A SYSTEM-WIDE APPROACH FOR INFRASTRUCTURE RESILIENCE

TECHNICAL NOTE

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GLOBAL CENTER ON ADAPTATION

ADB

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On the cover: The Noi Bai–Lao Cai Highway is an integral section of the eastern link of the Greater Mekong Subregion Northern Economic Corridor, connecting Kunming, Yunnan Province, in the People's Republic of China with Ha Noi as well as Hai Phong and Cai Lan ports in Viet Nam (photo by ADB).

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FOREWORD

A revolution in the planning, design, financing, and delivery of infrastructure is urgently needed to meet the acute needs of our warming world.

Climate risk is affecting infrastructure development strategies and investments worldwide. Rising temperatures, changes in rainfall patterns and intensity, and the increasing frequency of extreme weather events are leading to losses in asset values, higher operating costs and reductions in the economic benefits that infrastructure generates.

Yet investing in climate-resilient infrastructure is critical to adapting to a warming world. The large amounts that are already being spent on post-coronavirus disease (COVID-19) fiscal stimuli provide an unprecedented opportunity to transform investment in, and the delivery of, resilient infrastructure systems. However, with governments under particular financial pressure, it is crucial that investments are sustainable.

This requires a fundamental systemic transformation. To make the case for the changes needed, the Asian Development Bank (ADB) and the Global Center on Adaptation (GCA) have collaborated on this report.

Key findings include the need to move climate-resilient infrastructure planning upstream, integrated at a strategic level; better use of analytical tools to understand climate risk at a systems level; and prioritizing resources for building resilience. Nature-based solutions for adaptation should be promoted and engineering standards improved to enhance resilience of individual assets.

For this to be possible, greater leadership from governmental finance and planning ministries is vital to allow more efficient and flexible responses.

ADB has identified building climate and disaster resilience as one of seven operational priorities under its Strategy 2030, and has set its climate financing targets – 75% of the number of its committed operations (on a three-year rolling average, including sovereign and non-sovereign operations) will be supporting climate change mitigation and adaptation by 2030; and climate finance from ADB's own resources will reach $80 billion cumulatively from 2019 to 2030. Meeting these climate targets will require expanding investments in climate adaptation, especially in the context of infrastructure investments. The recommendations of this report will support ADB's developing member countries in moving beyond climate proofing of individual infrastructure assets to undertake upstream planning for resilient infrastructure systems, generate a pipeline of resilient infrastructure projects, and adopt nature-based solutions for infrastructure resilience.

GCA is catalyzing a global effort to mainstream climate-resilient infrastructure. This work is focused on three pivotal areas: integrating resilience into infrastructure standards; mobilizing finance for resilient infrastructure; and enhancing the resilience of infrastructure systems. On an individual project level, it is working to build capacity for climate-resilient procurement, bringing public investment into the equation. Beyond this, GCA is also working to realize the potential of adopting a whole systems approach, working on initiatives with Bangladesh and Ghana to develop pipelines of resilient infrastructure and fully realize the potential of nature-based solutions. These are bringing together leading researchers, governments, private sector and financing institutions to mobilize investment. It will build on these recommendations to scale up efforts and initiatives to reach more countries and regions.

ADB and GCA are committed to working with partners to support the transformation of climate-resilient infrastructure systems, which will be critical in preparing our societies for the impacts of a changing climate, and sustaining progress toward the Sustainable Development Goals, the Sendai Framework for Disaster Risk Reduction, and the Paris Agreement.

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ABBREVIATIONS

ADB	Asian Development Bank
COVID-19	coronavirus disease
GCA	Global Center on Adaptation
PPP	public–private partnership

EXECUTIVE SUMMARY

What change is needed?

Approaches to planning, delivery, financing, and managing infrastructure need to evolve to prepare for changes in climate in coming decades. Following current practices alone will risk higher costs, poorer service quality, and growing liabilities for the public sector. The leadership of ministries of finance and planning will be crucial to develop resilient infrastructure systems: enabling efficient, flexible responses that enhance resilient economies in a changing climate.

Global infrastructure investment needs over the next decade are estimated at $57 trillion–$95 trillion. These will include the funding for stimulus packages to respond to the coronavirus disease (COVID-19) crisis. It also includes infrastructure to deliver on the internationally agreed 2030 Agenda for Sustainable Development (the Sustainable Development Goals, or SDGs) and for progress toward the goals of the Paris Agreement to limit climate change. Efforts to make infrastructure more climate resilient (so-called climate-proofing) need to be scaled up—and doing so sooner than later will provide excellent value for money.

However, incremental changes to make specific assets resilient will not be enough to tackle the climate change adaptation challenge. A fresh approach is needed. While full appreciation of what this approach requires will only emerge over time, it will include the use of systems thinking to deliver resilient infrastructure through three main actions:

- Moving resilience upstream by integrating climate risk assessment into strategic and early-stage planning of infrastructure, to provide strategic coherence and efficient delivery
- Investing financial resources in adaptation projects, especially green adaptation infrastructure (nature-based solutions or ecosystem-based adaptation), to reduce climate risks and deliver economic growth and socioeconomic benefits
- Mainstreaming the use of climate-resilient standards and regulations throughout the process of infrastructure development, to simplify and deliver resilience as the new normal

Why is change needed?

Transformation is necessary because climate change will fundamentally alter the context in which infrastructure is financed and delivered over the next few decades. Events that are rare today will become much more common. In many parts of Asia, for example, climate change could mean that a river flood that happens currently once a century (the 1-in-100-year event) on average, instead happens once every 20 years, on average. Similarly, extreme heat events are increasing, and unprecedented high temperatures have been recorded in many locations across Asia in the last few years (including exceeding 50°C for the first time). As investors are now aware, these changes are an economic and financial risk for infrastructure. Governments and private infrastructure providers will need to prepare for increased risks of asset-value losses, increases in capital and operating costs, and/or a decline in the economic benefits or revenues that infrastructure assets generate.

Acting now is much cheaper than deferring until the future, and will generate greater economic benefits. The magnitude of the costs of inaction—versus the benefits of proactive action—are large; disproportionately so in Asia and the Pacific. Delaying action will make it much harder to tackle climate risks, and may make large future costs inevitable. Opportunities for building resilience in infrastructure planning will decline with time.

However, the impact of climate change on infrastructure financing will extend beyond any individual asset. Climate change will also have implications for the entire approach to planning, delivering, financing, and managing infrastructure in a country (i.e. at the systems-level), and thus on the national public finances. This is due to four key issues:

- An increased chance of cascading risks, as damage to critical infrastructure leads to knock-on impacts in other sectors and geographies. These will magnify the economic damage of climate-related disasters and exacerbate their fiscal impact.
- Credit rating agencies factoring climate change risks into sovereign creditworthiness increasing risk premiums. This could increase borrowing costs, requiring government spending on debt servicing rather than development.
- Climate change leading to contingent liabilities with implications for financing models, including public–private partnership (PPP), potentially. Difficulties in allocating climate risks may make PPPs increasingly unattractive for infrastructure financing.
- Rising climate extremes undermining insurance, with availability of insurance declining and/or its price rising, increasing the risk of financial instability.

What do these changes mean in practice? Why are they worth addressing?

Moving climate resilient infrastructure planning upstream involves integrating—or mainstreaming—climate change into all development planning. This means, for example, that when deciding where development takes place, or which investments and sectors should be supported, these decisions take account of climate risks. Countries often make changes *after* a disaster strikes; for example, changing where development is permitted to occur or what infrastructure should serve a location. A key part of moving climate adaptation upstream is to assess climate-related risks and make changes before lives are lost and economies disrupted.

Upstream planning can be facilitated by new analytical tools that help stakeholders see the bigger picture and understand the resilience of infrastructure at the network level. For example, efforts to make tracks more resilient to floods may not be sufficient if the electricity substation that powers the trains on this railway are at risk of flooding. Using these tools can help with the prioritisation of resources, for example, protecting the most important nodes across the infrastructure network. It also offers the potential to develop integrated cross-cutting or cross-sectoral solutions. Small investments in these tools can yield large dividends in terms of reduced costs and enhanced resilience.

Investing in climate adaptation infrastructure brings high economic benefits and offers a range of other socioeconomic gains. Demand for such infrastructure—and the value it generates—will increase with climate change. Finance and planning ministries need to factor in rising resilience infrastructure requirements into national infrastructure plans. Green adaptation infrastructure is often particularly attractive. For example, urban green infrastructure can reduce the risks posed by flooding, but it can also deliver amenity, mitigation and environmental benefits. That makes it a good economic development project as well as being a good adaptation project. Many adaptation projects are also labor intensive, making them attractive for COVID-19 recovery packages.

Mainstreaming the use of climate resilient standards can help to achieve many of these changes. Standards provide a low-cost way to facilitate the sharing of best practice. They can be used to adjust engineering practice to improve climate resilience in individual assets. Standards can also drive other necessary changes, for example, by focusing development in areas less prone to hazards or helping organizations incorporate systems thinking.

International partners can offer support for developing countries to embrace this new agenda. As the reality of climate change becomes increasingly clear, all countries will need to make these changes. In developing countries, technical and financial support from a wide array of multilateral and bilateral partners is available to help make infrastructure provision fit for purpose in the 21st century.

SECTION 1

Infrastructure Needs for Changing Climate in the 21st Century

A cargo ship anchored at Malé port in Maldives. Photo: ADB.

Infrastructure plays a key role in social and economic development, and infrastructure investment can help to deliver sustained economic growth and to eradicate remaining poverty. Worldwide, the demand for new infrastructure is estimated at between $57 trillion to $95 trillion by 2030.[1] Similar estimates of infrastructure needs for Asia and the Pacific are $23 trillion over the period 2016–2030, equivalent to $1.5 trillion a year (ADB 2017a). This is concentrated in sectors such as power, transport, telecommunications, and water and sanitation. These needs are driven by ageing infrastructure in advanced economies, and higher growth and structural change in emerging market and developing countries especially from rapid urbanization, and an increasing focus in all countries on the transition to low-carbon development.

Infrastructure built over the next decade needs to address climate change for two key reasons:

- ***Infrastructure has a long lifetime.*** Infrastructure built over the next decade will operate under very different climate conditions to today. Climate change may affect operating costs and/or the revenues delivered, while the increasing frequency and severity of extreme weather could cause asset damage or failure. Although the Paris Agreement[2] agreed goals to help reduce the most severe risks, some climate change is inevitable—current pledges in the Nationally Determined Contributions indicate warming of 3°C (UNEP 2019). Therefore, there is a clear need to integrate resilience into the design of new infrastructure.
- ***Infrastructure decisions can lock-in development patterns for decades.*** Once infrastructure and/or land-use change have occurred, they are often difficult or costly to reverse. As an example, a new road could encourage development in an area that becomes impacted by rising flood risks from climate change, leading to significant damage. There is often a one-off opportunity to prevent these lock-in risks during design.

For these reasons, it is much easier to act now, and doing so will lead to greater benefits. Delaying action makes it much harder to reduce climate risks, and may make large future costs inevitable. Furthermore, opportunities for building resilience in infrastructure planning will decline with time.

Taking account of climate change is vitally important. The size of the costs of inaction—and thus the benefits of preparing for climate change—are very large. Projections point to rising temperatures and more extreme heatwaves, increasing sea-level rise and coastal flooding, more intense rainfall and river and surface flooding, changes in rainfall patterns, and more (IPCC 2018, 2019). While these will affect all regions, they are particularly important for Asia and the Pacific. Of the 10 countries with the highest climate-related disaster risks globally, seven are in the region (ADB, 2017b). From 2008 to 2017, disasters triggered by natural hazards in the region resulted in physical losses of $496 billion (ADB 2019a). The impacts of these events are rising and global losses from weather-related and geophysical hazards in recent years are the highest on record (Jeworrek 2018). Looking to the future, Asia is projected to experience disproportionately high economic costs from climate change, with impacts double the global average by mid-century (OECD 2015).

Climate change is now considered a financial risk. Until recently, climate change was seen primarily as an environmental concern. However, the focus is now shifting to its financial implications.[3] The Task Force on Climate-related Financial Disclosures, established by the G20's Financial Stability Board, aims to increase reporting of climate-related financial information, to help factor them into public and private sector decisions.[4] Many central banks are involved in the Network for Greening the Financial System, a global initiative to ensure the financial system is more resilient (NGFS 2019). Recognizing and tackling climate risks is now expected by financial markets and investors, and benefits will accrue for countries and organizations that move early to demonstrate these are being managed.

Infrastructure investment, especially low-carbon and climate resilient infrastructure, can play a crucial role in building back better from the COVID-19 pandemic. A "good" recovery has several key characteristics, including that investments can be made quickly, are labor-intensive in the short-term, have high economic multipliers, and contribute to the productive asset base (Bhattacharya and Rydge 2020; Hepburn et al. 2020). Many green infrastructure measures, especially if "shovel-ready", perform well against these criteria. This includes measures that target low-carbon development, as well as infrastructure that builds climate and disaster resilience (including nature-based solutions). There is an opportunity to include these investment opportunities in post-COVID-19 stimulus packages.

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1 Low and high estimates are from the GCEC (2014) and OECD (2017) reports.
2 The 2015 Paris Agreement agreed the goal of limiting temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit to 1.5°C.
3 It will also lead to risks with the transition to a low-carbon economy, but these are not the focus of this paper.
4 Task Force on Climate-related Financial Disclosures. https://www.fsb-tcfd.org/.

Several recent studies identify the benefits of making infrastructure climate resilient. The Global Commission on Adaptation (2019) and the World Bank Lifelines report (Hallegatte et al. 2019) both show that making existing and new infrastructure more resilient to the shocks and stresses of the changing climate, makes sound economic sense; on average, the benefits outweigh costs by a ratio of 4:1. The net benefit of investing in resilience in developing countries could be $4.2 trillion over the lifetime of new infrastructure.

Major initiatives recognize the need to encourage more climate-resilient investment:

- The G7 Ise-Shima Principles for Promoting Quality Infrastructure Investment[5] aim to bridge the global demand-supply gap by promoting quality infrastructure investments. The first principle is to ensure effective governance, economic efficiency, sustainability and reliable operation of a project as well as safety and resilience against disaster risks. The fourth principle focuses on alignment with economic and development strategies at the national and regional level, including climate change and environment. It sets out that climate change resilience, conservation of biodiversity and disaster risk reduction should be considered, including through ecosystem-based approaches and green infrastructure.
- The G20 Finance Ministers and Central Bank Governors Principles for Quality Infrastructure Investment (QII), agreed in Fukuoka, Japan in June 2019, emphasize the importance of quality infrastructure investment to close the infrastructure gap. This is supported by the G20 Global Infrastructure Hub, which aims to drive an ambitious agenda on sustainable, resilient, and inclusive infrastructure through action-oriented programs.[6]
- The Helsinki Principles,[7] from the Coalition of Finance Ministers for Climate Action. These include six common principles, and include the need to take climate change and the need for Paris alignment into account in macroeconomic policy, fiscal planning, budgeting, public investment management, and procurement practices.

However, there is a greater need—and a larger opportunity—to act now and in a more transformative way. Despite the benefits of early action, to date, implementation at scale for addressing climate risks in infrastructure has not taken place, and applications so far have focused on making individual assets more resilient. This is likely to be insufficient, given how climate change can affect all aspects of infrastructure planning, delivery, financing, and management. There is a need to go beyond adaptation of individual projects to ensure that whole systems are more resilient (GCA 2019). This includes considering what to build, and where to build it, as well as making sure that the services infrastructure assets provide are climate-resilient. This requires a move from a standard project investment cycle to country and sector-level planning. Alongside this, direct investment in adaptation projects will need to be scaled up to ensure continued economic growth in a changing climate (Box 1).

Box 1. Two Types of Climate Resilient Investment

Adaptation of projects. This aims to improve the climate resilience of existing or planned infrastructure assests such as new roads. It focuses on the additional adaptation response—and the marginal costs and benefits—to tackle climate risks or take advantage of opportunities[a] (also known as adaptation in projects).

Projects for adaptation. This focuses on investments that are deliberately designed and delivered to address climate change risks: to protect people, investments, and economic activity. It involves targeted adaptation (such as a new coastal defence project to reduce the effects of sea-level rise), rather than adaptation of existing projects.

[a] While typically referred to as climate proofing, it should be stressed that it is not practical nor economically efficient to seek to eliminate climate risk.

Source: Authors.

[5] G7 Ise-Shima Principles for Promoting Quality Infrastructure Investment. https://www.mofa.go.jp/files/000196472.pdf.

[6] Global Infrastructure Hub. https://www.gihub.org/.

[7] The Coalition of Finance Ministers for Climate Actions. https://www.financeministersforclimate.org/helsinki-principles.

Border check point on the Lao side of the Mekong River. On the horizon is the second Thai–Lao Friendship Bridge which connects Mukdahan Province in Thailand with Savannakhet in Lao PDR. Photo: ADB.

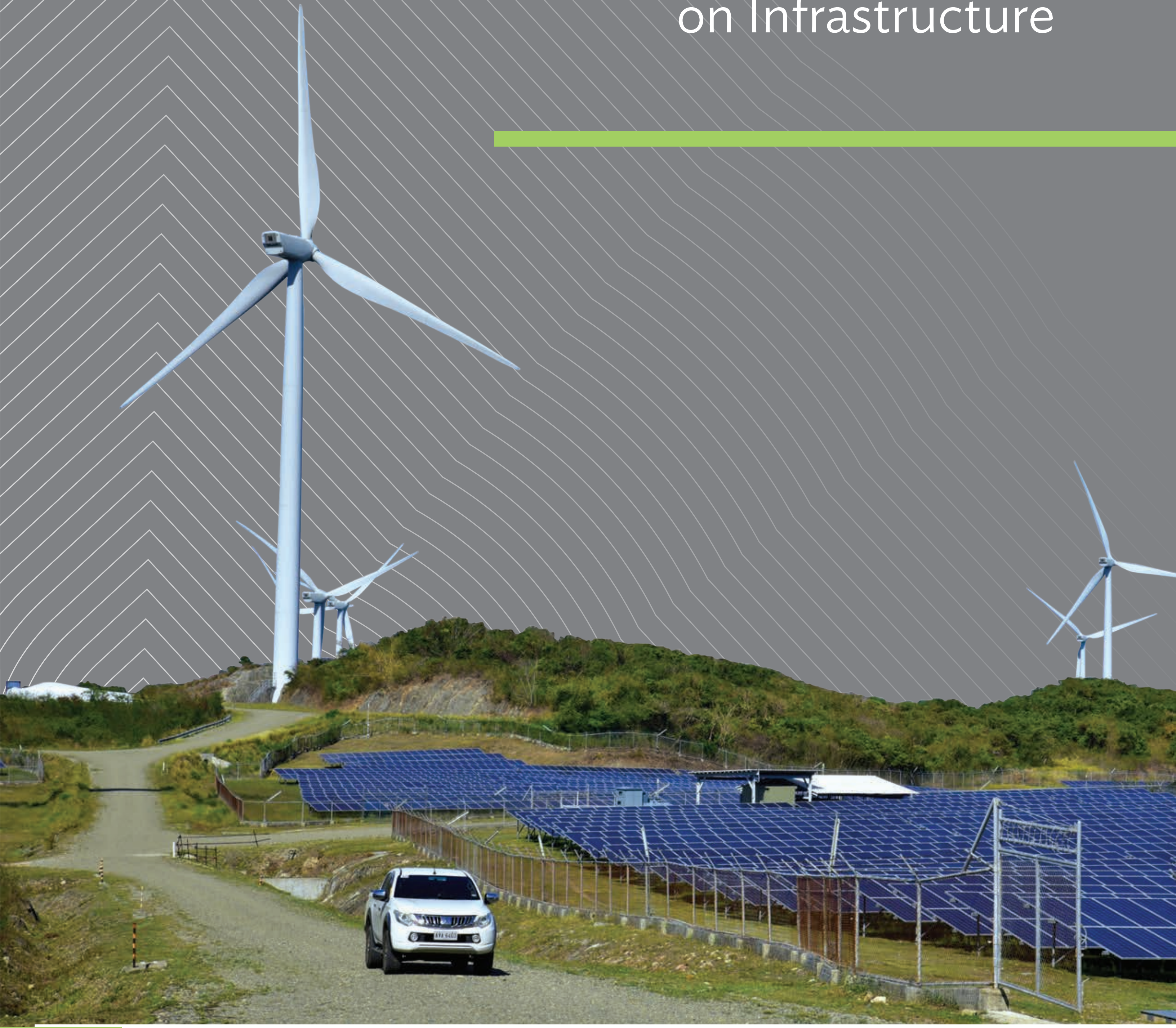
This report is a call for action to step up the consideration of climate-related financial risks in infrastructure, but to extend beyond current initiatives to consider in planning, delivering, financing, and managing national infrastructure plans. It has been developed as an input to the Global Commission on Adaptation's Climate Adaptation Summit 2021 (January 2021), and has been jointly produced by the Asian Development Bank (ADB) and the Global Center on Adaptation (GCA). It is presented recognizing this is only the start of a new agenda, and there is much more to learn.

Planning and finance ministries will have a critical role to play in delivering on this call to action. The impact of climate change on economies could affect a country's tax revenues, trade balance, and capital flows, leading to risks to macroeconomic stability, public finances, and debt sustainability (Hallegatte, Rentschler, and Rozenberg 2020), all of which concern finance ministries.
The impacts of climate change on infrastructure can propagate operational, liquidity, market and credit risks. At the same time, a more strategic approach to managing the climate risks faced by infrastructure and expanding resilience infrastructure will require integration of climate change considerations into the existing national planning cycle and national infrastructure plans.

Section 2 of this report explores how climate change can affect the performance and financing of infrastructure assets, distinguishing between individual assets and the broader system-wide implications of climate change. Section 3 identifies how those responsible for the planning, financing, delivery, and management of infrastructure might respond to these growing system-wide implications, and the wider economic benefits this can generate.

SECTION 2

Economic Implications of Climate Change Impacts on Infrastructure



Solar panels gathering sun power and turbines harvesting wind power at the Burgos Wind and Solar Farm in Burgos, Ilocos Norte in the Philippines. Photo: ADB.

Climate change is not just a social and environmental challenge. It can and will have fundamental impacts on the economics and financing of infrastructure assets, and more widely on financial markets. This section explores these implications in detail. The first part discusses how climate change is expected to impact the financial and operational performance of individual infrastructure assets. The second part identifies how the implications of climate change for infrastructure go beyond individual assets and could have systemic economy-wide implications for infrastructure, for the financial models used to deliver it, and on the public finances.

2.1. The Impact of Climate Change on Individual Assets

Climate change can affect the financial and economic performance of infrastructure assets. It is now recognised that climate change—both more frequent and severe extreme weather events as well as slow onset changes (in temperature, rainfall, etc.)—are likely to have an important influence on key financial parameters of infrastructure, including asset values (capital), current expenditures (operating and maintenance costs), and revenues (ADB 2020). These changes in turn will affect:

- Economic returns delivered by the infrastructure asset—whether the total economic and social benefits generated by the asset are sufficient to justify the costs of investment
- Cash flows (cost and revenues) and hence financial returns delivered by the project—and, in some cases, whether cash flows generated by the asset are sufficient to meet the return requirements of investors

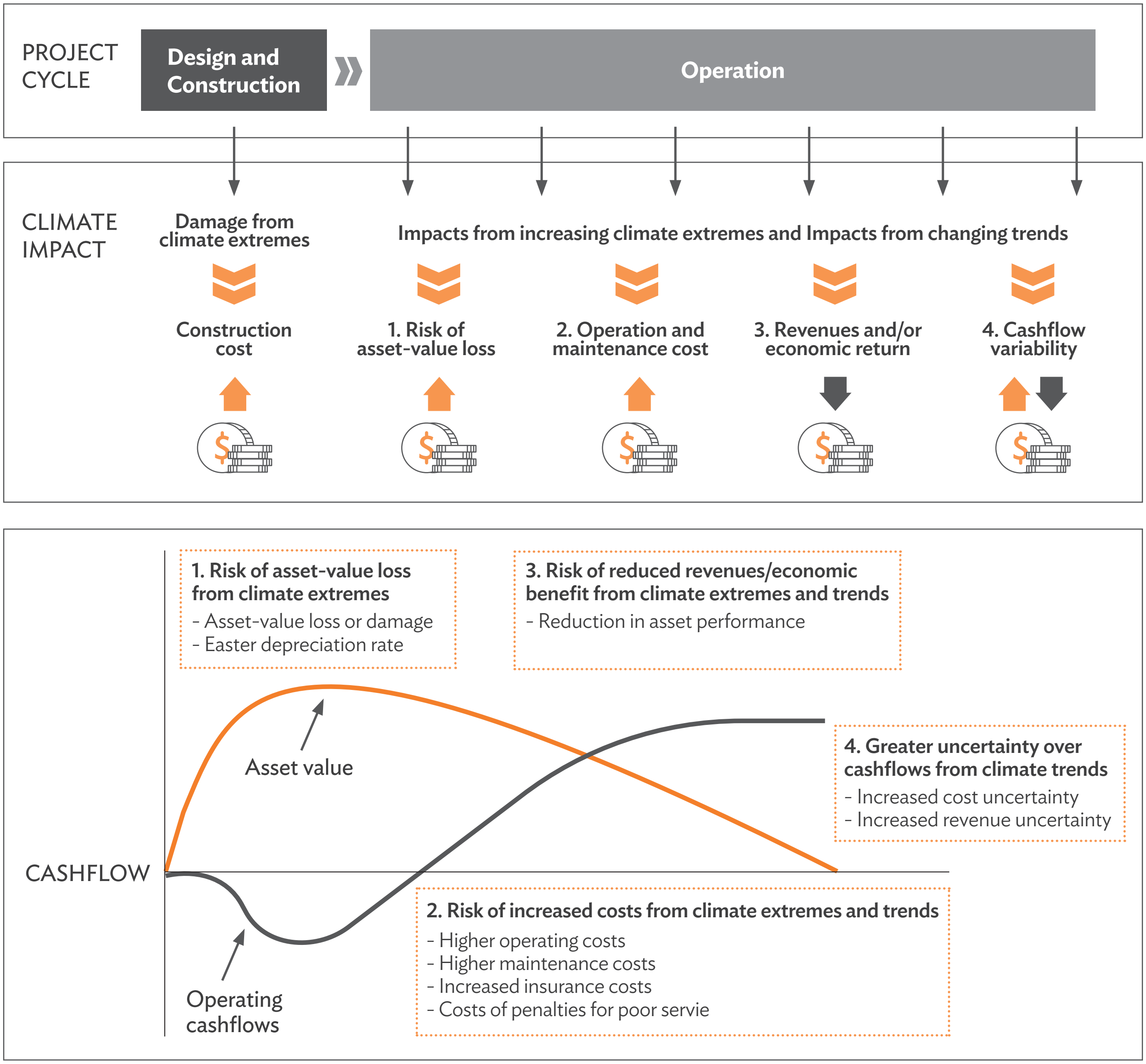
Correspondingly, these changes will have important implications for how infrastructure projects are financed, delivered, and managed.

Figure 1 identifies four direct ways that climate change will impact the financial and economic performance of infrastructure assets.

- Direct damage caused by extreme weather events that either require additional rehabilitation spending or lead to a deterioration in the performance and/or value of the asset and the services it provides
- Increase in operating costs that may result from climate change impacts
- Possibility that climate change will reduce the function or services provided by the infrastructure assets, and hence their revenue generation potential or the socioeconomic benefits that they are expected to produce
- Increased variability of infrastructure asset performance and hence the greater uncertainty in the financial returns that an infrastructure asset will provide

Nurek hydropower plant in Tajikistan. Photo: ADB.

Figure 1: Impacts of Climate Change on Infrastructure Asset Financial Performance



Source: Authors.

The implication of these changes will vary according to the model through which the infrastructure asset is owned and financed. Different ownership possibilities imply involvement of a range of different parties (such as lenders, project development companies, insurers). These different possibilities affect how the changes outlined above affect different partners. Discussion focuses on four "typical" models of infrastructure financing:

- ***Government.*** In this case infrastructure is owned and financed directly by the government out of tax revenues and general government borrowing. Many road assets, for example, fall into this category.
- ***State-Owned Enterprise.*** Owned and operated by a government-owned company that typically has its own debt-raising capacity and operates at arm's length from the state. Power sector and railway assets, for example, often fall into this category. The Organisation for Economic Co-operation and Development analysis finds that in 2016, state-owned enterprises owned 61% of total global electricity installed capacity and were responsible for 52% of the capacity either planned or under construction (Prag, Rottgers, and Scherrer 2018).

- ***Public–Private Partnership (PPP).*** Where infrastructure provision is governed by a long-term contract between a private party and a government entity, in which the private party bears significant risk and management responsibility and remuneration linked to performance, yet the public sector maintains an ongoing role.[8] This has become an increasingly common form of infrastructure provision across different infrastructure types.

- ***Private.*** Infrastructure owned and operated by a private company, with public sector involvement ordinarily restricted to activities relating to regulating the use of that asset, such as the prices the owner may charge. Independent power producers are typically in this category. Electricity distribution and transmission assets might also be owned and financed in this way in some countries.

Risk of Asset-Value Losses

Even today, extreme weather causes significant direct damages and losses to infrastructure assets. For example, expected annual damages to road and railway assets in the Lao People's Democratic Republic and Myanmar, and in Georgia and Tajikistan, are already in excess of 0.2% of national gross domestic product (Koks et al. 2019a), while annual damages to power plants in India, Indonesia, and the People's Republic of China are greater than 0.5% of their current value (Nicolas et al. 2019). In the most extreme cases, major infrastructure assets, for example hydro-power plants, may be completely lost.

Cyclone Evan in Samoa in 2012 illustrates the devastating impact of extreme weather. Reconstruction of physical assets amounted to more than double the normal value of construction in the country. Transportation and electricity infrastructure were worst hit. Overall damage to physical assets and losses, through lost production and increased production costs, were equivalent to 28% of Samoa's 2011 gross domestic product (Government of Samoa 2011).

Climate change is projected to increase extreme events and significantly increase infrastructure asset value losses. Looking forward, climate change could increase the intensity (strength) and the frequency of heavy precipitation and flood damage (river and surface), sea-level rise (including storm surges), wind storms, extreme heat, drought, and wildfires. The bullets below explore the impacts of river flooding, storm surges and extreme sea level, and extreme heat in Asia in more detail.

- In many parts of Asia, what is currently a 1-in-100-year river flood event (in today's climate) might become a 1-in-20-year event with climate change in the next few decades, due to changes affecting the intensity of annual monsoons (NRDI 2016). This implies that the chance of a major extreme event affecting a new infrastructure project rises to very high when viewed over the typical 25–40–year lifetime of infrastructure under construction today. Consistent with this, one recent study estimates that in damages from river floods in Bangladesh could increase by 585% at a global average of 2°C warming from pre-industrial temperatures, and by 2,933% with 4°C of warming (Alfieri et al. 2017).

- Similarly, extreme sea-level events—that historically occurred once a century—are projected to happen much more frequently, potentially every decade, or even more frequently by the end of the century under high-warming scenarios (IPCC 2019). For example, it is estimated that 2000 of Indonesia's smaller islands could be inundated by mid-century (USAID 2017) and most of the Southern region of Viet Nam could be periodically flooded over the same period (Kulp and Strauss 2019) if adaptation actions are not taken. The average intensity of tropical cyclones, the proportion of Category 4 and 5 tropical cyclones,[9] and associated average precipitation rates are also projected to increase, although with local variations (IPCC 2019). This will also lead to an increased risk of extreme sea-level events, i.e., higher water levels from mean sea level, and bigger storm surges and tides.

- Extreme heat events are increasing. Asia has experienced unprecedented heat extremes over the last few years, with temperatures in the region exceeding 50°C for the first time. Large increases in the frequency of unprecedented extreme heat events are projected, with South Asian cities projected to be the most heat-stressed in the world over the coming century (Matthews, Wilby, and Murphy 2017). As well as the well-documented impact of heat on human mortality and morbidity, these events can cause direct infrastructure failures or damage (e.g., to road and rail infrastructure).[10]

8 Definition adapted from that provided by the PPP Knowledge Lab. https://pppknowledgelab.org/.

9 The category of a tropical cyclone refers to the wind speed of that cyclone. A Category 4 cyclone has wind speeds of 157-200 kilometer per hour while a Category 5 cyclone has wind speeds in excess of 200 kilometer per hour.

10 Other impacts on infrastructure from extreme heat are discussed later in the report.

For infrastructure directly financed from government budgets, finance ministries will either need to find additional resources to replace damaged assets, or to accept the political, social, and economic consequences of increasingly disrupted provision. Budgets to repair damages will grow at the same rate as the expected increase in asset damages themselves. For example, the increase in extreme weather in Bangladesh discussed on page 8 would require budgets for asset repair and rehabilitation to grow at about 6% a year to make good the additional losses. Alternatively, the quality of services provided by the infrastructure could decline, reducing the effectiveness of infrastructure in supporting economic prosperity and alleviating poverty, the very purpose of building the asset in the first place. Finance ministries could experience similar problems where infrastructure is provided by state-owned enterprises unable to cope with increased costs without recourse to government support.

Finance ministries may be exposed to the same effects even where infrastructure is financed by the private sector (either through a PPP or a fully privatized infrastructure provider). Whereas in these cases the private provider might absorb modest asset losses, some extreme weather may be too damaging to absorb, with the reduction in asset value leading to financial failure. In these cases, despite an apparent transfer of risk, finance ministries may face the dilemma of either allowing the infrastructure to fail—and accepting the political, social and economic consequences of this—or stepping in to support reconstruction efforts. For example, following the La Niña floods of 2010–2011 in Colombia, which led to $88 million of damages to roads financed through a PPP contract, protracted disputes occurred between the concessionaires and the government as to who should cover the cost of repairs (OECD 2018).

Risk of Operating and Capital-Cost Increases

Climate change impacts could also increase the operating costs of many infrastructure assets. This may arise from extreme events or gradual (slow-onset) climate change raising recurrent costs needed to provide the same service performance. For example, road damages are projected to rise with climate change, from the combination of increased extreme heat and floods, which could reduce surface lifetime and increase maintenance costs—and so bring current refurbishment cycles forward. Similarly, to the extent that the infrastructure asset is insured, changing patterns of extreme events could push up insurance premiums.

Extreme heat can cause infrastructure asset construction to take longer, further increasing costs. There is a well-documented negative relationship between measures of heat exposure[11] and labor productivity. The negative impacts are greatest for labor intensive outdoor jobs, such as those required in most infrastructure construction. For example, Kjellstrom, Lemke, and Otto (2013) suggest that annual work hours for high-intensity work in the sun in Southeast Asia could shrink by 29% in 2050 compared to 1975.

The consequences for finance ministries will be the same as the risks associated with asset-value losses. For assets directly owned and financed by the government, budgets will need to expand to accommodate these costs or the assets will gradually become less effective in supporting prosperity and development. Finance ministries may be more insulated when the asset is owned and operated by state-owned enterprises, although in some countries their financial frailty can mean that any increase in costs leads to exactly the same increase in the need for government subsidy. In PPPs and where the assets are privately owned, these extra costs would typically be expected to be absorbed by the private sector. However, and especially if the private provider is highly leveraged, large increases in costs could lead to disputes such as those mentioned in Colombia over whether the risks should be transferred to the government.

Risk of Revenue/Service Provision Losses

The revenue generation, or economic benefits, of some infrastructure assets could also be affected by climate change, both from extreme events and slow-onset change. Extreme events can reduce revenue generation and service provision during the event itself and the period of repair. There is also a risk from the shift in climate over time, which can affect infrastructure that relies on climate sensitive inputs (e.g., power projects, water projects, and agriculture projects including irrigation). One such case is the power sector. One study finds that droughts and warm years reduce utilization rates for hydropower by 5% and for thermal power, which relies on water for cooling, by 4% (Van Vliet et al. 2016). These impacts will increase over time in locations where climate change is expected to reduce water availability. Numerous studies, such as Yalew et al. (2020), explain the potential for large impacts from climate change on future hydropower production in some regions. Other revenue impacts are possible: temperature increases reduce the efficiency of photovoltaic systems, which could drop by about 0.5% for every 1°C rise (Patt, Pfenninger, and Lilliestam 2018).

[11] Typically adjusted to account for humidity, sunlight, and wind.

As a consequence, finance ministries could receive lower tax revenues than anticipated, and may need to provide more support to state-owned enterprises. In many countries, infrastructure with revenue generating potential (e.g., electricity, railways) is provided either by state-owned or private enterprises. At the very least, the fall in output experienced by these organizations will lead to lower tax receipts. However, in many countries, the precarious financial position of state-owned enterprises already represents a sizable fiscal risk for government. In these cases, climate change-induced reductions in revenue will only magnify the financial strain. Moreover, regardless of the ownership structure of assets, price increases to attempt to offset the reduction in output may have political repercussions.

Increased Cash-Flow Uncertainty

In many cases, climate change could also increase uncertainty over future revenues. For example, the implications of climate change on water availability are highly uncertain. One study found that, in the Nile Equatorial Lakes region, compared to a baseline with no climate change, climate change could result in between a 50% increase in hydropower revenues in scenarios where water availability increased and a 60% loss in revenues where water availability fell (Cervigni et al. 2015). In seven large river basins it was impossible to conclude whether hydropower revenues would increase or decrease. The same pattern was seen for irrigation infrastructure revenues.

Cash-flow uncertainties will affect finance ministries where infrastructure financing has been transferred to the private sector. In these cases, governments may have to accept higher prices for the services provided by affected infrastructure, and the political implications this may have. Many governments are already concerned by the high expected rates of return required by private infrastructure providers to compensate for risks associated with investment. For example, PwC analysis shows that annualized 10-year returns on infrastructure investment in Asia were 10.6% between 2006 and 2015, around 25% higher (2.8 percentage points higher) than rates of return on real estate (PwC 2018). As climate risks and uncertainty are further priced in, these may increase further. This could place governments under increasing political pressure to spend more to offset the impacts of higher prices on poor and vulnerable households.

It is important to stress that the impact of climate risks could influence investor risk appetite well before climate impacts themselves are experienced. Even if the (uncertain) impact of climate impacts on cash flows only manifest 10 or more years into the future, the result would be an increase in present-day financing costs, given that future uncertainty will increase the return expectations of investors today.

Summary of Implications for Infrastructure, Project Financing, and Public Finances

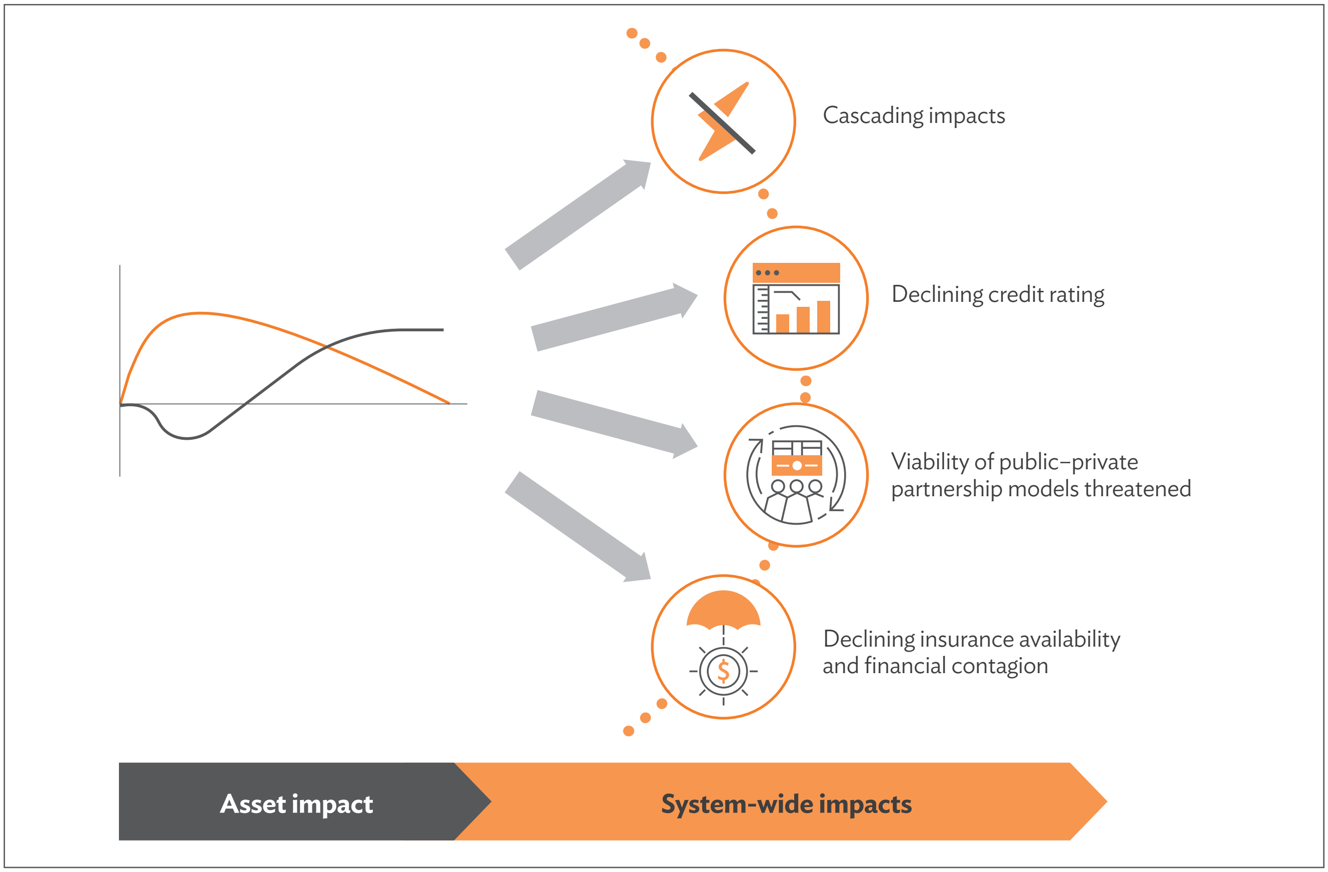
The previous sections demonstrate that climate change could have important implications for infrastructure projects and their financing. Depending on the context, climate change has the potential to influence infrastructure asset values, their operating costs, their revenue generation potential (and/or socioeconomic benefits) and the confidence of investors in the potential of the infrastructure to generate cash flow. These changes could all have direct implications for finance and other government ministries. For infrastructure directly financed by governments, annual budgets for operating and maintenance costs will likely need to increase. Further, risks assumed to have been passed to the private sector may reemerge, while state-owned enterprises providing infrastructure may become (even) more financially fragile. These all stand to make climate change a source of fiscal and, potentially, macroeconomic instability. At the same time, governments may have to contend with private sector infrastructure providers responding to the physical risks of climate change by increasing their return requirements, which will lead to higher prices for services reliant on privately financed infrastructure.

2.2. Systemic Implications of Climate Change in Infrastructure Funding, Delivery

Climate change can also have implications for infrastructure at the system and national level, and therefore on the wider role of infrastructure in economic development. This may, in turn, have consequences for public finances. The implications of climate change for infrastructure delivery and financing go beyond cash flows and the operational performance of individual assets. Important though these are, exclusive focus on how climate change might influence individual assets risks will not account for the more fundamental implications on infrastructure planning, delivery, financing, and management. This section explores four of these potential pathways (Figure 2):

- cascading impacts associated with infrastructure failure
- the impact of climate change on country-risk premiums
- threats to the viability of PPPs
- the challenge of reduced insurance availability

Figure 2: Possible Systemic Impacts of Climate Change on Infrastructure



Source: Authors.

Cascading Impacts

There is increasing risk of cascading impacts of climate-related disasters on secondary sectors and geographies. Activities and services such as heating, lighting, mobility, water and sanitation are essential for modern society and they increasingly rely on each other, for example from interdependencies and interconnectivities with electricity and information and communication technology. Damage to critical infrastructure from extreme weather in one sector or geography can therefore lead to important indirect (cascading) economic losses through interdependent infrastructure linkages.

Cascading impacts can magnify the economic damage caused by climate-related disasters. These cascading impacts can lead to economic costs that are can be as large as the direct damages themselves, especially for large events (Hallegatte and Przyluski 2010). The World Bank Lifelines report suggests that disruption to power, water, and transport infrastructure (from all causes) reduces firm utilization rates in low and middle-income countries by $150 billion a year (Hallegatte, Rentschler, and Rozenberg 2019). A study in Viet Nam found that disruption to the most critical road and rail infrastructure, which is most likely to cause cascading impacts, could be associated with damages of $1.9 million per day for road disruption and $2.6 million per day for railway failures (Oh et al. 2020).

They can also have harm long-term development outcomes. Studies in South Asia have shown that infrastructure failures leading to long power outrages reduce per capita income, girls' study time, and female labor force participation (Zhang 2019).

For finance ministries, cascading impacts exacerbate the fiscal implications of disasters. If the cascade of disasters through an economy reduces economic activity and employment, then tax receipts will fall. Additionally, supporting those whose vulnerability increases because of disasters could require an increase in government spending. The longer-term "development drag" caused by cascading impacts means that government spending will either have to increase, or become more effective, to achieve its goals.

Country Risk Premiums

The major credit rating agencies have identified climate change as a global mega-trend that could impact sovereign creditworthiness. Some rating agencies are starting to consider climate risk in credit worthiness assessments, both at the country level and for individual companies (Moody's 2017; S&P Global Ratings 2015, 2017). For example, Standard and Poor's analysis suggests that climate change could, on average, be expected to lead to an average downgrade of 0.23 notches among emerging and developing countries, an assessment that only captures the additional risks from flooding and tropical cyclones. As credit ratings in climate vulnerable countries decline, so the cost of borrowing for the governments of these countries will increase. Spillovers into investor's return requirements for other investments in climate vulnerable countries, including infrastructure financed by the private sector, could also occur.

Climate-related disclosures, while helping investors manage physical risks, could raise investor awareness and exacerbate these challenges. Increasing investor information, driven in part by climate-related financial disclosures, is providing more detail about the relative risks of investment portfolios and locations. This, in turn, is altering investor perceptions. Some evidence exists, for example, that properties exposed to potential sea-level rise sell at a 7% discount to less-exposed properties in some areas of the United States (Kusisto and Campo-Flores 2018; Bernstein, Gustafson, and Lewis 2019). In turn, this information is starting to be considered in pricing Real Estate Investment Trusts (Four Twenty Seven and GeoPhy 2018).

For finance ministries, this implies a larger proportion of the government budget may need to be allocated to servicing debt. As Figure 3 shows across low and middle-income countries, debt-servicing costs, as a percentage of gross national income, have increased steadily since 2011, and in 2019 reached their highest since 2006.[12] Challenges associated with recovery from COVID-19 are likely to result in further increases in the short term. However, on top of this, finance ministries—especially in the most climate vulnerable countries—will need to factor in that climate change impacts could make managing borrowing costs even more difficult in the medium and long terms. They will also need to contend with the political and economic challenges if return requirements for privately financed infrastructure rise, and so increase the price of using that infrastructure.

Figure 3: Debt Service Costs as a % of GDP for Low- and Middle-Income Countries

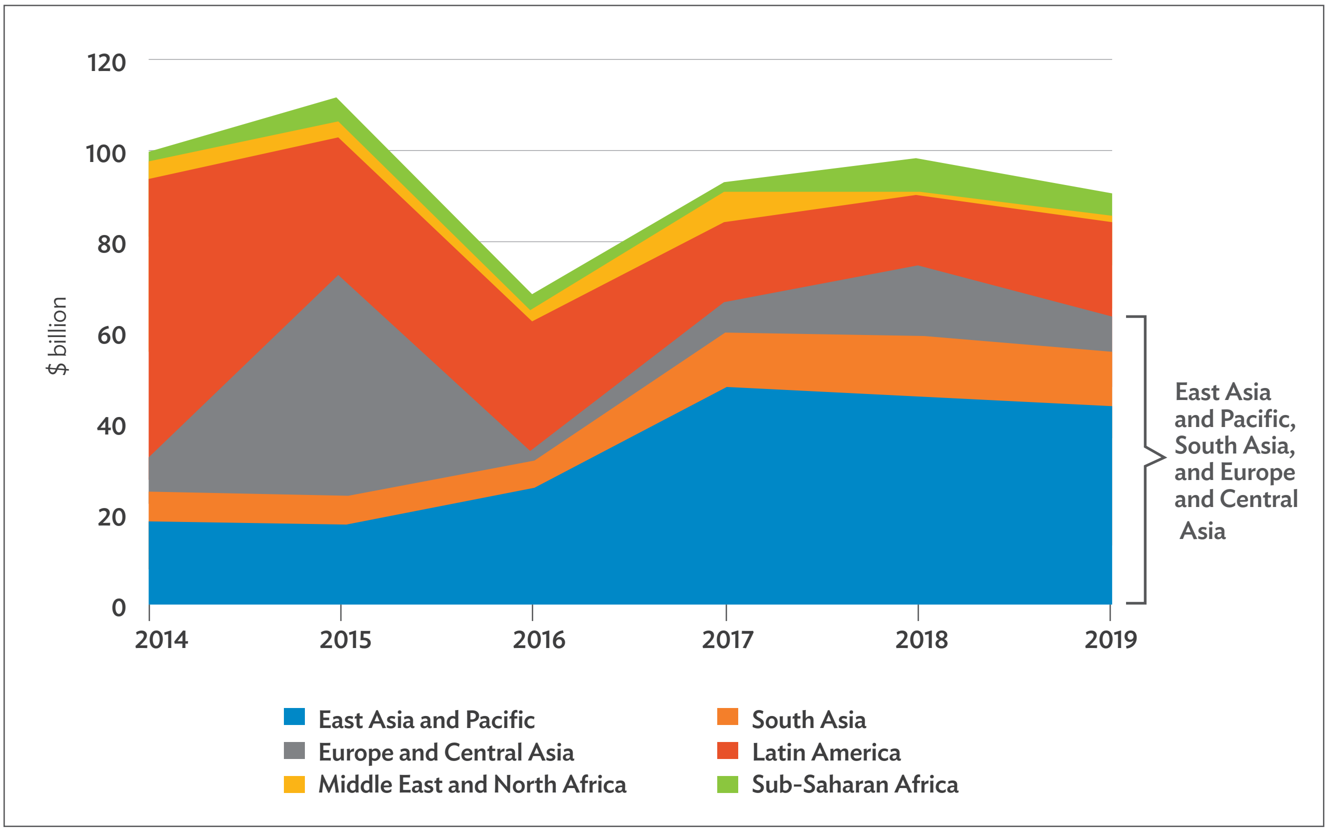
COVID-19 = coronavirus disease, GNI = gross national income.
Source: World Development Indicators.

12 World Bank Data.

Contingent Liabilities and Implications for Financing Models

PPPs are an increasingly important option for delivering infrastructure assets. According to World Bank data, between 350 and 400 infrastructure projects each year in low- and middle-income countries make use of PPP models, with annual investment flows of between $70 billion and $110 billion. As Figure 4 shows, PPPs have become particularly important in Asia, where each year from 2017 to 2019, annual infrastructure flows of $50 billion to $60 billion were financed through PPP.[13] Such arrangements are often attractive for governments operating in constrained fiscal environments, which, as discussed above, could become more likely for many countries as climate impacts become more apparent.

Figure 4: Value of Infrastructure PPP Deals Around the World, 2014–2019



PPP = Public–private partnership.
Source: Private Participation in Infrastructure Database.

However, challenges exist in allocating climate risks within PPP arrangements, with the result that many contracts do not deal with these risks explicitly. Some of the specific implications of how climate impacts could affect infrastructure assets currently being delivered through PPP arrangements were discussed in section 2.1, both in terms of the risks of damage and in operating revenues. However, as well as climate impacts possibly undermining the expected partnership model within existing PPPs, climate risks could have a "chilling" impact on use of this model for future infrastructure delivery. An integral feature of the PPP approach for delivering infrastructure is that specific risks are assigned to the party which is best able to manage the risk. At present, it is rare for future climate risks to be considered and explicitly allocated to a party as part of this process. While this partly reflects that the physical risks of climate change are only beginning to be appreciated, it also reflects the inherent uncertainty associated with estimating the exposure, likelihood of occurrence, and impact of these risks.

[13] Private Participation in Infrastructure Database (active and concluded projects, PPP projects only). Accessed 16th December 2020.

For finance ministries, this may make it more difficult to execute an attractive approach for infrastructure financing and delivery. Without clarity over how these risks are allocated, the realization of a particular extreme event could lead the public sector to face unexpected contingent liabilities and/or lengthy contractual disputes. Conversely, efforts to transfer these risks to the private partner could increase project costs substantially and make the initial negotiation of PPP contracts more complex and time-consuming. While continued effort is being made to work through different contractual solutions, and develop associated tools to increase government capacity to manage this issue (Frisari et al. 2020), without a system-wide approach to reducing climate risks, one of the most important ways in which governments look to deliver infrastructure could become less attractive.

Insurance Availability and Financial Contagion

Climate change could have a system-wide impact on infrastructure planning, delivery, financing, and management through altering the availability and price of insurance and the associated possible implications on financial stability.

At present, the role of insurance in underpinning infrastructure construction and operation is limited. For example, in the United States between 2009 and 2018 only around 30% of losses related to transportation infrastructure from catastrophes were insured (Tonn et al. 2021). The percentage is likely to be much lower in developing countries. Where insurance is taken out, it is more frequently to cover risks during the construction of the infrastructure assets, with policies then lapsing during operations (Lloyds of London 2018).

As climate change intensifies, many infrastructure operators and financiers, as well as policymakers, are likely to see greater value in insuring infrastructure. This uses insurance as part of the solution to help manage some of the physical risks of climate change (the climate-related extremes), by spreading and transferring some of these risks to other parties. As well as providing support for the cash flows of assets, insurance can also help speed up recovery after disasters, reducing their macroeconomic impacts (Von Peter, Von Dahlen, and Saxena 2012). It can also increase awareness of the magnitude and allocation of risks and help tackle the challenge of climate-related contingent liabilities.

However, assuming that insurance alone can help infrastructure be delivered in a time of heightened physical risks may be misguided. First, insurance is a valuable tool for managing extreme events (i.e., low-likelihood, high-impact), but is less effective at managing longer-term trend changes. Second, especially if efforts to achieve rapid reduction in emissions do not succeed, and climate change becomes severe, insurance may become more expensive, with problems for affordability (Tesselaar et al. 2020) or availability. A report by the Bank of England's Prudential Regulation Authority concluded that, in the longer term:

"[T]he impact of changing climatic conditions can cause disruption in established insurance arrangements and associated risks and create important issues for public policy. Increasing levels of physical risks could also present challenges to general insurance liabilities from increasing correlation between modelled risks, and more severe and frequent indirect, non-modelled risks, which are often difficult to anticipate or predict."

—Bank of England Prudential Regulation Authority (2015).

These impacts could have different implications in different countries:

- For developing countries, where insurance use is already limited, these impacts could reduce the availability of insurance, just as finance ministries and other parties interested in infrastructure financing want to make greater use of it.
- For developed countries, where insurance for infrastructure assets is currently more prevalent, insurance weakens the link between physical asset losses and financial losses. Especially for infrastructure that is privately financed, the reduction or removal of this insurance "cushion" could mean that physical risks become a source of financial instability, especially when assets are highly leveraged (Mandel et al. 2020).

Summary

The impact of climate change on infrastructure financing is likely to extend beyond any individual asset. Infrastructure failures threaten cascading impacts across the economy, while economy-wide risk premiums are likely to rise in climate vulnerable countries, regardless of how well adapted individual assets may be. Moreover, climate change may expose latent contingent liabilities that reduce the flexibility over which financing models to pursue. Finally, an expectation that insurance can be used to address these impacts may become increasingly difficult to justify as heightened, uncorrelated risks make insurance more difficult to obtain.

SECTION 3

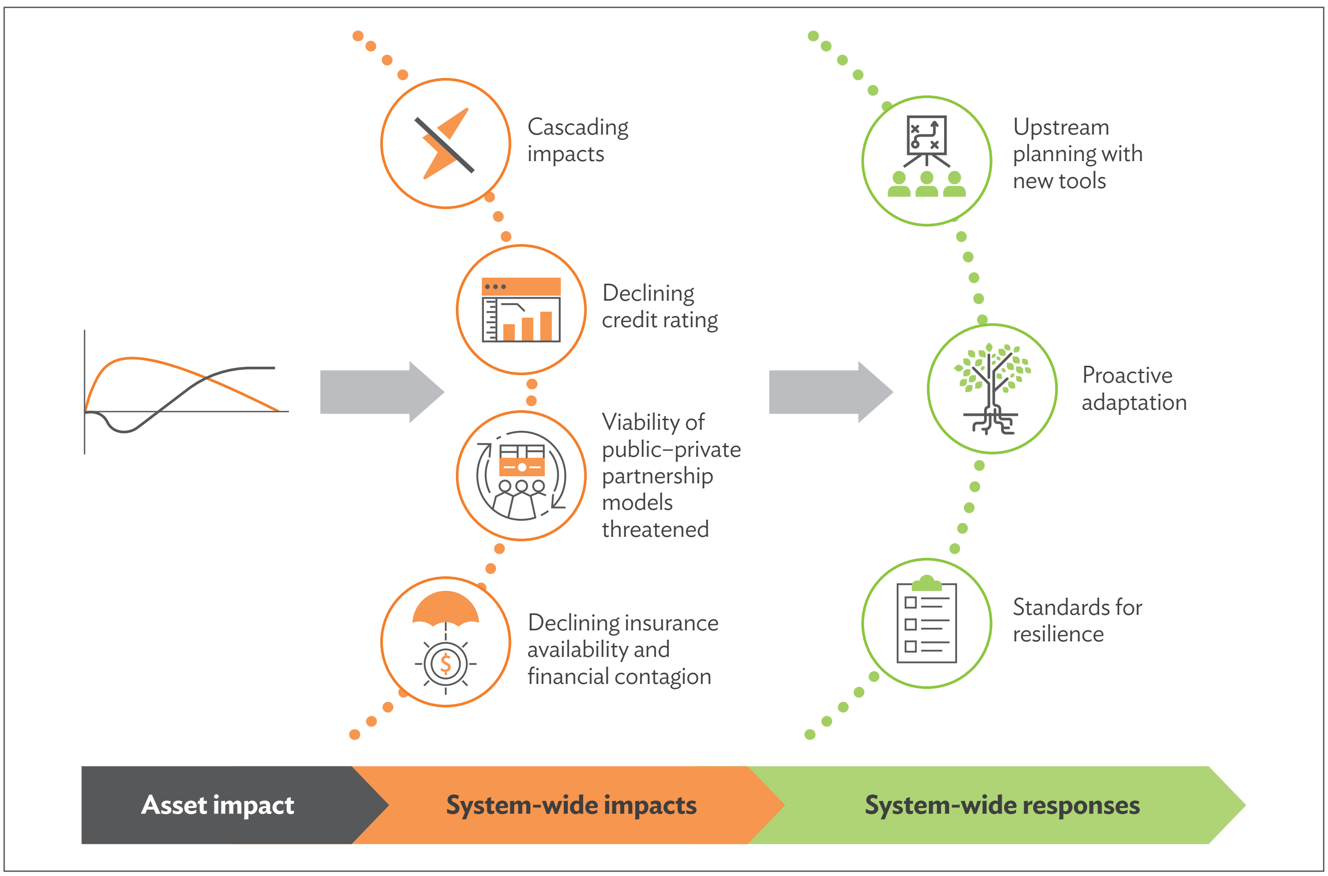
Toward a Systems Approach to Managing the Climate Risks on Infrastructure

Bangkok Mass Transit System in Bangkok, Thailand. A skytrain approaching a station in Bangkok. Photo: ADB.

In light of the challenges discussed in section 2, a fresh approach to dealing with issues of planning, delivering, financing, and managing infrastructure amid a changing climate is needed. Ongoing work by multilateral development banks and others to screen projects for climate risk (due diligence) and incorporate adaptation to improve the climate resilience of infrastructure is important and needs to be mainstreamed across major investments. However, many of the challenges identified in section 2 are system-wide; piecemeal adaptation activities at the level of individual infrastructure assets are insufficient to resolve them. Instead, it is essential to use systems thinking in the planning, delivery, financing, and management of infrastructure, to deliver more effective and flexible risk management. While the full extent of this agenda will only emerge over the coming years, this section considers three elements of a more strategic approach to tackling climate risks faced by infrastructure and the benefits they can deliver. The elements, summarized in Figure 5, are to:

- Better incorporate climate risks in early-stage planning of infrastructure (to move "upstream"), delivering both strategic benefits and more efficient climate resilience
- Invest financial resources in adaptation projects that reduce the climate risks that infrastructure, and its users, would otherwise face, and to generate other socioeconomic benefits
- Mainstream the use of standards and regulations throughout infrastructure development, to simplify resilience and deliver it as the new normal

Figure 5: Key Elements of a More Strategic Approach to Climate Risks in Infrastructure



Source: Authors.

Adopting this more comprehensive and strategic approach to infrastructure development that incorporates these elements offers multiple benefits, including greater efficiency and effectiveness. Most obviously, it provides an appropriate response to the scale of the challenge posed by climate change. For example, improvement in the climate resilience of individual assets is unlikely to prevent widespread repricing of sovereign debt in response to evidence of climate vulnerability. Moving upstream allows stakeholders to *prevent rather than repair* climate risk exposure, and offers a much more efficient way to integrate resilience (i.e., a strategic resilience analysis will automatically mainstream all subsequent downstream investments). It will also help identify priorities, reduce costs, and improve effectiveness. Resilience projects not only can reduce risks (and avoided costs), they can improve the quality of life of those living and working nearby; while the reduction in risk they provide can stimulate additional dynamic risk-taking and entrepreneurial activity (Tanner et al. 2015). Finally, standards offer ways to introduce change into the planning, delivering, financing, and management of infrastructure to incentivize good practice and simplify implementation, which generates cost savings and raises the bar across all projects.

These shifts require consideration of climate change and its implications for infrastructure across a range of entry points within the cycle of national infrastructure planning. Table 1 highlights typical opportunities for actors operating at different planning levels, illustrating that the identified changes require climate change to be integrated into major national development plans rather than through standalone national adaptation plans alone. The table also references the development of long-term, low-emission and climate resilient strategies – which countries have been invited to develop under the Paris Agreement. Designed well, so as to cover both climate resilience as well as emission reductions, these have the potential to provide the overarching framework through which countries define how they will integrate climate change into their overall development plans.

Table: Entry Points for Climate Resilience in National Infrastructure Planning

Planning level	Entry point for strategic/system level infrastructure resilience	Potential for strategic elements
National government and cross-sector ministries (finance, planning)	• National development vision (long-term; e.g., 2040) • Long-term low-emissions and climate resilience strategy • Macroeconomic forecasting • National development plan (e.g., a 5-year/medium-term plan). • National infrastructure plan (or master plan) • National budget allocation process	• Upstream and strategic analysis • Resilience projects
Sector ministries (with major infrastructure portfolios)	• Sector development plans • Sector master plans	• Cascade down of strategic analysis • Resilience projects • Standards
Subnational authorities (e.g., regions or districts)	• Decentralization plans • Region or district plans	• Resilience projects • (projects implemented with standards)

Source: Authors.

In turn, this requires the involvement of finance ministries (or equivalent) as well as planning ministries and/or commissions, acting on an enhanced appreciation of the risks climate impacts can pose to (i) the management and financing of infrastructure, and (ii) the potential knock-on implications for macroeconomic stability and fiscal strength. International finance institutions, through country diagnostics and country partnership plans—coupled with technical assistance and capacity building—can help these different bodies perform their roles in mitigating for climate risks.

3.1 Moving Upstream

Moving climate resilience upstream involves integrating climate change in all key development planning processes and documents. In the national development context, this starts with a long-term vision and cascades through national, sectoral, and regional development and infrastructure plans. It recognizes that climate change brings inevitable consequences and that there is a need to plan and budget for these accordingly. Throughout, the key point is that climate change should be considered from a more strategic and system-wide perspective first, in advance of specific infrastructure projects being developed.

There are a number of advantages of such an approach:

- High-level processes and plans critically shape spatial and sectoral patterns of development. Some patterns will substantially increase exposure and vulnerability to climate risks, while others can substantially reduce them. A conscious focus on patterns of development that reduce future lock-in to climate risk can be much more effective in reducing risk than trying to adapt infrastructure in "at risk" areas (or those climate change will render "at risk") later.
- Acknowledging the risks of climate change in macroeconomic planning documents is the crucial first step in preparing for how countries will respond when these risks materialize, and in ensuring that enough finance is in place to execute these plans. Clarke and Dercon (2016) show how taking time to prepare and plan for disasters (both climate-related and other) can significantly reduce their macroeconomic, fiscal, and development impacts.

New tools can make for more informed, strategic upstream analysis. Tools embedding systems thinking can allow decision makers (or problem owners) to see the bigger picture and to identify underlying drivers or key leverage or vulnerability points. They are likely to be particularly important in addressing network level and cascading risks by allowing stakeholders to understand the consequences of damage beyond the impacts on the functioning of the individual assets alone. This can facilitate the prioritisation of resources and also offers the potential to develop integrated (cross-cutting or cross-sectoral) solutions. For example, a study employing systems modelling to look at the electricity network in the United Kingdom found that although almost all network assets would benefit from a protective wall, investments in just 25% of locations would generate more than half of the total benefits. These studies involve low costs, but generate high benefits to cost ratios through the value of information and the avoided losses downstream for subsequent individual projects.

An upstream approach to enhancing the resilience of infrastructure systems can be adopted at both at national and sub-national levels and by both governments and international financial institutions.

For example, at the national level, the GCA is pioneering the development of resilient infrastructure programs that combine cutting-edge analytical tools, extensive stakeholder engagement and partnerships with financing institutions to support implementation. At a sub-national level, the ADB-administered Urban Climate Change Resilience Trust Fund is making sure that climate change is a central element of city planning. ADB has also adopted an upstream approach in the design of its country partnership strategy in Fiji. In all cases, the key focus is a move away from an asset-by-asset assessment of risk to considering what is needed to support the resilience of the system as a whole. Box 2 provides more information.

Box 2. Examples of Moving Climate Resilience Upstream

In Ghana, the GCA catalyzed a joint initiative between the Ministry of Environment, Science, Technology and Innovation, United Nations Office for Project Services, United Nations Environment Programme, and the University of Oxford's Environmental Change Institute to explore the performance of Ghana's energy, water and transportation system as the climate changes, and to identify actions at both the system-level and asset level that can help improve the resilience of national infrastructure.

The work involves *joint* consideration of the energy, water and transportation system and is identifying the linkages between the built, enabling and natural environments in terms of collective performance. This includes a geospatial risk analysis to understand how climate hazards might influence the future provision of infrastructure services, as well as how climate change will affect infrastructure users. On the basis of this analysis, it is then undertaking an assessment of different resilience options, considering criteria such as asset damage, economic losses, and social impacts, such as access to hospitals and other essential services. This will be used to develop a pipeline of bankable infrastructure projects, which is based on a systems approach (and not individual assets), for engagement with funders.

This builds on previous collaborative work between the University of Oxford and United Nations Office for Project Services and/or the World Bank. A study in Viet Nam looking at the road and rail networks, undertaken with the support of the World Bank, further illustrates the benefits of the approach. This mapped the networks and identified direct and indirect effects from climate change—and therefore locations where risks were concentrated. By looking at adaptation options across a network, the analysis allowed identification of hot spots where greater climate resilience in infrastructure was most urgent; strengthening the argument for targeted investment.

At a sub-national level, ADB administered Urban Climate Change Resilience Trust Fund has financed climate risk assessment work to support the holistic development of New Clark City (NCC) in the Philippines. The analysis found that the existing development plans for the city would require massive amounts of earthworks, would fail to leverage the river as one of the biggest amenities in the region, and, even then, might not provide sufficient drainage capacity when accounting for climate change. As a result of the more strategic approach, the analysis recommended the city's development plans leveraged its river to help it become a smart, green, and disaster-resilient city. These formed the basis for the establishment of the NCC Riverpark which is now a popular recreational and place-making feature of NCC.

Finally, ADB's country partnership strategy in Fiji is a good example where climate change has been considered upstream, during the development of the multi-year country partnership program, rather than only through climate risk screening of individual investments during the project preparation. This led to resilience being identified as one of three key strategic priorities in the partnership, which in turn, has influenced the planned investments. For example, the partnership strategy is targeting a resilience project for Nadi, as this is the key hub for logistics and tourism on the islands. ADB is also working with the government to introduce climate resilient standards in all infrastructure investments, and strengthening public financial management and building fiscal buffers to enhance resilience.

Source: Interviews with key stakeholders and ADB. 2019c. *Fiji: Country Partnership Strategy (2019–2023)*. Manila: ADB.

3.2 Proactive Investment in Adaptation Projects (Investing in Resilience)

Given the scale of the climate challenge, moving climate resilience upstream will likely identify the need for increased direct investment in adaptation projects—where the primary objective is to address climate change. Such projects often build on existing resilience investments that address current climate risks, e.g. flood defences, but are designed to accommodate expected climate change. Funding might come from the public sector, such as in flood defences; but sometimes may involve private capital, such as in water management projects that help address the effects of increasing rainfall variability and drought.

It is important that these projects are identified as part of the process of integrating climate risks into upstream planning. The country, sector, or regionwide assessments of climate risks undertaken in an upstream approach will help identify where adaptation projects can be most valuable, taking into account critical interdependencies and vulnerabilities. The same assessments can also help identify where investments should be avoided because, for example, they would encourage development in places that involve lock-in to long-term risks, or because it would lead to cascading failures elsewhere.

Adaptation projects often offer good value for money and can play an especially important roles in ensuring the countries build back better from the COVID-19 pandemic. Regardless of financing source, evidence now exists showing that such projects offer good value for money, with typical benefit:cost ratios of between 4:1 and 5:1 (Shreve and Kelman 2015; ECONADAPT 2017; GCA 2019). The value of such projects is likely to be even higher in the short term because they can also support pandemic recovery.

Economic appraisal guidance should recognise climate risks and resilience benefits and can help support green investments. Climate change is a major issue for international and national appraisal guidance, and there is a need to ensure climate risks are considered and integrated, for example, the United Kingdom Treasury has recently updated its economic appraisal guidance to account for climate change (Defra 2020). Furthermore, appraisal guidance (and cost-benefit analysis) is sometimes narrowly framed, and does not adequately recognize the economic benefits of resilience investments. For example, it may fail to take into account how resilience investments help avert the high indirect economic costs that could otherwise be caused by cascading impacts following a disaster, or the potential co-benefits or positive distributional implications of many resilience investments.

There is a particularly important opportunity to advance green adaptation investments. While gray (conventional) resilience infrastructure will be needed, consensus is emerging on the economic benefits of green infrastructure. These nature-based solutions use eco-resilience and ecosystem-based adaptations to provide disaster risk reduction and climate change adaptation. Coastal storm protection provided by mangroves is an example, as is the use of wetlands for water regulation and flood management.

Adaptation investments generally—and green adaptation investments specifically—offer important economic, social, and environmental benefits. For example, urban green infrastructure can reduce the risks posed by flooding, but it can also deliver amenity, mitigation and environmental benefits. Similarly, GCA analysis suggests that mangrove restoration contributes almost as much benefit for fisheries, forestry, and recreation as it does in reducing losses caused by coastal flooding. In other words, in many cases, good green adaptation infrastructure projects are also often good economic development projects, even as they can sometimes be challenging to finance.

Where necessary, a range of financing options, including within the international climate finance architecture, is available to support these investments. The international climate finance architecture, which includes the Green Climate Fund, the Pilot Programme for Climate Resilience, the Adaptation Fund, and the Special Climate Change Fund, can provide some or all of the financing for such adaptation projects. For low-income countries in particular, these resources are available on heavily concessional terms. Nonetheless, finance available in international funds is insufficient to deliver future needs, and therefore multilateral development banks will need to step in for additional finance and explicitly support countries with climate resilience projects. For example, the Asian Development Fund 13 (2021–2024), ADB's window providing resources to lower-income developing countries, includes a thematic pool to provide grant resources to promote investments in, among other areas, climate adaptation and disaster risk reduction. The resources are intended for projects or outputs with the primary purpose of building resilience, especially ones that improve multiple aspects of resilience, including physical, social, institutional, and ecosystem resilience.

3.3 Regulations and Standards

Standards reflect distilled best practice by recognized experts. Standards can either be set by an international body in response to a market need—such as the ISO standards—at a national level by public or private bodies with a recognized expertise (for example, the Australian Construction Code), or by a sectoral organization with international pre-eminence, such as the International Union of Railways, which has developed a sector guide on adaptation in the railway sector. Standards include *organizational standards*—which define how an organization functions and manages its relationships; *specification standards*—that apply to products and services and typically determine the performance they must deliver; and *test methods and analysis standards*—used to determine whether a standard has been met.

The use of standards to drive desired changes brings several advantages. As they are drafted by recognized experts and emerge from a transparent and consensus-based process, standards can be seen as politically neutral statement of best-practice. They can relatively easily insert detailed technical requirements into legislation or contracts (hence providing "teeth") and can be a convenient way to enable international best practice to be shared, allowing a commonality of approach that encourages trade. As a consequence, they are often a highly cost effectivecost-effective intervention (Hallegatte et al., 2019). Given these benefits, there is a need to accelerate the use of resilience standards throughout the world.

One important role for standards is in helping to adapt already planned infrastructure projects. Adjusting existing infrastructure engineering standards with climate uplifts can rapidly improve infrastructure assets across a country, increasing resilience and lowering costs. Instead of having to carry out detailed technical analysis for every project, adjustment allows an autonomic and highly efficient rollover of improved resilience, which saves on design costs and ensures best practice is followed. For example, during the project preparation phase for a recent roads project in Viet Nam, work was undertaken to update design standards to incorporate climate "safety margins" for basic variables such as heavy precipitation, wind speeds, wave heights, sea-level rise, and river flow. This means that from now on all road projects will account for climate change as a matter of course.[14] Consistent with this, Koks et al (2019ab) find generally positive benefit-cost ratios from the introduction of climate resilient standards for road design globally.

Wastewater treatment facilty in Suva, Fiji. The Urban Water Supply and Wastewater Management Investment Program ensures sustainable urban growth and improved public health. It aims to provide access to sustainable water supply and sewerage services in greater Suva area. Photo: ADB.

However, standards also play a critical role in supporting the more transformative approach to adaptation outlined in this report:

- Standards can be used to encourage a shift to upstream approaches. In many countries, they can be important for paving the way to more climate resilient development patterns. For example, in the People's Republic of China, there is a standard for urban residential area planning and design. These types of standard can focus development in areas that are less hazard-prone, or where this is less feasible, ensure that forecasting and warning systems are introduced in new developments as a matter of course. This can be further facilitated by use of organizational standards (such as ISO 14001 *Environmental management systems* and ISO 9001 *Quality management systems*) that can help to drive the increased capacity, governance, knowledge, and leadership needed to fully operationalize an upstream approach.
- Standards can help organizations operationalize systems thinking. ISO 14090, focused on adaptation to climate change, specifies the use of systems thinking to scope out the coverage of an adaptation plan for addressing cascading risks.

[14] The opposite is also true—standards that fail to take into account future climate change may lock in bad infrastructure planning practice by providing a false sense of security that risks have been addressed when they have not.

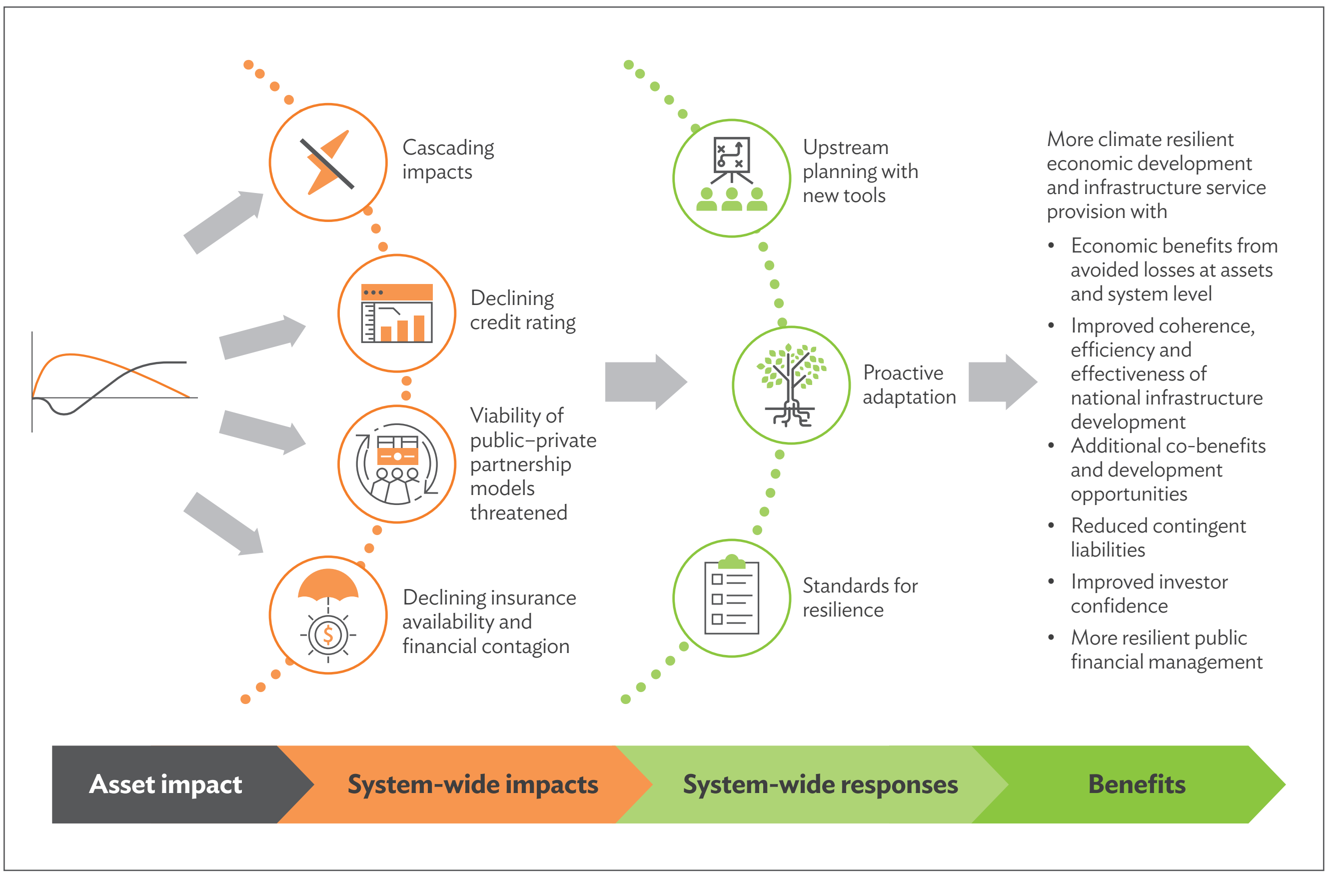
- Standards can also be used to help identify and then design dedicated adaptation projects. For example, in the water sector, ISO 24518 *Crisis management of water utilities* can help water utilities understand the adaptation investments that make crises less likely in the first place.

Summary

Current approaches to planning, delivery, financing, and managing infrastructure need to evolve to prepare for the changing climate of the next few decades. In light of challenges posed by climate change identified in section 2, continuing to follow historic practice risks higher costs over time, poor service quality, and growing liabilities for the public sector. Instead, leadership from finance and planning ministries will be crucial to developing resilient infrastructure systems and enabling efficient, flexible responses that improve resilience in a changing climate.

This report highlights three key recommendations (Figure 6) to help build infrastructure systems that will be resilient to the changing climate as well as lowering costs, supporting fiscal stability, and facilitating growth and development. However, this is only the start of a discussion on this new agenda and there is much more to learn. This report is therefore a call for action, and encourages the piloting, testing and learning of these new approaches in planning, delivering, financing, and managing national infrastructure plans.

Figure 6: A System-wide Response to Climate Change Can Improve Risk Management, Reduce Costs, and Promote Fiscal Stability



Source: Authors.

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A System-Wide Approach For Infrastructure Resilience

Technical Note

Climate change is affecting infrastructure investments worldwide, leading to asset value losses, higher operating costs, and reduced economic benefits. This technical note is a call for action to improve how climate-related financial risks are considered in infrastructure, including for the planning, delivery, and management of national infrastructure plans. The Asian Development Bank and the Global Center on Adaptation jointly developed this technical note as an input to the Global Commission on Adaptation's Climate Adaptation Summit 2021.

About the Asian Development Bank

ADB is committed to achieving a prosperous, inclusive, resilient, and sustainable Asia and the Pacific, while sustaining its efforts to eradicate extreme poverty. Established in 1966, it is owned by 68 members —49 from the region. Its main instruments for helping its developing member countries are policy dialogue, loans, equity investments, guarantees, grants, and technical assistance.

About the Global Center on Adaptation

GCA was established in 2018 as a solutions broker for climate adaptation, with the mission of enabling the development and implementation of innovative approaches to drive adaptation at scale. Its work focusses on high-level policy development, new research contributions, advocacy, and catalyzing partnerships to deliver scaled-up action. GCA's headquarters are located in the Netherlands, with regional offices in Africa, South Asia and Asia Pacific.

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