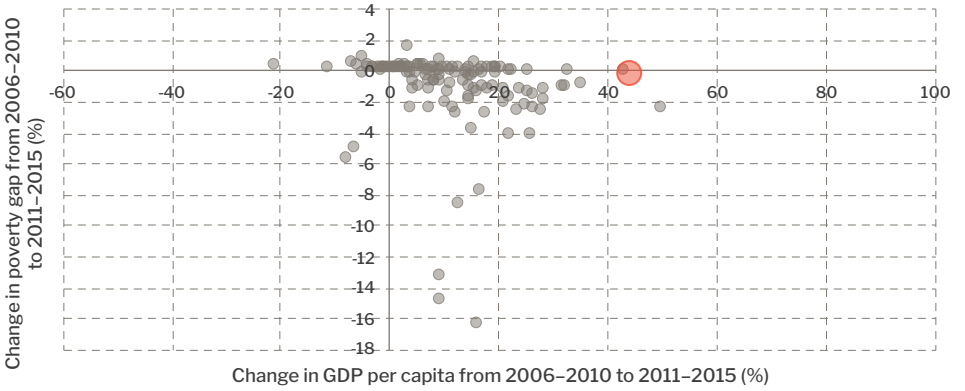
A2.1 >> Is growth rapid, robust, and inclusive?

Figures A2.1 and *A2.2* illustrate how simple benchmarking can inform an analysis of economic growth and its inclusiveness and impact on poverty headcount or poverty gap. In *figure A2.1*, Honduras (yellow dot) has a negative income growth, suggesting it cannot reduce poverty and population vulnerability without first improving its basic economic performance. Mozambique (red dot) has an impressive aggregate income growth, but only a 2 percent growth rate for the bottom 40 percent, suggesting that growth is not inclusive, so population vulnerability could be reduced much faster. In figure *A2.2*, Ethiopia (red dot) has

grown its economy by 43 percent in five years but has not reduced the poverty gap. This suggests that poor people are not benefiting from aggregate growth and are likely to remain highly vulnerable unless growth is made more inclusive.

FIGURE A2.2 >>

Change in poverty gap vs. change in per capita GDP, 2006–2015



Source: World Bank World Development Indicators.
Notes: Gray dots represent all countries with available data. The red dot denotes Ethiopia.

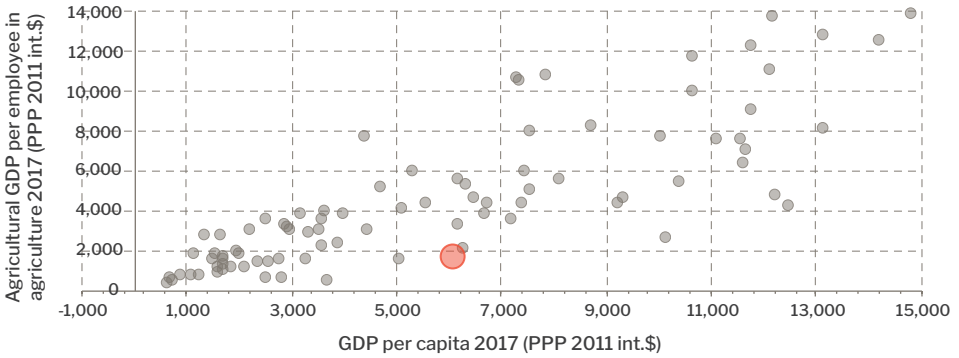
A2.2 >> The vulnerability of farmers and food security

Farmers' productivity, income and access to inputs and improved seeds are critical aspects of climate change vulnerability in many poor and rural countries. Here again, simple benchmarking exercises using the World Development Indicators can provide insight about the vulnerability of farmers. *Figure A2.3* shows that Angola (red dot) has low agricultural productivity, with only $1,700 of agricultural GDP per employed person in agriculture (y-axis), compared to national per capita GDP of $6,000 (x-axis). That Angola is below other countries with similar per capita GDP suggests that there is potential to increase agricultural productivity, which would reduce farmers' vulnerability to disasters and the effects of climate change. Other indicators—such as percentage of crop land with irrigation or fertilizers and improved seed use—can offer similar indications of farmer vulnerability and help identify opportunities for action.

But climate change impacts on agriculture do not only affect farmers. Food price increases can threaten food security, especially where people already spend a large share of their income on food or consumers are not well connected to regional and world markets and depend on local production. *Figure A2.4* shows how available indicators can help identify countries that are particularly vulnerable to spikes in food prices, due to the large share of comestibles in the average consumption basket. In El Salvador (red dot), for example, food and beverages represent more than 60 percent of the average consumption basket, suggesting a high vulnerability to changes in food prices.

FIGURE A2.3 >>

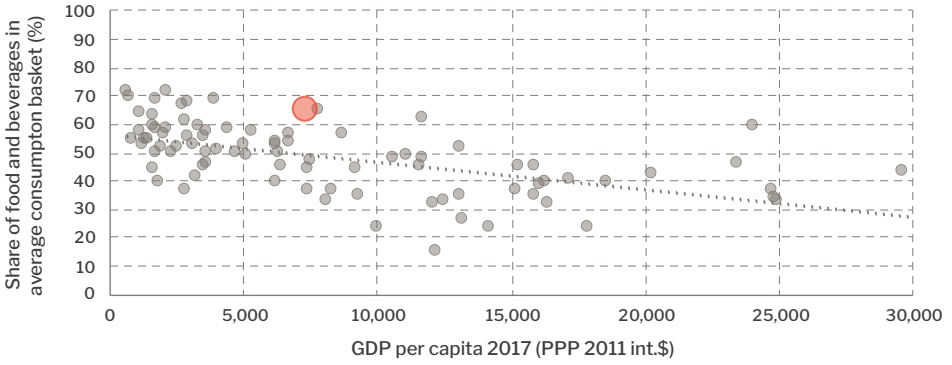
Agricultural GDP per employee, 2017



Source: World Bank World Development Indicators.
Notes: Gray dots represent all countries with available data. The red dot denotes Angola. GDP is expressed as 2011 international $ in purchasing power parity (PPP).

FIGURE A2.4 >>

Share of food and beverages in the average consumption basket, 2017



Source: World Bank World Development Indicators.
Notes: Gray dots represent all countries with available data. The red dot denotes El Salvador. GDP is expressed as 2011 international $ in PPP.

A2.3 >> Infrastructure services

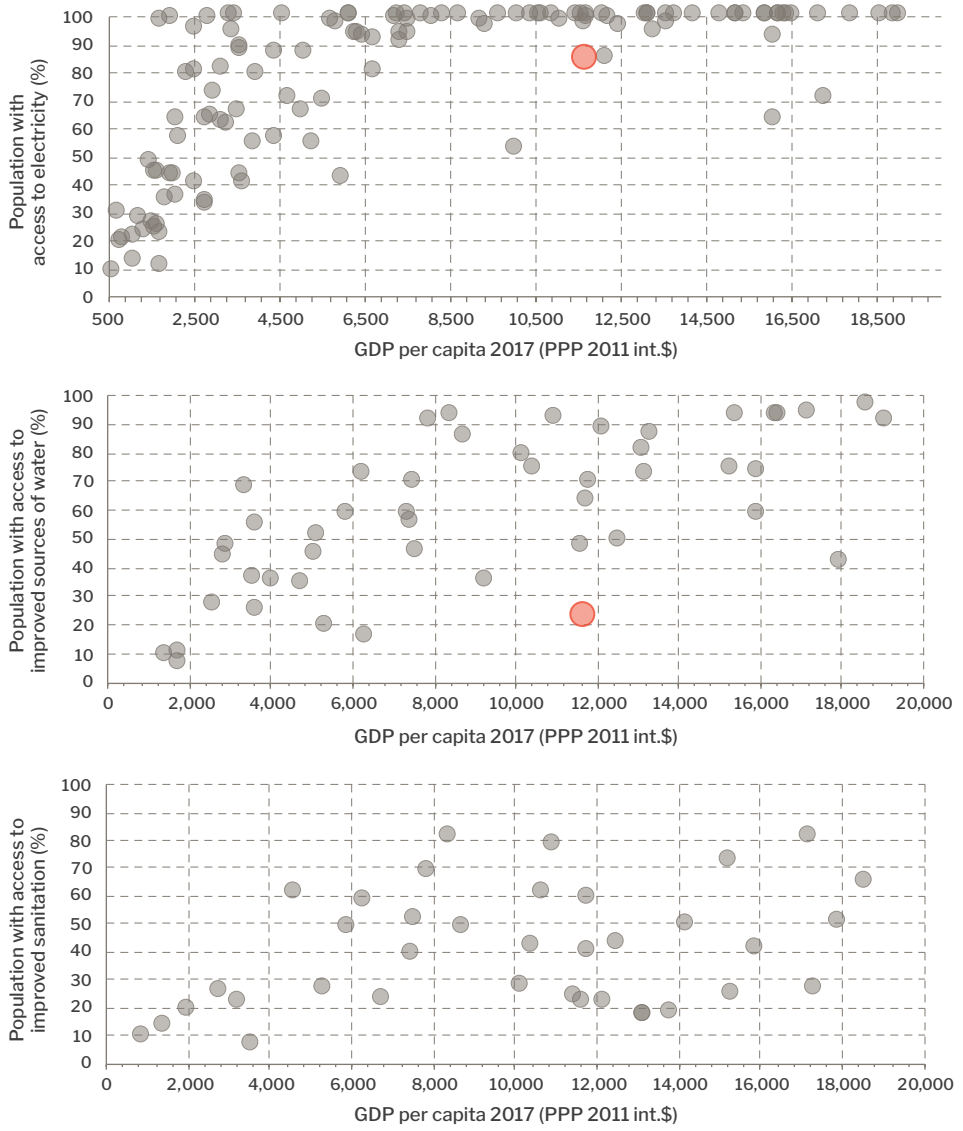
Existing infrastructure access indicators can help highlight population vulnerabilities. For example, *figure A2.5* shows that Mongolia (red dot) provides access to electricity and improved water to a lower proportion of its population than other countries at the same income level (Mongolia is not in the bottom panel because data on sanitation is lacking). This will be a driver of vulnerability. A lack of improved water and sanitation, for example, makes people more vulnerable to the health impacts of climate change, such as higher frequency of water-borne disease and diarrhea (Hallegatte et al. 2015).

Even when there is access to infrastructure services, their quality and reliability is unequal worldwide. The frequency of disruptions is generally closely linked to the level of economic development. Using per capita GDP as a proxy, *Figure A2.6*

shows electricity and water outages in 137 countries. Infrastructure disruptions cost households and firms in low- and middle-income countries $391–647 billion a year. Although disruptions have a wide range of causes—including poor maintenance, mismanagement, and underfunding—case studies suggest that natural hazards cause 10–70 percent of all disruptions, depending on sector and region.

FIGURE A2.5 >>

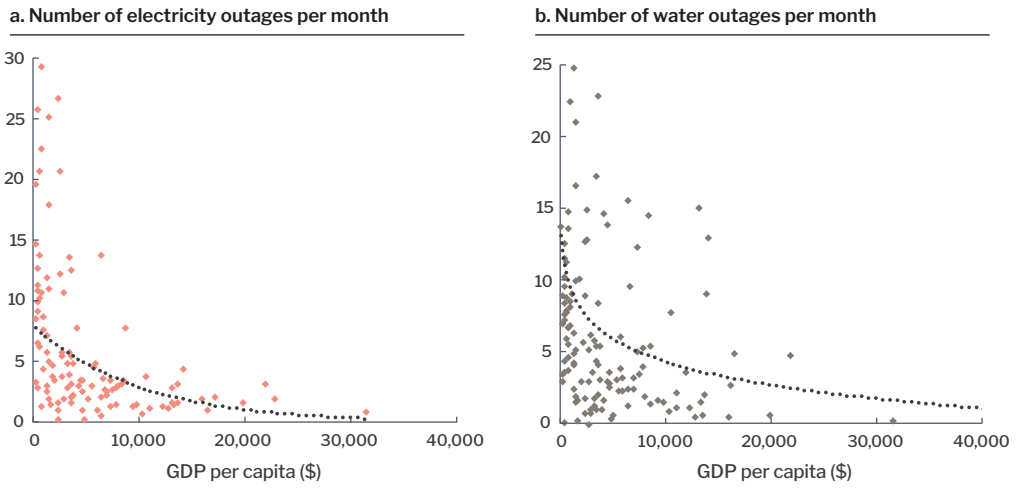
Common indicators of infrastructure access: electricity, water, and sanitation, 2017



Source: World Bank World Development Indicators.
Notes: Gray dots represent all countries with available data. The red dot denotes Mongolia. GDP is expressed as 2011 international $ in PPP.

FIGURE A2.6 >>

Monthly electricity and water outages worldwide



Source: Rentschler et al. 2019, based on World Bank's Enterprise Surveys.
Notes: Both panels use the latest available survey data for 137 countries, with none older than 2009. Panel a. only shows countries with up to 30 outages a month and does not include the eight countries (all with per capita GDP below $9,000) that reported 30–95 outages a month.

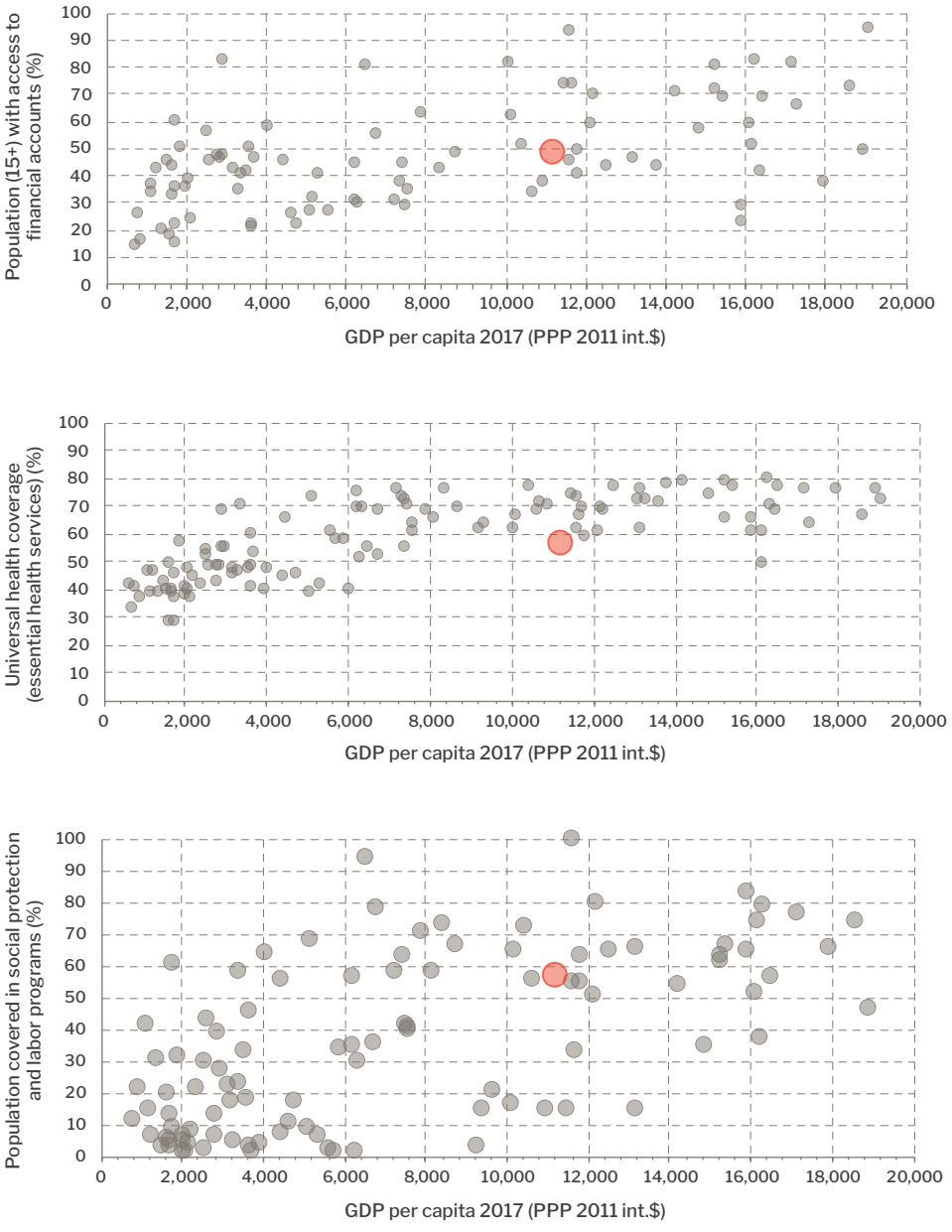
A2.4 >> Financial inclusion, macrofiscal risks, and socioeconomic resilience

Socioeconomic resilience is a population's ability to cope with and recover from shock and adapt to changes (Hallegatte et al. 2016b). Widely available databases, such as the World Bank's *Findex*[51] and *Aspire*,[52] provide data about financial inclusion or social protection coverage that can inform on a population's socioeconomic resilience. *Figure A2.7* shows three indicators for financial inclusion, health care coverage, and social protection coverage. While Indonesia (red dot) is level with its peers for social protection coverage and financial inclusion, it clearly lags on health care coverage. This could therefore be an area of progress for building the population's resilience.

Figures A2.1–A2.7 show how using simple indicators can help countries identify their vulnerabilities to climate change and natural disaster, highlighting opportunities to build resilience through development and growth. More sophisticated analyses are possible in each dimension. For example, a full analysis of social protection should go beyond coverage and consider a system's targeting, generosity, and ability to respond to shocks (see *Priority Area 3*).

FIGURE A2.7 >>

Sample indicators for socioeconomic resilience: looking at financial inclusion, health care coverage, and social protection coverage



Source: World Bank World Development Indicators.
Notes: Gray dots represent all countries with available data. The red marker denotes Indonesia. GDP is expressed as 2011 international $ in PPP.

References

Albala Bertrand, J M. 1993. *Political Economy of Large Natural Disasters*. Oxford, England: Oxford University Press; New York: Clarendon Press.

April, L and Sutherland, R. 2019. *Disaster Response: A Public Financial Management Review Toolkit.* https://www.gfdrr.org/en/publication/disaster-response-public-financial-management-review-toolkit.

Asonuma, T, Li, X, Papaioannou, M, and Thomas, S. 2017. *Sovereign Debt Restructurings in Grenada*. IMF working papers 17 (171). https://doi.org/10.5089/9781484311035.001.

Badola, R and Hussain, S. 2005. "Valuing Ecosystem Functions: An Empirical Study on the Storm Protection Function of Bhitarkanika Mangrove Ecosystem, India." *Environmental Conservation* 32 (1): 85–92. https://doi.org/10.1017/S0376892905001967.

Bagley, J, Desai, A, Harding, K, Snyder, P, and Foley, J. 2014. "Drought and Deforestation: Has Land Cover Change Influenced Recent Precipitation Extremes in the Amazon?" *Journal of Climate* 27 (1): 345–61. https://doi.org/10.1175/JCLI-D-12-00369.1.

Bakkensen, L and Barrage, L. 2018. *Climate Shocks, Cyclones, and Economic Growth: Bridging the Micro-Macro Gap*. NBER working paper.

Barrot, J-N and Sauvagnat, J. 2016. "Input Specificity and the Propagation of Idiosyncratic Shocks in Production Networks." *Quarterly Journal of Economics* 131, 1543–1592.

Battiston, S, Mandel, A, Monasterolo, I, Schütze, F, and Visentin, G. 2017. "A Climate Stress-Test of the Financial System." *Nature Climate Change* 7 (4): 283–88. https://doi.org/10.1038/nclimate3255.

Baum-Snow, N. 2007a. "Did Highways Cause Suburbanization?" *Quarterly Journal of Economics* 122 (2): 775–805.

———. 2007b. "Suburbanization and Transportation in the Monocentric Model." *Journal of Urban Economics* 62 (3): 405–23.

Becerra, O, Cavallo, E, and Noy, I. 2013. "Where Is the Money? Post-Disaster Foreign Aid Flows." *Environment and Development Economics*, November: 1–26.

Beddington, J. 2010. "Food Security: Contributions from Science to a New and Greener Revolution." *Philosophical Transactions of the Royal Society B: Biological Sciences* 365 (1537): 61–71. https://doi.org/10.1098/rstb.2009.0201.

Beltrán, A, Maddison, D, and Elliott, R. 2018. *Is Flood Risk Capitalised in Property Values?* Ecological Economics 146: 668-685. https://www.sciencedirect.com/science/article/abs/pii/S0921800916314732.

Benson, C, and Clay, E. 2004. *Understanding the Economic and Financial Impacts of Natural Disasters*. Disaster Risk Management Series. World Bank: Washington DC. http://elibrary.worldbank.org/doi/abs/10.1596/0-8213-5685-2.

Berry, H, Bowen, K, and Kjellstrom, T. 2010. "Climate Change and Mental Health: A Causal Pathways Framework." *International Journal of Public Health* 55: 123–32.

Bin, O and Polasky, S. 2004. "Effects of Flood Hazards on Property Values: Evidence Before and After Hurricane Floyd." *Land Economics* 80 (4): 490. https://doi.org/10.2307/3655805.

Bolton, P, Despres, M, Pereira, Da Silva, LA, Samama, F and Svartzman, R. 2020. *The Green Swan: Central Banking and Financial Stability in the Age of Climate Change*. https://www.bis.org/publ/othp31.pdf.

Borensztein, E, Cavallo, E and Valenzuela, P. 2009. "Debt Sustainability under Catastrophic Risk: The Case for Government Budget Insurance." *Risk Management and Insurance Review* 12 (2): 273–294.

Bowen, T, del Ninno, C, Andrews, C, Coll-Black, S, Gentilini, U, Johnson, K, Kawasoe, Y, Kryeziu, A, Maher, B, and Williams, A. 2020. *Adaptive Social Protection: Building Resilience to Shocks.* International Development in Focus. World Bank: Washington, DC. https://doi.org/10.1596/978-1-4648-1575-1.

British Standards Institution. 2011. *Climate Change Adaptation—Adapting to Climate Risks Using ISO 9001, ISO 14001, BS 25999, and BS 31100.* British Standards Institution: London.

Brookshire, D, Chang, S, Cochrane, H, Olson, R, Rose, A, and Steenson, J. 1997. "Direct and Indirect Economic Losses from Earthquake Damage." *Earthquake Spectra* 13 (4): 683–701. https://doi.org/10.1193/1.1585975.

Brown, J, Zelenska, T and Mobarak, M. 2013. "Barriers to Adoption of Products and Technologies that Aid Risk Management in Developing Countries." In *World Development Report 2014*, 1–40. https://openknowledge.worldbank.org/handle/10986/16365.

Bryan, G, Chowdhury, S, and Mobarak, A M. 2012. *Seasonal Migration and Risk Aversion*. CEPR discussion paper. https://cepr.org/active/publications/discussion_papers/dp.php?dpno=8739.

Bunn, C, Lundy, M, Castro-Llanos, F. 2018. "Replication Data for: The impact of climate change on coffee production in Central America." Harvard Dataverse. https://doi.org/10.7910/DVN/9QUGUR

Burke, M, Hsiang, S and Miguel, E. 2015. "Global Non-Linear Effect of Temperature on Economic Production." *Nature* 527 (7577): 235–39. https://doi.org/10.1038/nature15725.

Campiglio, E, Dafermos, Y, Monnin, P, Ryan-Collins, J, Schotten, G, and Tanaka, M. 2018. "Climate Change Challenges for Central Banks and Financial Regulators" *Nature Climate Change* 8: 462–68. https://www.nature.com/articles/s41558-018-0175-0/.

Carney, M. 2015. *Breaking the Tragedy of the Horizon—Climate Change and Financial Stability*. Speech given at Lloyd's of London. https://www.bis.org/review/r151009a.htm.

Carsell, K, Pingel, N, and Ford, D. 2004. "Quantifying the Benefit of a Flood Warning System." *Natural Hazards Review* 5 (3): 131–40.

Cavallo, E, Galiani, S, Noy, I, and Pantano, J. 2013. "Catastrophic Natural Disasters and Economic Growth." *Review of Economics and Statistics* 95 (5): 1549–61. https://doi.org/10.1162/REST_a_00413.

Cervigni, R and Morris, M. 2016. *Confronting Drought in Africa's Drylands: Opportunities for Enhancing Resilience*. Africa Development Forum Series. World Bank. https://doi.org/10.1596/978-1-4648-0817-3.

Chambwera, M, Heal, G, Dubeux, C, Hallegatte, S, Leclerc, L, Markandya, A, McCarl, B, Mechler, R, and Neumann, J. 2014. "Economics of Adaptation." In Field, C, Barros, V, Dokken, D, Mach, K, Mastrandrea, M, Bilir, T, Chatterjee, M et al. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects.* Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, 945–77. Cambridge University Press: Cambridge, United Kingdom and New York, NY, USA.

Chopra, S and Sodhi, M. 2004. "Managing Risk to Avoid Supply-Chain Breakdown: By Understanding the Variety and Interconnectedness of Supply-Chain Risks, Managers Can Tailor Balanced, Effective Risk-Reduction Strategies for Their Companies." *MIT Sloan Management Review* 46 (1): 53–62.

Clarke, D, Coll-Black, S, Cooney, N, and Edwards, A. 2016a. *A Methodology to Assess Indicative Costs of Risk Financing Strategies for Scaling Up Ethiopia's Productive Safety Net Programme*. World Bank policy research working paper. https://doi.org/10.1596/1813-9450-7719.

Clarke, D, Mahul, O, Poulter, R, and Teh, T-L. 2016b. *Evaluating Sovereign Disaster Risk Finance Strategies: A Framework.* https://openknowledge.worldbank.org/handle/10986/24637.

Clarke, D and Dercon, S. 2016. *Dull Disasters? How Planning Ahead Will Make a Difference*. https://tinyurl.com/y879ylwz.

Clarke, D and Poulter, R. 2014. *A Methodology for Calculating the Opportunity Cost of Layered Sovereign DRFI Strategies.* SDRFI Impact Appraisal Project.

Cochrane, H. 2004. "Economic Loss: Myth and Measurement." *Disaster Prevention and Management: An International Journal* 13 (4): 290–96. https://doi.org/10.1108/09653560410556500.

Coffman, M and Noy, I. 2012. "Hurricane Iniki: Measuring the Long-Term Economic Impact of a Natural Disaster Using Synthetic Control." *Environment and Development Economics* 17 (2): 187–205. https://doi.org/10.1017/S1355770X11000350.

Cohen, A J. 1989. "Prices, Capital, and the One-Commodity Model in Neoclassical and Classical Theories." *History of Political Economy* 21 (2): 231–51. https://doi.org/10.1215/00182702-21-2-231.

Cohen, A J and Harcourt, G C. 2003. "Retrospectives Whatever Happened to the Cambridge Capital Theory Controversies?" *Journal of Economic Perspectives* 17 (1): 199–214. https://doi.org/10.1257/089533003321165010.

Colon, C, Hallegatte, S, and Rozenberg, J. 2019. *Transportation and Supply Chain Resilience in the United Republic of Tanzania: Assessing the Supply-Chain Impacts of Disaster-Induced Transportation Disruptions.* https://openknowledge.worldbank.org/handle/10986/31909.

Council of Standards Australia. 2013. *Climate Change Adaptation for Settlements and Infrastructure: A Risk Based Approach.* AS 5334—2013, Standards Australia: Sydney. https://infostore.saiglobal.com/store/details.aspx?ProductID=1631218.

Damania, R, Desbureaux, S, Hyland, M, Islam, A, Moore, S, Rodella, A-S, Russ, J, and Zaveri, E. 2017. *Uncharted Waters: The New Economics of Water Scarcity and Variability*. World Bank. https://doi.org/10.1596/978-1-4648-1179-1.

Dar, M, de Janvry, A, Emerick, K, Raitzer, D, and Sadoulet, E. 2013. "Flood-Tolerant Rice Reduces Yield Variability and Raises Expected Yield, Differentially Benefitting Socially Disadvantaged Groups." *Scientific Reports* 3. https://doi.org/10.1038/srep03315.

Das, S and Vincent, J. 2009. "Mangroves Protected Villages and Reduced Death Toll during Indian Super Cyclone." *Proceedings of the National Academy of Sciences of the United States of America* 106 (18): 7357–60. https://doi.org/10.1073/pnas.0810440106.

de Janvry, A, del Valle, A, and Sadoulet, E. 2016. *Insuring Growth: The Impact of Disaster Funds on Economic Reconstruction in Mexico*. https://tinyurl.com/yb2lebkh.

de Janvry, A, Finan, F, Sadoulet, E, and Vakis, R. 2006. "Can Conditional Cash Transfer Programs Serve as Safety Nets in Keeping Children at School and from Working When Exposed to Shocks?" *Journal of Development Economics* 79 (2): 349–73. https://doi.org/10.1016/j.jdeveco.2006.01.013.

Dell M, Jones B, and Olken B. 2012. "Temperature Shocks and Economic Growth: Evidence from the Last Half Century. *American Economic Journal: Macroeconomics* 4(3): 66–95.

Dellink, R, Lanzi, E, and Chateau, J. 2019. "The Sectoral and Regional Economic Consequences of Climate Change to 2060." *Environmental and Resource Economics* 72 (2): 309–63. https://doi.org/10.1007/s10640-017-0197-5.

Dennig, F, Budolfson, M, Fleurbaey, M, Siebert, A, and Socolow, R. 2015. "Inequality, Climate Impacts on the Future Poor, and Carbon Prices." *Proceedings of the National Academy of Sciences of the United States of America* 112 (52): 15827–32. https://doi.org/10.1073/pnas.1513967112.

Deryugina, T. 2017. "The Fiscal Cost of Hurricanes: Disaster Aid Versus Social Insurance." *American Economic Journal: Economic Policy* 9 (3): 168–98.

Deryugina, T and Hsiang, S. 2017. *The marginal product of climate.* Working paper no. 24072. National Bureau of Economic Research.

Dieppe, A, Kilic Celik, S, and Okou, C. Forthcoming. *Productivity after Major Events*. World Bank working paper.

Dollar, D, Kleineberg, T, and Kraay, A. 2013. *Growth Still Is Good for the Poor.* VOX, CEPR Policy Portal. http://voxeu.org/article/growth-still-good-poor.

Eberhard, A. 2007. *Infrastructure Regulation in Developing Countries: An Exploration of Hybrid and Transitional Models.* World Bank working paper 4. Washington, DC. https://tinyurl.com/y8num463.

EBRD and GCECA. 2018. *Advancing TCFD Guidance on Physical Climate Risks and Opportunities.*

Erman, A, Motte, E, Goyal, R, Asare, A, Takamatsu, S, Chen, X, Malgioglio, S, Skinner, A, Yoshida, N, and Hallegatte, S. 2018. *The Road to Recovery: The Role of Poverty in the Exposure, Vulnerability and Resilience to Floods in Accra*. World Bank policy research working paper. https://doi.org/10.1596/1813-9450-8469.

Erman, A, Tariverdi, M, Obolensky, M, and Hallegatte, S. 2019. *Flooded in Dar Es Salaam – the Role of Poverty in Disaster Risk.* World Bank policy research working paper.

European Commission. 2014. *Commission Implementing Decision of 28.5.2014 on Deciding to Make a Standardisation Request to the European Standardisation Organisations*. European Commission: Brussels. www.etsi.org/images/files/ECMandates/M526.pdf.

Fankhauser, S and Tol, R. 2005. "On Climate Change and Economic Growth." *Resource and Energy Economics* 27: 1–17. https://doi.org/10.1016/j.reseneeco.2004.03.003.

FAO, IFAD, and WFP. 2015. *The State of Food Insecurity in the World: Meeting the 2015 International Hunger Targets: Taking Stock of Uneven Progress.* Rome, Italy. http://www.fao.org/3/a-i4646e.pdf.

Fargher, S, and Hallegatte, S. 2020. *Best Investments for an Economic Recovery from Coronavirus: An Illustration Based on the Fiji Climate Vulnerability Assessment to Pinpoint Stimulus Options*. World Bank: Washington, DC.

Felbermayr, G and Gröschl, J. 2014. "Naturally Negative: The Growth Effects of Natural Disasters." *Journal of Development Economics, Special Issue: Imbalances in Economic Development*, 111 (November): 92–106. https://doi.org/10.1016/j.jdeveco.2014.07.004.

Feyen, E, Utz, R, Zuccardi Huertas, I, Bogdan, O, and Moon, J. 2020. *Macro-Financial Aspects of Climate Change*. World Bank.

Francisco, H, Predo, C, Manasboonphempool, S, Tran, P, Jarungrattanapong, R, The, B, Penalba, L, Tuyen, N, Tuan, TH, Elazegui, D, Shen, Y, and Zhu, Z. 2011. *Determinants of Household Decisions on Adaptation to Extreme Climate Events in Southeast Asia.* EEPSEA Research Reports. Vol. 5. http://www.eepsea.net/pub/rr/2011-RR5%20(By%20Hermi%20et%20al).pdf.

Gentilini, U, Almenfi, M, and Dale, P. 2020. *Social Protection and Jobs Responses to COVID-19: A Real-Time Review of Country Measures.* World Bank: Washington, DC.

Gerling, K. 2017. *The Macro-Fiscal Aftermath of Weather-Related Disasters: Do Loss Dimensions Matter?* https://tinyurl.com/y9xzuux9

GFDRR and World Bank Group. 2014. *Financial Protection against Disasters: An Operational Framework for Disaster Risk Financing and Insurance*. World Bank: Washington, DC.

Gilbert, N. 2012. "African Agriculture: Dirt Poor." *Nature* 483 (7391): 525–27. https://doi.org/10.1038/483525a.

Gill, I, Izvorski, I, van Eeghen, W, and de Rosa, D. 2014. *Diversified Development: Making the Most of Natural Resources in Eurasia.*

Glachant, M, Dechezleprêtre, A, Fankhauser, S, and Stoever, J. 2020. *Invention and Global Diffusion of Technologies for Climate Change Adaptation: A Patent Analysis.*

GCA. 2019. *Adapt Now: A Global Call for Leadership on Climate Resilience.* Global Commission for Adaptation. https://cdn.gca.org/assets/2019-09/GlobalCommission_Report_FINAL.pdf.

Government of Fiji and World Bank. 2017. *Climate Vulnerability Assessment: Making Fiji Climate Resilient.* https://tinyurl.com/ydefb2x9.

Government of the Commonwealth of Dominica. 2017. *Post-Disaster Needs Assessment Hurricane Maria: A Report by the Government of the Commonwealth of Dominica.*

Gunasekera, R, Ishizawa, O, Aubrecht, C, Blankespoor, B, Murray, S, Pomonis, A, and Daniell, J. 2015. "Developing an Adaptive Global Exposure Model to Support the Generation of Country Disaster Risk Profiles." *Earth-Science Reviews* 150, 594-608. Elsevier. https://doi.org/10.1016/j.earscirev.2015.08.012.

Guo, C and Costello, C. 2013. "The Value of Adaption: Climate Change and Timberland Management. *Journal of Environmental Economics and Management* 65: 452–68.

Haasnoot, M, Kwakkel, J, Walker, W, and ter Maat, J. 2013. "Dynamic Adaptive Policy Pathways: A Method for Crafting Robust Decisions for a Deeply Uncertain World." *Global Environmental Change* 23 (2): 485–98.

Haimes, Y and Jiang, P. 2001. "Leontief-Based Model of Risk in Complex Interconnected Infrastructures." *Journal of Infrastructure Systems* 7 (1): 1–12.

Hallegatte, S. 2008. "An Adaptive Regional Input-Output Model and Its Application to the Assessment of the Economic Cost of Katrina." *Risk Analysis: An International Journal* 28 (3): 779–99. https://doi.org/10.1111/j.1539-6924.2008.01046.x.

———. 2012. *A Cost Effective Solution to Reduce Disaster Losses in Developing Countries. Hydro-Meteorological Services, Early Warning, and Evacuation.* World Bank policy research working paper. https://doi.org/10.1596/1813-9450-6058.

———. 2013. "Modeling the Roles of Heterogeneity, Substitution, and Inventories in the Assessment of Natural Disaster Economic Costs." *Risk Analysis* 34 (1): 152–67. https://doi.org/10.1111/risa.12090.

Hallegatte, S and Dumas, P. 2009. "Can Natural Disasters Have Positive Consequences? Investigating the Role of Embodied Technical Change." *Ecological Economics* 68 (3): 777–86. https://doi.org/10.1016/j.ecolecon.2008.06.011.

Hallegatte, S and Ghil, M. 2008. "Natural Disasters Impacting a Macroeconomic Model with Endogenous Dynamics." *Ecological Economics* 68 (1–2): 582–92. https://doi.org/10.1016/j.ecolecon.2008.05.022.

Hallegatte, S and Rentschler, J. 2015. "Risk Management for Development-Assessing Obstacles and Prioritizing Action." *Risk Analysis* 35 (2): 193–210. https://doi.org/10.1111/risa.12269.

———. 2018. *The Last Mile.*

Hallegatte, S and Rozenberg, J. 2017. "Climate Change through a Poverty Lens." *Nature Climate Change* 7 (4): 250–56. https://doi.org/10.1038/nclimate3253.

Hallegatte, S and Vogt-Schilb, A. 2019. "Are Losses from Natural Disasters More than Just Asset Losses? The Role of Capital Aggregation, Sector Interactions, and Investment Behaviors." In: Okuyama, Y and Rose, A (eds.) *Advances in Spatial and Economic Modeling of Disaster Impacts.* Advances in Spatial Science (The Regional Science Series), 15–42. Springer International Publishing. https://doi.org/10.1007/978-3-030-16237-5_2.

Hallegatte, S, Bangalore, M, Bonzanigo, L, Fay, M, Kane, T, Narloch, U, Rozenberg, J, Treguer, D, and Vogt-Schilb, A. 2015. *Shock Waves: Managing the Impacts of Climate Change on Poverty.* World Bank Publications. https://doi.org/10.1596/978-1-4648-0673-5.

Hallegatte, S, Green, C, Nicholls, R, and Corfee-Morlot, J. 2013. "Future Flood Losses in Major Coastal Cities." *Nature Climate Change* 3 (9): 802–6. https://doi.org/10.1038/nclimate1979.

Hallegatte, S, Hourcade, JC, and Ambrosi, P. 2007a. "Using Climate Analogues for Assessing Climate Change Economic Impacts in Urban Areas." *Climatic Change* 82, 47–60. https://doi.org/10.1007/s10584-006-9161-z.

Hallegatte, S, Hourcade, JC, and Dumas, P. 2007b. "Why Economic Dynamics Matter in Assessing Climate Change Damages: Illustration on Extreme Events." *Ecological Economics* 62 (2): 330–40. https://doi.org/10.1016/j.ecolecon.2006.06.006.

Hallegatte, S, Rentschler, J, and Rozenberg, J. 2019. *Lifelines: The Resilient Infrastructure Opportunity. Sustainable Infrastructure Series.* World Bank Group: Washington, DC. https://doi.org/10.1596/978-1-4648-1430-3.

Hallegatte, S, Rentschler, J, and Walsh, B. 2018. *Building Back Better: Achieving Resilience through Stronger, Faster, and More Inclusive Post-Disaster Reconstruction*. https://elibrary.worldbank.org/doi/abs/10.1596/29867.

Hallegatte, S, Rogelj, J, Allen, M, Clarke, L, Edenhofer, O, Field, C, Friedlingstein, P, van Kesteren, L, Knutti, R, Mach, K, Mastrandrea, M, Michel, A, Minx, J, Oppenheimer, M, Plattner, G-K, Riahi, K, Schaeffer, M, Stocker, T, and van Vurren, D. 2016a. "Mapping the Climate Change Challenge." *Nature Climate Change* 6 (7): 663–68. https://doi.org/10.1038/nclimate3057.

Hallegatte, S, Vogt-Schilb, A, Bangalore, M, and Rozenberg, J. 2016b. *Unbreakable: Building the Resilience of the Poor in the Face of Natural Disasters*. World Bank. https://doi.org/10.1596/978-1-4648-1003-9.

Hallstrom, D and Smith, K. 2005. "Market Responses to Hurricanes." *Journal of Environmental Economics and Management* 50 (3): 541–61. https://doi.org/10.1016/j.jeem.2005.05.002.

Hamel, G and Valikangas, L. 2003. "The Quest for Resilience." *Harvard Business Review*. https://hbr.org/2003/09/the-quest-for-resilience.

Hammer, S and Hallegatte, S. 2020. *Planning for the Economic Recovery from COVID-19: A Sustainability Checklist for Policymakers*, (blog) April 14. https://tinyurl.com/y8jrf52k.

Harrison, A and Rodriguez-Clare, A. 2009. *Trade, Foreign Investment, and Industrial Policy for Developing Countries*. National Bureau of Economic Research. http://www.nber.org/papers/w15261.

Heal, G and Park, J. 2016. "Reflections—Temperature Stress and the Direct Impact of Climate Change: A Review of an Emerging Literature." *Review of Environmental Economics and Policy*, 10(2), 347–362.

Henriet, F, Hallegatte, S, and Tabourier, L. 2012. "Firm-network Characteristics and Economic Robustness to Natural Disasters." *Journal of Economic Dynamics and Control* 36 (1): 150–67. https://doi.org/10.1016/j.jedc.2011.10.001.

Hesse, H, Ahluwalia, M, Bacha, E, Lord, B, Browne, J, Dervis, K, Foxley, A, Tong, GC, Duck-soo, H, Hübner, D, Jämtin, C, Kuczynski, P-P, Leipziger, D, Manuel, T, Mohieldin, M, Okonjo-Iweala, N, Rubin, R, Solow, R, Spence, M, Venner, D, Zedillo, E, and Xiaochuan, Z. 2008. *Export Diversification and Economic Growth Commission on Growth and Development*. World Bank: Washington, DC.

Holway, J and Burby, R. 1990. "The Effects of Floodplain Development Controls on Residential Land Values." *Land Economics* 66 (3): 259. https://doi.org/10.2307/3146728.

Hornbeck, R and Keniston, D. 2017. "Creative Destruction: Barriers to Urban Growth and the Great Boston Fire of 1872." *American Economic Review*. Vol. 107. https://doi.org/10.1257/aer.20141707.

Hsiang, S and Jina, A. 2014. *The Causal Effect of Environmental Catastrophe on Long-Run Economic Growth: Evidence From 6,700 Cyclones.* https://doi.org/10.3386/w20352.

Hsiang, S, Delgado, M, Mohan, S, Rasmussen, D J, Muir-wood, R, Wilson, P, Oppenheimer, M, Larsen, K, and Houser, T. 2017. "Estimating Economic Damage from Climate Change in the United States." *Science* 356 (6345): 1362–69. https://doi.org/10.1126/science.aal4369.

IAIS/SIF. 2018. *Issues Paper on Climate Change Risks to the Insurance Sector.*

IFC and EBRD. 2013. Climate Risk Case Study—Pilot Climate Change Adaptation Market Study: Turkey.

ILO, 2017, World Social Protection Report 2017-19: Universal social protection to achieve the Sustainable Development Goals. International Labour Office—Geneva: ILO, 2017.

IMF. 2014. *Sustaining Long-Run Growth and Macroeconomic Stability in Low-Income Countries—the Role of Structural Transformation and Diversification.* IMF Policy Paper.

——— 2017. *World Economic Outlook, October 2017: Seeking Sustainable Growth: Short-Term Recovery, Long-Term Challenges.* International Monetary Fund. https://www.imf.org/en/Publications/WEO/Issues/2017/09/19/world-economic-outlook-october-2017.

——— 2019. *Building Resilience in Developing Countries Vulnerable to Large Natural Disasters.* IMF Policy Paper. https://tinyurl.com/y4vxcz7x.

IMF and World Bank. 2018. *St. Lucia: Climate Change Policy Assessment.* https://www.imf.org/en/Publications/CR/Issues/2018/06/21/St-46007.

Inoue, H and Todo, Y. 2019. "Firm-level Propagation of Shocks through Supply-chain Networks." *Nature Sustainability* 2 (9): 841–47. https://doi.org/10.1038/s41893-019-0351-x.

International Labor Organization. 2019. *Working on a Warmer Planet: The Effect of Heat Stress on Productivity and Decent Work.* https://www.ilo.org/global/publications/books/WCMS_711919/lang--en/index.htm.

IPCC. 2014. *Climate Change 2014: Synthesis Report*. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change — core writing team, Pachauri, R and Meyer, L (eds.). IPCC: Geneva, Switzerland.

Ishizawa, O and Miranda, J. 2016. *Weathering Storms Understanding the Impact of Natural Disasters on the Poor in Central America.* https://ideas.repec.org/p/wbk/wbrwps/7692.html.

ISO. 2015. *Practical Tools for Addressing Climate Change.* International Standards Organisation: Geneva.

Jafino, BA, Walsh, B, Rozenberg, J and Hallegatte, S. 2020. *Revised estimates of the impact of climate change on extreme poverty by 2030*. World Bank policy research working paper.

Jamison, D, Summers, L, Alleyne, G Arrow, K, Berkley, S, Binagwaho, S, Bustreo, F, Evans, D, Feachem, R, Frenk, J, Ghosh, G, Goldie, S, Guo, Y, Gupta, S, Horton, R, Kruk, M, Mahmoud, A, Mohohlo, L, Ncube, M, Pablos-Mendez, A, Reddy, KS, Saxenian, H, Soucat, A, Ultveit-Moe, KH, and Yamey, G. 2013. "Global Health 2035: A World Converging within a Generation." *The Lancet* 382 (9908): 1898–1955.

Jassogne, L, Läderach, P, and Van Asten, P. 2013. "The Impact of Climate Change on Coffee in Uganda. Lessons from a Case Study in the Rwenzori Mountains." *Oxfam Policy and Practice* 9: 16.

Kahn, M, Mohaddes, K, Ng, RNC, Hashem Pesaran, M, Raissi, M, and Yang, JC. 2019. *Long-Term Macroeconomic Effects of Climate Change: A Cross-Country Analysis.* Cambridge, MA.

Kahneman, D. 2011. *Thinking, Fast and Slow*. Farrar, Straus and Giroux.

Kalra, N, Hallegatte, S, Lempert, R, Brown, C, Fozzard, A, Gill, S, and Shah, A. 2014. *Agreeing on Robust Decisions New Processes for Decision Making Under Deep Uncertainty.* World Bank policy research working paper. Vol. No. 6906. https://doi.org/doi:10.1596/1813-9450-6906.

Kashiwagi, Y, Matous, P, and Todo, Y. 2018. *International Propagation of Economic Shocks through Global Supply Chains.* WINPEC working paper series E1810.

Kenward, S, Cordier, L, and Islam, R. 2012. *Chars Livelihoods Programme: A Study to Assess the Performance of CLP Raised Plinths, Low Cost Latrines and Access to Clean Water during the July 2012 Flood.* Dhaka, Bangladesh.

Kijewski-Correa, T and Taflanidis, A. 2012. "The Haitian Housing Dilemma: Can Sustainability and Hazard-Resilience Be Achieved?" *Bulletin of Earthquake Engineering* 10 (3): 765–71. https://doi.org/10.1007/s10518-011-9330-y.

Kinnan, C and Townsend, R. 2012. "Kinship and Financial Networks, Formal Financial Access, and Risk Reduction." *American Economic Review* 102 (3): 289–93. https://doi.org/10.1257/aer.102.3.289.

Klomp, J. 2017. "Flooded with Debt." *Journal of International Money and Finance* 73: 93–103.

Klomp, J and De Haan, J. 2015. "Bank Regulation and Financial Fragility in Developing Countries: Does Bank Structure Matter?" *Review of Development Finance* 5 (2): 82–90.

Klomp, J and Valckx, K. 2014. "Natural Disasters and Economic Growth: A Meta-Analysis." *Global Environmental Change* 26 (1): 183–95. https://doi.org/10.1016/j.gloenvcha.2014.02.006.

Koetsier, I. 2017. *Natural Disasters and (Future) Government Debt. In Public or Private Goods?* Edward Elgar Publishing.

Kolstad, C and Moore, F. "Estimating the Economic Impacts of Climate Change Using Weather Observations." *Review of Environmental Economics and Policy* 14.1 (2020): 1–24.

Kornejew, M, Rentschler, J, and Hallegatte, S. 2019. *Well Spent: How Governance Determines the Effectiveness of Infrastructure Investments*. World Bank policy research working paper.

Kreibich, H, Thieken, A, Petrow, T, Müller, M, and Merz, B. 2005. "Flood Loss Reduction of Private Households Due to Building Precautionary Measures—Lessons Learned from the Elbe Flood in August 2002." *Natural Hazards and Earth System Science* 5 (1): 117–26. https://doi.org/10.5194/nhess-5-117-2005.

Kunreuther, H and Heal, G. 2003. "Interdependent Security." *Journal of Risk and Uncertainty* 26 (2/3): 231–49. https://doi.org/10.1023/A:1024119208153.

Kunreuther, H, Pauly, M, and McMorrow, S. 2013. *Insurance and Behavioral Economics: Improving Decisions in the Most Misunderstood Industry.* Cambridge University Press: New York.

Lall, S and Deichmann, U. 2012. "Density and Disasters: Economics of Urban Hazard Risk." *World Bank Research Observer* 27 (1): 74–105. https://doi.org/10.1093/wbro/lkr006.

Lempert, RJ and Groves, DG. 2010. "Identifying and Evaluating Robust Adaptive Policy Responses to Climate Change for Water Management Agencies in the American West." *Technological Forecasting and Social Change* 77 (6): 960–74.

Lempert, RJ, Popper, SW, and Bankes, SC. 2003. *Shaping the Next One Hundred Years: New Methods for Quantitative, Long-Term Policy Analysis*. RAND: Santa Monica, CA.

Lis, E and Nickel, C. 2010. "The Impact of Extreme Weather Events on Budget Balances." *International Tax and Public Finance* 17 (4): 378–399.

Macours, K, Premand, P, and Vakis, R. 2012. "Transfers, Diversification and Household Risk Strategies: Experimental Evidence with Lessons for Climate Change Adaptation." *Uma Ética Para Quantos?* XXXIII (2): 81–87.

Mahul, O and Ghesquiere, F. 2010. *Financial Protection of the State against Natural Disasters: A Primer.* https://doi.org/10.1596/1813-9450-5429.

Mannakkara, S, Wilkinson, S, and Potangaroa, R. 2014. "Build Back Better: Implementation in Victorian Bushfire Reconstruction." *Disasters* 38 (2): 267–90. https://doi.org/10.1111/disa.12041.

McCarl, B, Villavicencio, X, and Wu, X. 2008. "Climate Change and Future Analysis: Is Stationarity Dying?" *American Journal of Agricultural Economics* 90 (5): 1241–47. https://doi.org/10.1111/j.1467-8276.2008.01211.x.

Melecky, M and Raddatz, C. 2011. *How Do Governments Respond after Catastrophes? Natural-Disaster Shocks and the Fiscal Stance.* World Bank policy research working paper, no. 5564: 59. https://doi.org/10.1596/1813-9450-5564.

Menezes-Filho, N and Muendler, M-A. 2011. "Labor Reallocation in Response to Trade Reform." *National Bureau of Economic Research Working Paper Series.* Vol. No. 17372. https://doi.org/10.3386/w17372.

Miyamoto International. 2019. *Overview of Engineering Options for Increasing Infrastructure Resilience.* Background paper for this report. World Bank: Washington, DC. http://documents.worldbank.org/curated/en/474111560527161937/pdf/Final-Report.pdf

Morduch, J. 1995. "Income Smoothing and Consumption Smoothing." *Journal of Economic Perspectives* 9 (3): 103–14. https://doi.org/10.1257/jep.9.3.103.

Muendler, M-A. 2010. "Trade Reform, Employment Allocation and Worker Flows." In Porto, G and Hoekman, B (eds.) *Trade Adjustment Costs in Developing Countries: Impacts, Determinants and Policy Responses*. World Bank: Washington, DC.

Murphy, K, Shleifer, A, and Vishny, R. 1988. *Industrialization and the Big Push*. Working paper 2708. National Bureau of Economic Research.

NGFS. 2020. *Guide for Supervisors: Integrating Climate-related and Environmental Risks into Prudential Supervision*. Network for Greening the Financial System. https://www.ngfs.net/sites/default/files/medias/documents/ngfs_guide_for_supervisors.pdf.

Nicolas, C, Rentschler, J, Potter van Loon, A, Oguah, S, Schweikert, A, Deinert, M, Koks, E, Arderne, C, Cubas, D, Li, J and Ichikawa, E. 2019. *Stronger Power: Improving Power Sector Resilience to Natural Hazards.* World Bank. http://documents.worldbank.org/curated/en/200771560790885170/

Nordhaus, W. 1994. *Managing the Global Commons: The Economics of Climate Change.*

Noy, I and Nualsri, A. 2011. "Fiscal Storms: Public Spending and Revenues in the Aftermath of Natural Disasters." *Environment and Development Economics* 16 (1): 113–28. https://doi.org/10.1017/S1355770X1000046X.

OECD. 2016. *Improving the Evidence Base on the Costs of Disasters. Key Findings from an OECD Survey Joint Expert Meeting on Disaster Loss Data*. Organisation for Economic Co-operation and Development.

———. 2019. *Good Governance for Critical Infrastructure Resilience*. OECD Review of Risk Management Practices. Organisation for Economic Co-operation and Development: Paris.

OECD and World Bank. 2019. *Fiscal Resilience to Natural Disasters: Lessons from Country Experiences*. OECD Publishing: Paris. https://doi.org/10.1787/27a4198a-en.

Okuno-Fujiwara, M. 1988. "Interdependence of Industries, Coordination Failure and Strategic Promotion of an Industry." *Journal of International Economics* 25 (1–2): 25–43.

Okuyama, Y and Rose, A. 2019. "Advances in Spatial and Economic Modeling of Disaster Impacts: Introduction." In: Okuyama, Y and Rose, A (eds.) *Advances in Spatial and Economic Modeling of Disaster Impacts.* Advances in Spatial Science (The Regional Science Series), 1–11. Springer International Publishing. https://doi.org/10.1007/978-3-030-16237-5_1.

Oosterhaven, J. 1988. "On the Plausibility of the Supply-Driven Input-Output Model." *Journal of Regional Science* 28 (2): 203–17. https://doi.org/10.1111/j.1467-9787.1988.tb01208.x.

Pack, H and Westphal, L. 1986. "Industrial Strategy and Technological Change. Theory versus Reality." *Journal of Development Economics* 22 (1): 87–128.

Peck, M, Levin, R, and Goto, A. 1987. "Picking Losers: Public Policy toward Declining Industries in Japan." *Journal of Japanese Studies* 13 (1): 79. https://doi.org/10.2307/132587.

Pindyck, R. 2013. "Climate Change Policy: What Do the Models Tell Us?" *Journal of Economic Literature* 51 (3): 860–72. https://doi.org/10.1257/jel.51.3.860.

Poontirakul, P, Brown, C, Seville, E, Vargo, J, and Noy, I. 2017. "Insurance as a Double-Edged Sword: Quantitative Evidence from the 2011 Christchurch Earthquake." *Geneva Papers on Risk and Insurance: Issues and Practice* 42 (4): 609–32. https://doi.org/10.1057/s41288-017-0067-y.

Porter, C and White, E. 2016. *Potential for Application of a Probabilistic Catastrophe Risk Modelling Framework to Poverty Outcomes: General Form Vulnerability Functions Relating Household Poverty Outcomes to Hazard Intensity in Ethiopia.* https://doi.org/10.1596/1813-9450-7717.

Porto, G. 2012. *The Cost of Adjustment to Green Growth Policies: Lessons from Trade Adjustment Costs*. World Bank policy research working paper series 6237. Washington, DC. https://openknowledge.worldbank.org/handle/10986/12079.

Przyluski, V and Hallegatte, S. 2012. *Gestion Des Risques Naturels: Leçons de La Tempête Xynthia.* Éditions Quae. Matière à Débattre et à Décider. http://www.sudoc.fr/165515759

Ranger, N, Milner, A, Dietz, S, Frankhauser, S, Lopez, A, and Ruta, G. 2010. *Adaptation in the UK: A Decision-Making Process.* Centre for Climate Change and Economics Policy.

Ratha, DK, Supriyo, D, Kim, EJ, Plaza, S, Seshan, GK and Yameogo, ND. 2020. *COVID-19 Crisis Through a Migration Lens*. Migration and Development Brief no. 32. World Bank Group: Washington, DC.

Ravallion, M. 2016. "Are the World's Poorest Being Left behind?" *Journal of Economic Growth* 21: 139-164. https://doi.org/10.1007/s10887-016-9126-7.

Ray, P and Brown, C. 2015. *Confronting Climate Uncertainty in Water Resources Planning and Project Design: The Decision Tree Framework.* World Bank. https://doi.org/10.1596/978-1-4648-0477-9.

Renn, O. 2008. "White Paper on Risk Governance: Toward an Integrative Framework." In Renn, O and Walker, K (eds.) *Global Risk Governance*, 3–73. Springer: Stuttgart.

Rentschler, J, de Vries Robbe, S, Braese, J, Nguyen, D, Van Ledden, M, and Pozueta, B. 2020. *Resilient Shores: Vietnam's Coastal Development Between Opportunity and Disaster Risk*. World Bank. http://hdl.handle.net/10986/34639.

Rentschler, J, Kornejew, M, Hallegatte, S, Obolensky, M, and Braese, J. 2019. *Underutilized Potential: The Business Costs of Unreliable Infrastructure in Developing Countries*. World Bank policy research working paper.

Rigaud, K, de Sherbinin, A, Jones, B, Bergmann, J, Clement, V, Ober, K, Schewe, J, Adamo, S, McCusker, B, Heuser, S, and Midgley, A. 2018. *Groundswell: Preparing for Internal Climate Migration*. World Bank: Washington, DC. https://openknowledge.worldbank.org/handle/10986/29461.

Robinson, J. 1973. *History Versus Equilibrium.* Collected Economic Papers of Joan Robinson. Thames Polytechnic.

Rodrik, D. 2004. *Industrial Policy for the Twenty-First Century*. Centre for Economic Policy Research, no. 4767.

Rose, A. 2009. *Economic Resilience to Disasters*. CREATE Research Archive.

Rose, A and Liao, S-Y. 2005. "Modeling Regional Economic Resilience to Disasters: A Computable General Equilibrium Analysis of Water Service Disruptions." *Journal of Regional Science* 45 (1): 75–112. https://doi.org/10.1111/j.0022-4146.2005.00365.x.

Rose, A, Oladosu, G and Liao, S-Y. 2007. "Business Interruption Impacts of a Terrorist Attack on the Electric Power System of Los Angeles: Customer Resilience to a Total Blackout." *Risk Analysis* 27 (3): 513–31. https://doi.org/10.1111/j.1539-6924.2007.00912.x.

Rosenstein-Rodan, P. 1943. "Problems of Industrialisation of Eastern and South-Eastern Europe." *The Economic Journal* 53 (210/211): 202. https://doi.org/10.2307/2226317.

Rozenberg, J and Fay, M. 2019. *Beyond the Gap: How Countries Can Afford the Infrastructure They Need While Protecting the Planet.*

Salat, S and Ollivier, G. 2017. *Transforming the Urban Space through Transit-Oriented Development: The 3V Approach*. 113822. World Bank.

Secretaria de Ingresos Publicos. 2019. Informe de Politica Tributaria—Diciembre de 2019. Buenos Aires: Presidencia de la Nacion.

Silva, H, Phelan, P, and Golden, J. 2010. "Modeling Effects of Urban Heat Island Mitigation Strategies on Heat-Related Morbidity: A Case Study for Phoenix, Arizona, USA." *International Journal of Biometeorology* 54 (1): 13–22. https://doi.org/10.1007/s00484-009-0247-y.

Silver, N. 2012. *The Signal and the Noise: Why so Many Predictions Fail—but Some Don't*. Penguin Press: New York.

Skidmore, M and Toya, H. 2007. "Do Natural Disasters Promote Long-Run Growth?" *Economic Inquiry* 40 (4): 664–87. https://onlinelibrary.wiley.com/doi/abs/10.1093/ei/40.4.664.

Stern, N. 2013. "The Structure of Economic Modeling of the Potential Impacts of Climate Change: Grafting Gross Underestimation of Risk onto Already Narrow Science Models." *Journal of Economic Literature* 51 (3): 838–59. https://doi.org/10.1257/jel.51.3.838.

Stone, B, Hess, J, and Frumkin, H. 2010. "Urban Form and Extreme Heat Events: Are Sprawling Cities More Vulnerable to Climate Change than Compact Cities?" *Environmental Health Perspectives* 118 (10): 1425–28. https://doi.org/10.1289/ehp.0901879.

Tan, J-P, Anderson, J, Belli, P, Barnum, H, and Dixon, J. 2001. *Economic Analysis of Investment Operations: Analytical Tools and Practical Applications.* WBI Development Studies. World Bank: Washington, DC.

Tanner, T and Rentschler, J. 2015. *Unlocking the 'Triple Dividend' of Resilience: Why Investing in Disaster Risk Management Pays Off*. Interim policy note. https://www.gfdrr.org/sites/default/files/publication/unlocking_triple_dividend_resilience.pdf.

Tanner, T, Curle, R, Reid, J, Wilkinson, E, Rajput, S, Surminski, S, and Rentschler, J. 2015. *The Triple Dividend of Resilience: Realizing Development Goals through the Multiple Benefits of Disaster Risk Management*. 122524. World Bank.

Tariverdi, M, Fotouhi, H, Moryadee, S, and Miller-Hooks, E. 2019. "Health Care System Disaster—Resilience Optimization Given Its Reliance on Interdependent Critical Lifelines." *Journal of Infrastructure Systems* 25 (1).

Tester, M and Langridge, P. 2010. "Breeding Technologies to Increase Crop Production in a Changing World." *Science* 327 (5967): 818–22. https://doi.org/10.1126/science.1183700.

Thieken, A, Kreibich, H, Müller, M, and Merz, B. 2007. "Coping with Floods: Preparedness, Response and Recovery of Flood-Affected Residents in Germany in 2002." *Hydrological Sciences Journal* 52 (5): 1016–37. https://doi.org/10.1623/hysj.52.5.1016.

Tilman, D, Balzer, C, Hill, J, and Befort, B. 2011. "Global Food Demand and the Sustainable Intensification of Agriculture." *Proceedings of the National Academy of Sciences of the United States of America* 108 (50): 20260–64. https://doi.org/10.1073/pnas.1116437108.

Tol, R. 2002. "Estimates of the Damage Costs of Climate Change: Part 1: Benchmark Estimates." *Environmental and Resource Economics* 21 (1): 47–73. https://doi.org/10.1023/A:1014500930521.

UNISDR. 2015. *Global Assessment Report 2015*. http://www.preventionweb.net/english/hyogo/gar/2015/en/gar-pdf/GAR2015_EN.pdf.

US National Institute of Standards and Technology. 2015. *Community Resilience Planning Guide for Buildings and Infrastructure Systems*. Vols. I and II. US Department of Commerce: Washington, DC. www.nist.gov/el/resilience/guide.cfm.

Vallejo, L and Mullan, M. 2017. *Climate-Resilient Infrastructure: Getting the Policies Right*. OECD Environment working paper 121, OECD Publishing: Paris. http://dx.doi.org/10.1787/02f74d61-en.

Viguié, V, Lemonsu, A, Hallegatte, S, Beaulant, A-L, Marchadier, C, Masson, V, Pigeon, G, and Salagnac, J-L. 2019. *Early Adaptation to Heat Waves and Future Reduction of Air-Conditioning Energy Use in Cities.*

von Peter, G, von Dahlen, S, and Saxena, S. 2012. *Unmitigated Disasters? New Evidence on the Macroeconomic Cost of Natural Catastrophes*. BIS working papers Vol. 394. https://ideas.repec.org/p/bis/biswps/394.html.

Walsh, B and Hallegatte, S. 2019. *Socioeconomic Resilience in Sri Lanka: Natural Disaster Poverty and Wellbeing Impact Assessment.* World Bank policy research working paper 9015.

Walsh, B and Hallegatte, S. 2020. "Measuring Natural Risks in the Philippines: Socioeconomic Resilience and Wellbeing Losses." *Economics of Disasters and Climate Change* 4: 249–93. https://doi.org/10.1007/s41885-019-00047-x.

West, C and Lenze, D. 1994. "Modeling the Regional Impact of Natural Disaster and Recovery: A General Framework and an Application to Hurricane Andrew." *International Regional Science Review* 17 (2): 121–50. https://doi.org/10.1177/016001769401700201.

WHO. 2014. *Research for Universal Health Coverage*. World Health Organization.

Wiener, J and Rogers, M. 2002. "Comparing Precaution in the United States and Europe." *Journal of Risk Research* 5 (4): 317–49.

Williams, B. 2002. *Fran, Floyd and Mitigation Policy*. Collinsville, IL, USA.

World Bank. 2013. *World Development Report 2014: Risk and Opportunity—Managing Risk for Development.* https://doi.org/10.1596/978-0-8213-9903-3.

———. 2017. *Sovereign Catastrophe Risk Pools: World Bank Technical Contribution to the G20*. Washington, DC. https://openknowledge.worldbank.org/handle/10986/28311.

———. 2018. *Advancing Disaster Risk Finance in Saint Lucia*. https://doi.org/10.1596/29736.

———. 2020a. *Helsinki Principle 4: World Bank Issues Note Climate-Smart Public Investment Management*. Prepared in Support of the Coalition of Finance Ministers for Climate Action.

———. 2020b. *Reference Guide to Framework Climate Change Legislation*. World Bank.

World Bank Group. 2014. *Financial Protection Against Natural Disasters: An Operational Framework for Disaster Risk Financing and Insurance.* Washington, DC.

———. 2015. *The State of Social Safety Nets 2015.* Washington, DC. https://doi.org/10.1596/978-1-4648-0543-1.

———. 2018. *Managing Coal Mine Closure: Achieving a Just Transition for All.*

World Meteorological Organization, World Bank Group, GFDRR, and USAID. 2015. *Valuing Weather and Climate: Economic Assessment of Meteorological and Hydrological Services.* World Meteorological Organization: Geneva. https://tinyurl.com/y740bqyn.

Endnotes

1. https://www.fsb-tcfd.org/
2. https://www.worldbank.org/en/topic/migrationremittancesdiasporaissues/brief/migration-remittances-data
3. http://thinkhazard.org
4. https://climateknowledgeportal.worldbank.org/
5. These include Fathom and Deltares for global flood maps, the Global Earthquake Model for global earthquake risk maps, and the UN Environment Programme's Global Risk Platform for multiple hazards.
6. https://www.gfdrr.org/en/disaster-risk-country-profiles
7. There are various sources on this risk. See International Labor Organization (2019) for more information.
8. https://agmip.org/data/
9. https://www.isimip.org/outputdata/
10. https://tinyurl.com/y3fpp2hp
11. https://tinyurl.com/y4b2tqv9
12. https://tinyurl.com/y2yfb856
13. Although many infrastructure assets are privately owned, they are heavily regulated and critical for economic performance and population well-being, so the government needs to monitor and regulate their climate change adaptation needs.
14. https://www.tcfdhub.org/recommendations/
15. A return period describes how much time is expected to pass before a natural shock of the same intensity occurs again. Using historic data and based on the statistical frequency of a shock of a certain intensity, it describes the probability of such an event. A flood with a 25-year return period (also known as a 1-in-25-year flood) has a 1/25 or 0.04 annual probability of occurring. In other words, each year there is a 4 percent chance of such an event occurring, regardless of when the last such event took place (Rentschler et al. 2020).
16. https://tinyurl.com/y3lq4xj7
17. https://www.meteoalarm.eu/
18. https://www.worldbank.org/en/news/feature/2013/12/12/improving-women-disasters
19. https://tinyurl.com/y26ujmq7
20. https://climate-laws.org/cclow/geographies/sweden/laws/climate-act
21. https://tinyurl.com/y6673p90
22. https://www.emdat.be/
23. https://www.desinventar.net/
24. https://www.munichre.com/en/solutions/for-industry-clients/natcatservice.html
25. https://www.swissre.com/institute/research/sigma-research.html
26. https://www.preventionweb.net/english/hyogo/gar/2015/en/home/data.php
27. This question was core to the Cambridge capital controversy on the limits of the one-commodity model (Cohen and Harcourt 2003). It is also related to Robinson's (1973) argument on path dependence. Indeed, capital stock can only be represented unambiguously through a single number if it is the result of optimal capital accumulation, or if it can be reallocated instantaneously and at no cost toward its optimal use. Only the assumption of optimal capital allocation allows the removal of relative prices and interest rate from the valuation of the capital stock, making it possible to measure capital with a single variable *K* (Cohen 1989).
28. Disasters have an observable impact on prices, especially in the construction sector (Hallegatte and Vogt-Schilb 2019) and sometimes on food prices. There is less evidence of price adjustments in other sectors, even in the presence of scarcity. One explanation is the combination of anti-gouging regulations (in many places, it is illegal to increase prices in a postdisaster context) and social norms (even if it is legal, it is often considered morally wrong to increase prices when people are struggling to cope with a disaster).
29. https://www.worldbank.org/en/programs/debt-toolkit/dsa
30. https://www.worldbank.org/en/programs/financial-sector-assessment-program
31. For example, Hallegatte et al. (2013) investigate the impact of sea level rise on coastal flood risks in 136 cities and show that assumptions on how these cities will respond to sea level rise are the main drivers of future risk levels, and are much more important than the magnitude and pace of sea level rise.
32. See Guo and Costello (2013) for the case in which adaptation is done through shifts across discrete technologies. In this case, the role of adaptation is more important and long-term impacts cannot be inferred from short-term impacts.
33. https://climate-laws.org/geographies/kenya/laws/climate-change-act-2016
34. https://en.wikipedia.org/wiki/Citizens__convention__for__ecological__transition
35. https://tinyurl.com/y3lq4xj7
36. https://tinyurl.com/y6d9n84h
37. https://tinyurl.com/y2cqd5wm
38. https://climate-laws.org/cclow/geographies/peru/laws/framework-law-no-30754-on-climate-change
39. The benefit-cost ratio or internal rate of return need to be used carefully, because they can change depending on how costs and benefits are defined. In practice, if a cost is relabeled as a negative benefit, then the ratio or rate can change. The NPV is more stable and should be preferred to decide if an investment is profitable.
40. https://www.pub.gov.sg/Documents/PUBOurWaterOurFuture.pdf
41. https://tinyurl.com/yxzkhlm6
42. https://climatescreeningtools.worldbank.org/
43. https://tinyurl.com/ya3gfqus
44. https://www.hydropower.org/news/new-guide-to-help-hydropower-build-resilience-to-climate-change
45. https://climate-laws.org/cclow/geographies/bangladesh/laws/the-climate-change-trust-fund-act
46. https://climate-laws.org/cclow/geographies/tuvalu/laws/climate-change-and-disaster-survival-fund-act-2015-no-11-of-2016
47. https://www.oecd.org/dac/environment-development/Revised%20climate%20marker%20handbook_FINAL.pdf
48. https://tinyurl.com/ycpc5kuo
49. https://www.greengrowthknowledge.org/resource/climate-change-public-expenditure-and-institutional-review-sourcebook
50. https://www.undp.org/content/undp/en/home/librarypage/climate-and-disaster-resilience-/knowing-what-you-spend.html
51. https://datacatalog.worldbank.org/dataset/global-financial-inclusion-global-findex-database
52. http://datatopics.worldbank.org/aspire/

Effective action on resilience and climate change adaptation can be a complex task—requiring coordinated efforts from the highest levels of government to individual households and firms. The *Adaptation Principles* offer a guide to effective climate change adaptation, containing hands-on guidance to the design, implementation and monitoring of national adaptation strategies. It specifies six guiding principles, which correspond to common policy domains:

- Ensuring resilient foundations through rapid and inclusive development;
- Facilitating the adaptation of firms and people;
- Adapting land use and protecting critical public assets and services;
- Increasing people's capacity to cope with and recover from shocks;
- Anticipating and managing macroeconomic and fiscal risks;
- Ensuring effective implementation through prioritization and continuous monitoring.

While outlining these universal *Adaptation Principles*, this guide shows that each country needs to tailor these actions to its specific needs and priorities. To guide this process, *Adaptation Principles* offers concrete and practical tools: Screening questions to identify the most urgent and effective actions, toolboxes illustrating common datasets and methodologies to support decisions, indicators to monitor and evaluate progress, and case studies on how the COVID-19 pandemic influences priorities in taking effective adaptation action.