PREPARE

Resilience at Scale

A Systems Approach to Climate-Resilient Infrastructure Planning

This report is an initiative of the President's Emergency Plan for Adaptation and Resilience (PREPARE). PREPARE is a whole-of-government effort to help more than half a billion people in developing countries adapt to and manage the impacts of climate change.

October 2024

TABLE OF CONTENTS

THE WHITE HOUSE
WASHINGTON

The climate crisis is a fundamental threat to human health, the economy, and our environment. Leading scientists have told us that we face unavoidable climate hazards over the next two decades from rising temperatures and sea levels to more catastrophic storms, fires, floods, droughts, and extreme heat. The impacts of these changes will undermine hard won development gains, exacerbate geopolitical tensions, worsen the food security crisis, and result in greater instability and humanitarian need. On November 1, 2021, the U.S. government launched the President's Emergency Plan for Adaptation and Resilience (PREPARE), a whole-of-government effort that unites the development, diplomatic, scientific, and technical expertise across the U.S. federal government to help more than half a billion people in developing countries adapt to and manage the impacts of climate change by 2030.

Twenty U.S. federal departments and agencies are implementing the PREPARE Action Plan, which includes a specific focus on climate-resilient infrastructure. Infrastructure serves as the backbone of economic development, enabling communities to thrive. Climate change is stressing infrastructure in new ways. Across much of the world, the risks associated with climate change have not been systematically addressed in infrastructure planning, design, or implementation, jeopardizing benefits over the decades-long life of these critical investments. A paradigm shift is needed to build more resilient infrastructure for the future.

Resilience at Scale is a new PREPARE-focused report that presents clear, actionable strategies for federal agencies implementing PREPARE to employ a systems approach to resilient infrastructure. It offers a path for considering systemic risks and opportunities, helping to pinpoint likely future climate-related risks and the most effective interventions, accelerate investment, and achieve resilient infrastructure at scale. Importantly, it includes commitments by key federal agencies—the U.S. Agency for International Development, the Millennium Challenge Corporation, the U.S. International Development Finance Corporation, the U.S. Army Corps of Engineers, and the National Oceanic and Atmospheric Administration.

Since launching PREPARE, we have partnered with over 115 countries to address the climate-related threats they face, and this is just the beginning. A systemic approach is critical to addressing multifaceted challenges posed by climate change and providing the international development assistance of the future. We are committed to doing our part in heralding a paradigm shift toward more resilient infrastructure systems, and in turn, helping to build a climate-resilient and sustainable world.

Sincerely,

John D. Podesta
Senior Advisor to the President for International Climate Policy

A MESSAGE ON OUR COMMITMENT

A Paradigm Shift

Climate change poses significant risks to infrastructure investments and calls for urgent and expanded action. Although U.S. government agencies and their partners already assess climate risks to infrastructure investments, those assessments are typically conducted on individual assets such as a road, a bridge, or a building. To achieve the long-term development and security objectives of the United States and our country counterparts, infrastructure *systems*, not just individual assets, must be resilient. For example, a road may be designed to be extremely climate-resilient, but if it connects to a non-resilient bridge that washes away during a flood, people will not be able to use the road when extreme weather hits—cutting off access to essential services, emergency response, and jobs.

At present, infrastructure systems in many low- and middle-income countries are not resilient. If climate change risks are not addressed in the system in which the infrastructure investment operates, the likelihood of failure of critical infrastructure services increases. Agencies implementing PREPARE have an opportunity to address resilience holistically. Working with our development partners, we can help achieve resilience across sectors and systems at scale. By adopting the principles and approaches laid out in this paper, PREPARE signatory agencies and our partners will promote a systems approach that goes beyond an individual asset's design to consider it as part of a broader, interconnected system.

This good practice will be integrated into each agency's existing processes. It should not be prescriptive, as circumstances vary greatly based on local context and the nature of the investment. Along the way, agencies will learn by doing, helping everyone gain experience and build capacity. Through these innovative new approaches to infrastructure and systems design, the U.S. government can protect and ensure the effectiveness of its own investments with our partner countries, while developing a pathway for others to join.

Trending in the Right Direction

A systems approach to resilient infrastructure planning represents a breakthrough opportunity to revolutionize how donors maximize their investment impact, allowing them to work smarter to achieve resilient infrastructure at scale. It also builds on a variety of existing U.S. government objectives that recognize the critical importance of climate-resilient infrastructure. A systems approach is consistent with the domestic National Climate Resilience Framework; President Biden's Executive Order 14008, Tackling the Climate Crisis at Home and Abroad; and the Partnership for Global Infrastructure and Investment.

Through this PREPARE effort to promote infrastructure resilience, the Millennium Challenge Corporation (MCC), the United States Agency for International Development (USAID), the United States International Development Finance Corporation (DFC), the National Oceanic and Atmospheric Administration (NOAA), and the United States Army Corps of Engineers (USACE) are committing to expand the systems approach to the international arena. Agencies have defined specific climate change strategy objectives tailored to their respective missions and goals. USAID's 2022–2030 Climate Strategy sets a strategic objective to encourage systems change throughout the Agency's programs to catalyze shifts to net-zero and climate-resilient pathways. MCC's Climate Change Strategy identifies support for partner country sectoral, master, and investment planning relevant to MCC's programs. USACE's 2024–2027 Climate Adaptation Plan supports climate-resilient infrastructure investments and efforts to manage USACE lands and waters for climate preparedness and resilience. In line with its 2022–2026 Strategic Plan, NOAA supports efforts to build climate readiness by providing climate information and services and supporting adaptation action, including related to infrastructure resilience. Deploying climate finance is a cross-cutting priority for DFC's private sector investments in nearly every sector of the economy including energy security, infrastructure, food security, health, and financial institutions.

Our Commitment

USAID, MCC, USACE, NOAA, and DFC have taken a leadership role within the U.S. government on infrastructure systems thinking, working with PREPARE agencies to catalyze more impactful and cost-effective infrastructure investment across the federal government. Together, with other federal agencies and our bilateral partners, we can create an outsized impact in partner countries.

As such, PREPARE-endorsing agencies will consider systemic risks and opportunities to achieve resilient infrastructure at scale in partner countries, where consistent with programmatic strategies and requirements, to inform investment decisions. Through our commitment, we will:

1. **Consistently consider infrastructure systems resilience.** Agencies already assess the resilience of individual infrastructure investments. Departments and agencies will expand the scope of this practice to consider the resilience of the system(s) in which our infrastructure investments operate.
2. **Collaborate across PREPARE to achieve systems resilience, initially targeting specific geographies where this can take place relatively easily.** For example, in a given location, this collaboration could involve MCC capital investments in infrastructure and reform, USAID programs to build individual and institutional capacity, and U.S. Trade and Development Agency (USTDA) investments in infrastructure project preparation.
3. **Learn by doing, identifying, refining, and sharing good practices.** The PREPARE Infrastructure Working Group will refine and share good practices in collaboration with our development partners.

To advance our commitment, MCC and USAID have developed this paper describing the benefits of a systems approach to resilient infrastructure planning, along with recommended steps to facilitate its implementation. This effort takes the U.S. government's commitment one step further toward considering climate change on a systemic basis and aims to unite U.S. government leadership to achieve climate-resilient infrastructure systems at scale.

We invite you to join this paradigm shift, as we rethink how to work at scale to build a more resilient world.

Sincerely,

Jonathan Richart
Deputy Vice President of Infrastructure, Environment and Private Sector (IEPS)
MCC

Gillian Caldwell
Chief Climate Officer and Deputy Assistant Administrator, Bureau for Resilience, Environment and Food Security
USAID

William Veatch, PhD, PH
Lead, Climate Preparedness and Resilience Community of Practice
U.S. Army Corps of Engineers

Susan Ruffo
Deputy Assistant Secretary for International Affairs
U.S. National Oceanic and Atmospheric Administration

Aparna Shrivastava
Acting Chief Climate Officer
U.S. International Development Finance Corporation

Transportation, energy, buildings, and natural systems are interconnected in this urban context.
Credit: Shutterstock

METHODOLOGY AND ACKNOWLEDGMENTS

This work was conducted as a collaborative interagency effort in support of the President's Emergency Plan for Adaptation and Resilience (PREPARE) and by a team led by Doug Mason and Hope Herron, Millennium Challenge Corporation (MCC), and Amy K. Swers, United States Agency for International Development (USAID). The interagency PREPARE Infrastructure Working Group, which provided ongoing guidance and valuable perspective, includes representatives from the U.S. Army Corps of Engineers, Development Finance Corporation, Department of State, Department of Transportation, Department of the Treasury, and Trade and Development Agency. The PREPARE leadership team at the Office of the Special Presidential Envoy for Climate (SPEC) and USAID provided significant insight and guidance for this initiative. The authors would like to acknowledge the leadership and contributions of Christina Chan, former Managing Director for Adaptation at SPEC; Amanda McCarty, former Senior Advisor at SPEC; Ann Vaughn, former USAID PREPARE Director; and Lindsey Doyle, current USAID PREPARE Director.

This document was developed over a two-year period through extensive desk research, key expert one-on-one interviews, and an in-person workshop with global experts from across the international development field. Taking a systems approach to infrastructure resilience is an emerging concept, and there is not yet a significant body of published literature or substantial outcomes from implemented projects and programs to refer to. As institutions have only recently begun embedding a systems approach into their processes, current literature does not provide a full perspective and understanding of the latest initiatives, successes, and challenges in this promising area of practice.

To capture and build on the most current knowledge and innovation on systems thinking, MCC and USAID conducted initial expert interviews in July and August 2023, and an in-person workshop on September 26, 2023, in Washington, D.C., hosted by MCC and co-chaired by USAID. Participants came from across the U.S. government as well as other international finance institutions and non-governmental organizations active in this area.

Knowledge from experts and thought leaders, gained through the interviews and the workshop, complemented desk-based research to ensure that the latest challenges and opportunities to integrate systems planning into infrastructure development are reflected in this paper. A full list of expert interviewees, workshop participants, and peer reviewers is included in the Annex of Contributors and Workshop Participants, and the authors would like to thank these individuals for their participation and expert insight, which helped shape the document into a thought leadership and action-oriented output.

In addition, the authors would like to acknowledge the extensive technical and country team support from the many MCC and USAID staff who reviewed the document and provided comments, as well as the valuable contributions from MCC's Private Sector Advisory Council, Energy and Climate Subcommittee, which held a focused workshop on this topic (Spring 2024) to comment on this initiative and report.

ICF provided research and technical support to conduct interviews, organize the workshop, and draft the content of this paper. Authors from ICF are Joanne R. Potter, Alec Bernstein, Brad Hurley, and Logan Pfeiffer, with editorial and technical support from Peter Schultz, Audrey Magnuson, Fiona Price, David Ostroff, and others.

When systems are not climate resilient, a single asset, such as a flooded road, can put an entire system at risk. Credit: Shutterstock

Natural systems, such as coastal mangrove forests, should be considered in conjunction with built infrastructure systems. Credit: Shutterstock

HIGHLIGHTS

Infrastructure is not simply a collection of individual assets, such as roads, bridges, buildings, dams, or power lines. Instead, these assets—and the services they provide—are part of an interconnected system whose components rely on and affect each other. The failure of one infrastructure component can trigger simultaneous failures or a cascading collapse of other critical services, with profound impacts on communities and ecosystems.

Climate hazards are a growing risk to infrastructure investments, acting as threat multipliers that combine with existing stressors to exacerbate impacts. Because infrastructure is part of an interconnected system, planning for climate-resilient infrastructure should happen at the systems level. Yet much infrastructure is developed on an asset-by-asset basis.

Transitioning to a systems approach to infrastructure resilience[1] planning can provide important advantages, including:

- **Improving the reliability of infrastructure services.** Infrastructure resilience to climate hazards is a property of the system. For example, even if a hospital building is resilient to flooding, it cannot provide essential services if transport to the hospital is impeded by a washed-out bridge.
- **Reducing economic losses and improved cost-effectiveness of investments.** An asset-by-asset approach can waste time and money by ignoring critical interactions among system components and the climate risks that occur at broader scales. Infrastructure disruptions cost households and businesses in low- and middle-income countries an estimated $391 billion to $647 billion annually.
- **Protecting multiple assets at once.** Understanding how the individual components of an entire network interact allows us to inject resources where they will have the biggest impact, achieving more cost-effective investments. A systems perspective allows funders and governments to work smarter to achieve resilient infrastructure at scale.

[1] USAID defines resilience as "the ability of people, households, communities, countries, and systems to mitigate, adapt to, and recover from shocks and stresses in a manner that reduces chronic vulnerability and facilitates inclusive growth."

The C40 Finance Facility supported development of a solar plant on a deactivated landfill in Curitiba, Brazil. Credit: USAID

- **Helping achieve broader development goals.** Planning at scale strengthens opportunities to address environmental, social, and economic objectives. A systems approach enables planners to identify infrastructure investments that support their country's Sustainable Development Goals such as poverty reduction, gender equality, clean energy, improved health, and sustainable economic development.

A paradigm shift

A systems approach to infrastructure investment represents an opportunity to revolutionize how governments and donors maximize their investment impact. It allows governments to develop, refine, and update—in coordination with prospective funders—a strong, climate-informed pipeline of investments that addresses future risks and demonstrates a coordinated, strategic approach to cost-effective infrastructure investment. This can increase donor confidence to invest, even in high-risk areas.

Although no countries currently use a comprehensive systems approach to infrastructure resilience, elements of a systems approach are being used for risk assessment and planning. Real-world examples of promising approaches are highlighted throughout this document.

Why a systems approach?

A systems approach to infrastructure planning can deliver more effective and climate-resilient services.

Clearing the path

To achieve the benefits of a systems approach, countries will need to overcome institutional, technical, and financial barriers.[2] This can be accomplished by integrating resilient systems planning processes into relevant institutions (and ensuring that all infrastructure investments are linked to a planning process that accounts for climate change), growing decision maker support, collaborating and sharing good practices across the development community, and supporting efforts to create enabling conditions. Specific steps include:

- **Identify institutional barriers.** Work with partners to overcome hurdles and push forward a systems approach through policy development and institutional processes, led by champions and mechanisms for coordination.

[2] This paper aims to highlight the importance of improving systems-level planning and implementation to increase resilience to climate change. This approach should be undertaken together with other best practices in infrastructure development that reduce environmental and social impacts and strive to achieve more equitable and inclusive development outcomes.

- **Pinpoint technical capacity gaps.** Work with local experts to ensure that technical capacity is available to analyze data and incorporate a systems approach in planning. Focus on using available data to make strategic decisions, recognizing that simpler may be better.
- **Understand the funding landscape and identify enabling financing options.** Leverage existing funding channels and maximize opportunities for public and private financing for systems resilience. This may include incorporating standards and practices and coordination among financing and implementing organizations.

Changing the model of donor and country partner support for infrastructure resilience

Governments, donors, and investors can unlock the benefits of resilient infrastructure systems by investing in four areas to address the highest priority constraints to systems planning:

- **Support in-country partners' systems approaches to infrastructure resilience.** Donors should promote systems approaches and provide incentives, funding, technical assistance, and capacity building to support country partners in addressing their institutional barriers, technical and data gaps, and capacity constraints.
- **Finance projects that contribute to systems resilience.** Donors should invite and commit to funding projects that are part of countries' plans for climate-resilient infrastructure systems.
- **Integrate resilient systems planning into donor and investor institutions.** Development institutions should improve their internal processes to support infrastructure systems resilience. Their investment policies should incentivize systems-level processes and outcomes.

A systems approach

1. Assess climate vulnerabilities and risks to systems, not just individual assets.
2. Incorporate systems-level resilience considerations into infrastructure planning and management.
3. Build in-country capacity for systems-level assessment and planning.
4. Work with governments, donors, and investors to target financing to priority adaptation actions to achieve systems resilience.

MCC Tanzania expanded electrical infrastructure by connecting the Zanzibar Archipelago to the mainland via an undersea cable. Credit: MCC

- **Collaborate across the development community and share good practices.** Donors and investors should work to align investments to meet systems resilience priorities and build awareness across the development community.

RESILIENCE AT SCALE: A SYSTEMS APPROACH TO CLIMATE-RESILIENT INFRASTRUCTURE PLANNING

The case for a systems approach to infrastructure resilience

In late 2023 in Ghana, a woman stands helplessly atop the roof of her home, along with her two young children. She is watching the floodwaters gush through the streets, inundating her home and destroying her possessions. A rescue boat floats down the street, picking up people stranded on cars and rooftops. Homes, trash dumps, sewage facilities, and other vulnerable infrastructure are flooded. Essential services like drinking water and electricity have been disrupted and are unavailable. The risks of disease outbreak and widespread hunger grow as conditions deteriorate and emergency services struggle to reach the afflicted. The woman on the roof wonders, when the flood water recedes, where she will buy food and water to feed her family, how she will earn money to pay for the food, how she will rebuild her home, and much more. Her fears of the long-term effects of this disaster on her livelihood, local businesses, and the community culminate in a living nightmare.

This nightmare was a reality. In 2023, months of heavy rains in Ghana led to overflows at two dams in the Volta River region, resulting in flooding that displaced nearly 26,000 people. The floods devastated many downriver communities and agricultural fields (Naadi 2023). Inadequate planning, infrastructure, and capacity, along with human error, exacerbated the consequences and led to cascading impacts. Infrastructure had been planned on an asset-by-asset basis, without considering interconnections across systems. Planning also had not accounted for climate change, which increases the risk of extreme weather events. The dam overflow systems were built in the 1960s and were not designed for such torrential rainfall, nor did they incorporate measures to reduce the impacts of overflow flooding on the 15 communities downriver of the dams.

Displaced locals use boats to rescue people and navigate the streets of their community. Credit: Climate Change News

Dams exemplify how natural systems like rivers interact with built infrastructure systems such as energy generation. Credit: Shutterstock

These critical gaps left essential services, such as roads, electricity, and water supply, vulnerable and ultimately destroyed. Furthermore, previous simulation exercises and the early warning system prior to the event were ineffective in alerting residents to prepare for the flood. Flood events like this already affect 45,000 Ghanaians annually and are likely to become more frequent and catastrophic in the years ahead unless the nation takes action.

Systems-level planning

Infrastructure is a mixture of traditional (gray) and nature-based investments that provide essential services for economic development and human well-being. To ensure the continuity of these services, infrastructure systems must be resilient to a changing climate, both structurally and functionally. Many are not. Systems-level planning can help make infrastructure systems (not just individual assets) resilient to climate impacts.

In fact, Ghana has already started to take action. The Global Centre for Adaptation (GCA), the University of Oxford, the United Nations Office for Project Services, and the United Nations Environment Programme (UNEP) worked with Ghana's government to quantify climate adaptation needs across the energy, water, and transport sectors and to develop a prioritized roadmap of investments, policies, and financing options. Ghana's experience, and the actions the government has taken since, point to the potential of new systems-level approaches that will help countries build more resilient and inclusive infrastructure to withstand the increasing threats of climate change.

Benefits of a systems approach

The term "infrastructure" brings to mind roads, power lines, water pipes, buildings, and other physical assets, but ultimately infrastructure represents investments in services such as reliable energy, clean water, shelter, effective sanitation, and efficient transportation. To continue providing these services in the future, infrastructure investments must be resilient to the intensifying impacts of climate change projected for the decades ahead. They must also account for the differentiated needs of the people who ultimately rely on these systems.

Infrastructure is at risk. By 2050, infrastructure investors risk losing over half of their portfolio under extreme climate change conditions if adaptation actions are not taken (Chau et al. 2023; Amenc et al. 2023). Avoiding these losses will require upfront investment: By 2030, it is estimated that the costs of adapting to climate change could be $140 billion to $300 billion per year, and $280 billion to $500 billion per year by 2050 (GCF 2019). But the net benefit of resilient infrastructure is significant, estimated at $4.2 trillion in low- and middle-income countries over the lifetime of new infrastructure. That represents $4 in benefits for every $1 invested. The extra cost of building climate resilience into infrastructure systems is modest, estimated by the World Bank at only 3% of overall investment needs (Hallegatte et al. 2019).

But as the example above illustrates, improving the resilience of individual roads and buildings may still be ineffective if the larger interconnected system cannot deliver the services it was designed to provide.

Infrastructure is part of a complex and dynamic ecosystem of natural, built, and human physical and non-physical networks (Hallegatte et al. 2019; Hill et al. 2019; Duan and Ayyub 2019). In this integrated system, components rely on and affect each other. In addition, population growth, land use changes, environmental degradation, and unregulated development interact with climate stressors to affect infrastructure in ways that can undermine the systems' ability to continue to provide services. Climate change is magnifying the risks to these interactions through impacts such as more frequent and severe storms, extreme heat and drought, changing coastlines, and changing hydrological systems. These impacts ripple through infrastructure networks and produce cascading impacts across systems, affecting societal services, ecosystems, and economies (Carmody and Chavarot 2021). Poorer and marginalized communities are often hit the hardest.

Traditional approaches to improving infrastructure resilience to climate change focus on individual assets. But lasting resilience cannot be achieved at this level. Rather, governments, development agencies, and their partners must plan and develop climate-resilient infrastructure systems.[3]

USAID Jordan improved the country's water supply network by replacing outdated components and installing smart meters and leak detection equipment. Credit: USAID

A systems approach to infrastructure resilience provides significant benefits:

Improved reliability of infrastructure services

The failure of one infrastructure component can trigger simultaneous failures or a cascading collapse of other critical services because of the strong interdependencies across infrastructure systems (GCF 2021; Mullan and Ranger 2022). For example, even if a hospital building can function following a climate disaster, it may not be able to provide

[3] This paper aims to highlight the importance of improving systems-level planning and implementation to increase resilience to climate change. This approach should be undertaken together with other best practices in infrastructure development that reduce environmental and social impacts and strive to achieve more equitable and inclusive development outcomes.

Considering larger systems and system interconnections—such as among water, food, and energy systems—can improve the resilience of infrastructure. Credit: Shutterstock

essential emergency or health services if transport to the hospital is impeded and medical staff, supplies, and those needing care cannot reach the hospital. In October 2023 in Sikkim, India, a glacial lake outburst flood in the Himalaya washed away 33 bridges, 2 government buildings, 1 hydropower dam, and 16 road and highway segments near the Teesta River. One event triggered cascading disruptions across transport, energy, and governance networks that disconnected Sikkim from the rest of India, prevented emergency services from reaching those affected, and blocked access to hospitals for many communities (Kumar and Travelli 2023; Roy 2024). Considering interactions among systems in resilience planning can help ensure reliable infrastructure services across sectors (Hallegatte et al. 2019).

By integrating systems-wide analysis of risks and understanding the critical links across assets and networks, investments can be targeted to reduce the risk of system disruption and damage, both during extreme events and due to long-term climate change stressors.

Reduced economic losses and improved cost-effectiveness of investments

Infrastructure disruptions impose costs ranging from $391 billion to $647 billion annually on households and businesses in low- and middle-income countries (Hallegatte et al. 2019). Improving the reliability of infrastructure services can support economic growth by reducing economic losses across the economy and improving the livelihoods of people. Systems analysis helps identify and address risks to critical links and components, creating a more robust system that is less vulnerable to disruptions—and the costs they incur (Carmody and Chavarot 2021; Chavarot et al. 2022; UNEP 2021).

Designing adaptation measures at the systems level also results in more cost-effective adaptation investments. It supports consideration of the broadest range of options to provide reliable infrastructure services (e.g., through the choice of sites for infrastructure, which can have a significant impact on both costs and reliability). Systems-level adaptation strategies—strategies that address the functional vulnerabilities of a system's interconnected elements—can reduce risks across multiple assets, thereby building the resilience of the entire system. For example, the use and maintenance of nature-based solutions such as bioswales—channels designed to concentrate and convey stormwater runoff while removing debris and pollution—to enhance drainage along a group of primary roads increases

"When we move from the project level to a systems level, one of the key benefits is minimizing the transaction cost at the project level so that we are not creating another roadblock for investment."

— Stephane Hallegatte, Senior Climate Change Advisor, World Bank, 9/26/2023

the resilience of the entire transportation network (Alfred Grünwaldt, IADB, pers. comm. 2024). When a systems-level strategy is in place, emergency relief construction funds can be targeted to build or restore critical infrastructure that helps to strengthen long-term systems resilience.

Adaptation measures that are taken at the asset level can likewise have system-wide benefits if that asset is a critical component of an overall network. But often the systems benefits of improving a crucial "weak link" are not recognized in cost analysis. The additional cost of design changes to protect a single exposed critical asset could increase a project's overall costs by 30 percent or more. However, the benefits of this investment accrue to the whole system. When the cost of this system-wide benefit is considered against the total investments made in the system as a whole, the increase to overall costs may be only 3 percent to 5 percent (Stephane Hallegatte, Planning Climate Resilience Infrastructure Systems Workshop, 2023).[4] Development practitioners typically evaluate climate adaptation costs on an asset-by-asset basis, and decision makers have often been reluctant to approve the additional costs given the perceived political and financial risks. Switching to a systems-level view of adaptation investments can increase buy-in for these improvements because their incremental cost is lower when assessed from a systems perspective.

Framing infrastructure development through a systems lens helps infrastructure planners identify the highest priority needs, design investments accordingly (ADB and GCA 2021), and align investments with their National Adaptation Plans. Prioritizing investment options will allow decision makers to understand and manage the exposure of infrastructure systems and individual assets, as well as other socioeconomic implications of physical climate risk (Carmody and Chavarot 2021). Engaging with local communities and community-based organizations (CBOs) will help decision makers and donors identify and avoid social and environmental risks.

A community-driven flood warning system for Nairobi: DARAJA

Infrastructure systems are more than concrete and steel; they involve the people they serve. In Kibera, Nairobi's largest slum, citizens are mobilizing and building climate resilience by implementing early warning system infrastructure. Funded by the UK Meteorological Office and the UK Foreign, Commonwealth & Development Office (FCDO), DARAJA (Swahili for *bridge*), pairs Kenyan Meteorological Society weather forecasts with activists trained to interpret them. These trained citizens translate forecasts and text them out to residents. Volunteers mobilize to unclog drains, clear drainage paths, and inform local residents of the upcoming flood risks. Ninety-eight percent of the residents state that they use DARAJA information services to prepare for extreme weather through actions that avoid damage and loss, such as repairing their homes/roofs (+300% on baseline), moving possessions to a safe place (+166%), cleaning households (+110%), and clearing community drains (+68%) (Resurgence 2023; Resurgence 2024). DARAJA's approach demonstrates inclusive development and builds systems resilience to climate change, helping to strengthen operational partnerships between decision makers and vulnerable communities to prevent economic and infrastructure damage due to extreme precipitation and flooding events.

[4] Subsequent references to presentations made at this workshop are cited as "Systems Workshop, 2023."

The USAID Philippines program supported mangrove and forest restoration to improve coastal resilience and the fishing industry. Credit: USAID

System-based prioritization can also support donors in making coordinated, synergistic investments across their respective funds. Development agencies, partner governments, communities, and private-sector investors will be better able to identify investment opportunities targeting priority components of a system-wide plan (Chavarot et al. 2022). This also helps investors avoid the unintended consequences of piecemeal investments, including investments that unintentionally increase vulnerability rather than reduce it by not adequately accounting for climate change in infrastructure systems. This approach allows governments to present to prospective funders a strong, climate-informed pipeline of investments that addresses future risks and demonstrates a robust plan of action.

For example, with support from the World Bank, Ho Chi Minh City built on decades of planning to invest in flood mitigation infrastructure to reduce flood impacts that involved multiple donors. Back in 1999, the Japan International Cooperation Agency developed a master plan for drainage infrastructure, which helped coordinate investments from the World Bank and the private sector in the subsequent decades. The plan served as a baseline strategy for investments to address flood risk, providing a roadmap for donors. However, this initial plan considered only historical rainfall patterns rather than future projections. It also did not anticipate the increased development that the new infrastructure triggered. Increased urbanization, combined with climate change, led to an increase in vulnerability to floods in the area (Hallegatte et al. 2012).

Following several floods, the city government and donors, including the World Bank, worked together to develop a more robust plan that accounted for future climate change and considered interactions between new development patterns and more extreme flooding. Ultimately, understanding the systems implications of infrastructure investments, such as donor coordination, has been critical as plans evolve to design resilient flood infrastructure in Ho Chi Minh City. A systems approach allows governments to develop, refine, and update, in coordination with prospective funders, a strong, climate-informed pipeline of investments that addresses future risks and demonstrates a robust plan of action.

Support for broader development goals

A systems approach enables planners to identify opportunities for infrastructure investments that support their country's Sustainable Development Goals, such as poverty reduction, gender equality, clean energy, improved health, and sustainable economic development—particularly in communities and environments that are most vulnerable to the impacts of climate change, such as agricultural areas impacted by increasingly severe drought and flood events. Risks to residents in informal urban settlements—currently home to approximately 1 billion people globally—are particularly high, as an influx of internal migrants move from more rural areas to be closer to jobs and services and settle in areas that are highly vulnerable to climate impacts, such as along steep slopes and waterways.

Systems-level planning to integrate climate-resilient infrastructure, safe housing, access to jobs and community services, and citizen engagement can reduce climate-related risks and build resilience for the most vulnerable populations (Satterthwaite et al. 2020). At the urban level, programs such as USAID's Building Healthy Cities are taking systems approaches to design integrated development and infrastructure strategies that ensure the differential needs of women and underrepresented groups are fully incorporated (UrbanLinks 2023).

Systems-based approaches facilitate the incorporation of social and environmental metrics, such as equity and access to services, especially when local communities are consulted. Similarly, they may put in perspective the systemic gains of nature-based solutions—for example, in addition to reducing flood risk, rehabilitating floodplains often brings biodiversity, livelihoods, and recreational benefits. Through the strategic use of infrastructure investments, countries can design projects that achieve emissions reductions that support their nationally determined contributions (NDCs), create jobs, and stimulate economic growth—achieving multiple goals through each investment (UNEP 2021; Adshead et al. 2022).

Zambezi River Basin multi-sectoral investment analysis strengthens development goals

Severe droughts in Zambia and Zimbabwe in 1991 and 1992 caused water levels in Lake Kariba to decline dramatically, severely impacting hydropower generation. The droughts exposed the vulnerability of both countries to an overreliance on a single power source. The results of a multi-sectoral investment analysis in the Zambezi River Basin, southern Africa's largest river, have shown that cooperative water development in the watershed could result in substantial development benefits, including poverty reduction, enhanced energy security, efficient agricultural production, increased employment, improved economic resilience, lower regional transport costs, and more reliable water supply for urban and industrial demand. The Batoka Gorge Hydroelectric Scheme was determined as key to this integrated plan for both countries, and the World Bank has invested in studying and financing the investment. A systematic sensitivity analysis of the design was conducted to understand the implications of climate change, upstream water use (especially agriculture), financing terms, labor costs, and other macroeconomic factors that contributed to investment decision making (World Bank 2010 and World Bank 2018).

MCC's El Salvador Compact helped build several bridges to improve connectivity between the northern zone across the Sierra Madre mountains and the rest of the country. Credit: MCC

CLEARING THE PATH: REMOVING BARRIERS TO A SYSTEMS APPROACH

Despite its many potential benefits, climate-resilient infrastructure systems planning is not yet standard practice. In most cases, governments and development partners focus on a project-by-project investment process, analyzing each asset decision separately. Understanding the overall resilience of interdependent infrastructure requires an assessment of system vulnerability as well as asset vulnerability. Examining this broader dimension provides countries and their investors with a more accurate and comprehensive understanding of structural and functional vulnerability, which then points to key risks and priorities for action (Ouyang 2009).

To date, there are no examples of a country using a comprehensive systems approach to improve infrastructure resilience to climate change (Michael Mullan, Systems Workshop, 2023). A range of institutional, technical, and financial barriers must be overcome to shift the state of practice (PCCB 2019). Some countries have begun to develop sector-specific plans that include an evaluation of systems-level vulnerability—an important step toward more comprehensive integrated approaches. These examples illustrate strategies that countries can use to overcome barriers to systems planning and move to more transformative approaches.

Applying a systems approach

The practical steps involved in applying a systems approach to infrastructure resilience to climate change include:

1. Assess climate vulnerabilities and risks to systems, not just individual assets.
2. Incorporate systems-level resilience considerations into infrastructure planning and management.
3. Build in-country capacity for systems-level assessment and planning.
4. Work with governments, donors, and investors to target financing to priority adaptation actions to achieve systems resilience.

The checklist of actions below summarizes concrete actions that countries and development partners can take to identify key barriers and strengthen enabling conditions over time.

Actions to Identify Barriers and Strengthen Enabling Conditions for Systems Planning

- ☐ **Identify the institutional barriers that would inhibit a systems approach.** Work with partners to identify key steps for overcoming these hurdles and push forward a systems approach through policy development, support to champions leading the cause, or developing new mechanisms for coordination. Example tasks may include:
  - Identify key personnel/agencies/departments in national and local governments that are crucial in the decision-making process for infrastructure and consider mechanisms to engage them.
  - Understand any policy or political limitations that may inhibit a systems approach at all levels of government.
  - Identify master plans, national strategies, policies, or legislation that account for climate change or enable a systems approach.
- ☐ **Pinpoint technical capacity gaps to implement a systems approach.** Work with local experts to ensure that technical capacity is available to analyze data and incorporate a systems approach in planning. Focus on using available data to make smart decisions, recognizing that simple may be better. Example tasks may include:
  - Identify where climate change information is already used and what data are available.
  - Inventory available in situ observed data that could be used to inform systems planning and local decision making.
  - Identify areas where globally available climate change datasets could be included in analysis/plans.
  - Assess available expertise and resources and identify potential training or technical support.
- ☐ **Understand the funding landscape and consider financing options that could enable a systems approach.** Leverage existing funding channels and maximize opportunities for public and private financing for systems resilience by incorporating standards and practices that can be easily adopted to improve the attractiveness for funding. Example tasks may include:
  - Review previous financing from multi-lateral development banks and bilateral development agencies for infrastructure projects and assess the degree of integration with systems approaches.
  - Understand the governmental processes required to solicit infrastructure financing to identify opportunities and potential barriers to finance.
  - Identify systems adaptation priorities that match donors' and private investors' objectives.
  - Strengthen internal capacity and systems to work with funders to secure appropriate financing.

Institutional barriers

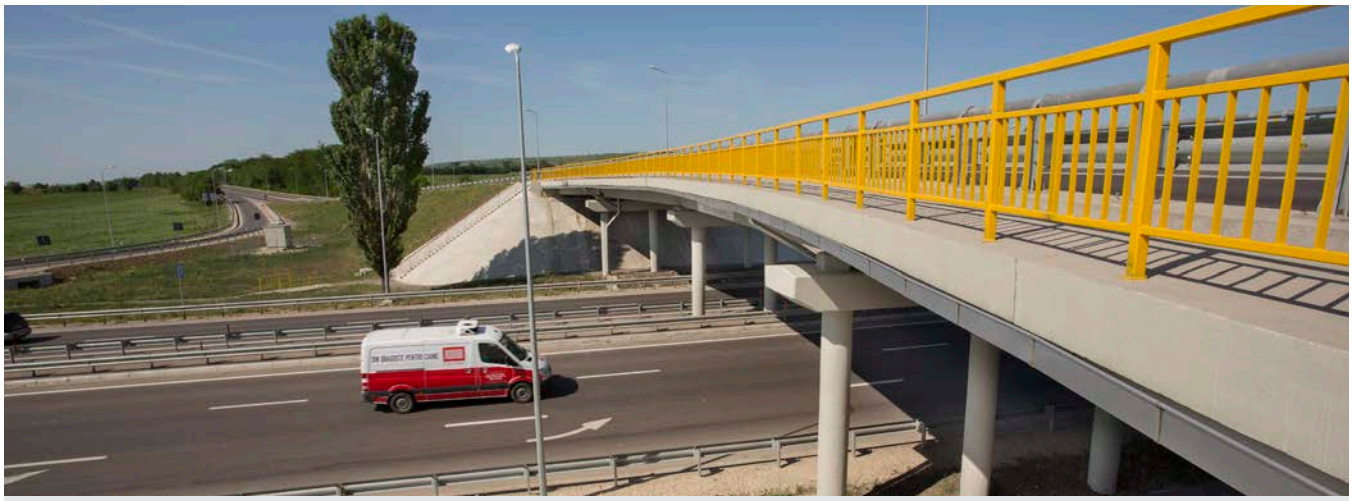
The most significant barriers to a systems-based approach to infrastructure planning are often institutional. Pivoting away from long-standing approaches to infrastructure investment requires committed leadership, coupled with institutional frameworks and policies that enable this transition. While most countries have national climate change commitments and plans, the lack of legislation, policies, regulation, and guidance to line ministries often results in a disconnect between high-level policies and sectoral actions. This issue is compounded by "stove-piped" government institutions that are not accustomed to working together and budgets that reinforce those divisions. Different ministries and agencies have explicit mandates and institutional priorities that may conflict with systems resilience priorities (Alfred Grünwaldt, Systems Workshop, 2023). Stove-piping can result in investments by individual agencies that may not contribute to—or even conflict with—national resilience goals.

Further, coordination with other entities is typically not considered part of a ministry's responsibilities, and few if any incentives exist for them to invest time and resources in working cross-agency. The lack of strong planning ministries or executive units able to coordinate across sectoral, environmental, and finance ministries hampers the ability of governments to design and implement strong and coordinated long-term strategies. For example, a Ministry of Public Works may be reluctant to use nature-based solutions to address systems-level flood management because it does not have the authority or budget to maintain ecological systems and would need to rely on an environmental ministry. Translating plans into practice can be challenging without a strong overarching policy framework, clear lines of responsibility for implementation, and the appropriate institutional structure and incentives for coordination. This can require shifts in traditional processes, new communication mechanisms, and augmented budgets.

Blue Spot Analysis: A holistic approach to the Dominican Republic's road infrastructure system

The Dominican Republic Ministry of Public Works and Communications, with the support of the Inter-American Development Bank (IDB), financed Resilient Transportation Infrastructure – Blue Spot Analysis in 2020 as a pioneering solution to support government institutions and decision makers in prioritizing investments in transport. This holistic approach examined the entire road/infrastructure network to identify the most critical areas to address to improve system performance during climate events. The approach included an inventory of the entire road network, use of available modeling to identify the most high-risk locations, identifying the most significant areas that are vulnerable to damage and economic loss, prioritizing investments, and developing a visualization tool and training for key government personnel (Global Infrastructure Hub 2018b).

Consistent, visionary leadership is also required to steer complex institutions toward systems approaches. The benefits of systems-level analysis to address climate risks can be difficult to communicate and may take time to achieve. Government leaders may prioritize simpler and short-term project investments that have broad appeal or are favored by powerful interests. Frequent turnover in elected leaders undercuts continuity in pursuing a long-range vision of resilience. In addition, corruption may drive infrastructure project development that is suboptimal or maladaptive to the overall system.



MCC's Moldova Compact rehabilitated a 96-km stretch of road to improve passenger and commercial traffic flow, supporting economic development and access to services. Credit: MCC

The lack of buy-in at the top levels of government results in a weak mandate for ministries and line staff. Absent clear direction, government ministries lack a clear purview and authority to conduct risk analysis and planning efforts to achieve transformative resilience. But mandates alone are not enough. To be willing to take a new approach, staff need to understand how systems analysis can help them achieve their responsibilities and deliver better results. Cultivating true institutional buy-in takes time, evidence, and ongoing discussion (Arghya Sinha Roy, ADB, pers. comm., September 2023; Alfred Grünwaldt, IADB, pers. comm., 2024).

Countries have begun to address these institutional challenges in several ways, catalyzed by strong leaders and donor support. Strategies to address institutional challenges include:

- Engage and support resilience champions.
- Strengthen institutional policies, alignment, and coordination.
- Develop enabling policies and enact legislation to provide the necessary authority and resources to key agencies.
- Integrate vertically across different levels of government.

Addressing institutional barriers

The first step toward addressing institutional barriers to systems-level approaches to infrastructure resilience is to identify those barriers, which may not always be obvious. For example, in Ghana, the government identified its priority areas for capacity building through a self-assessment, using the Capacity Assessment Tool for Infrastructure (CAT-I). The findings helped Ghana and its donors focus training and technical support on the most significant institutional barriers (GIZ and UNEP 2022).

Engage and support resilience champions

Having an individual or organizational champion with decision-making power helps accelerate and improve systems planning efforts. A trusted local champion who understands the value of systems thinking can set the tone for embedding systems planning into existing processes across ministries. Identifying and charging

a champion with leading these efforts can help ensure that connections are made whenever necessary and efforts are targeted in the right areas to consider and implement systems resilience. A resilience champion can catalyze coordination and collaboration across ministries, agencies, and donors, and should be supported to build on existing institutional knowledge to integrate systems thinking into investments.

Strengthen institutional policies and processes for alignment and coordination

Creating organizational structures that facilitate and incentivize coordination helps governments overcome traditional institutional barriers to systems approaches. This can be achieved by empowering a strong planning ministry or executive unit able to coordinate across sectoral, environmental, and finance ministries—supporting the ability of governments to design and implement robust and coordinated long-term strategies. Inter-ministry working groups can be created to conduct coordinated analysis and develop effective plans for systems investments. Establishing the appropriate institutional structure for coordination, along with clear lines of responsibility for implementation, helps countries develop well-integrated plans and translate these plans into practice—improving resilience through investments across line agencies and levels of government.

Develop enabling policies and enact legislation to provide the necessary authority and resources to key agencies

Establishing a strong overarching policy framework and enabling legislation provides the policy framework and mandate that enables government ministries to take action. This may include institutional changes, such as expanding the authority and resources of specific ministries or establishing new entities focused on whole-of-government coordination. Legislation to require government infrastructure investments to incorporate systems-level considerations, including climate risks, helps ensure that financing is steered to projects and programs that build systems resilience. Further,

MCC supports systems planning with a resilience champion in Indonesia

MCC's work with the Government of Indonesia through the $350 million Advancing Transport and Logistics Accessibility Services Project (ATLAS) program demonstrates how the agency is moving toward systems planning in infrastructure development. The ATLAS project works in five provinces where transport and logistics need improvement. ATLAS collaborates with municipal governments to develop sub-national government capacity and investment guidelines that will create a prioritized roadmap to facilitate greater capacity for infrastructure planning and preparation at the local level across the country. Investing in improving the capacity for infrastructure planning will increase the efficiency of delivering investments while improving the quality of infrastructure.

ATLAS also demonstrates how a local champion in the Government of Indonesia can help push forward systems thinking initiatives through partnerships with countries. In Indonesia, respected individuals within the Ministry of Finance have mobilized other ministries to coordinate and align priorities. MCC identified a champion through its work with the Ministry of Finance and collaborated with that person to make the case for a new approach. The credibility of systems thinking across ministries and levels of government gained traction due to the leadership of the Indonesian champion, paving the way for MCC's engagement (Jason Jones and Marycel Tuazon, MCC, pers. comm., 25 August 2023 and MCC 2023a).

policies that promote upstream systems-level approaches with a primary purpose of delivering adaptation and resilience benefits demonstrate countries' commitment to a coordinated, strategic investment approach. This increases donor confidence to invest even in high-risk areas (Arghya Sinha Roy, Systems Workshop, 2023).

Integrate vertically across different levels of government

In addition to horizontal coordination across ministries, it is important to align and integrate priorities across local, regional, and national jurisdictions, as well as with sovereign nations where they are present. This requires top-down and bottom-up coordination and dialogue among national ministries and local governments, including inclusive engagement across diverse constituencies. Clear and consistent planning and investment policies and requirements are needed to reinforce systems-level approaches to infrastructure investments, from the national level to the local level. For example, in South Africa, national laws that focus on operational resilience in the banking sector (Directive 2021/10) are embedded into local municipal laws, which can more easily be operationalized into action (Vladimir Stenek, IFC, pers. comm., 24 August 2023). As a result, all banks in South Africa were required to develop and implement operational risk management and resilience plans by June 2023.

Technical barriers

Developing countries often face constraints in staff capacity, technical expertise, data availability, and technical tools. Country partners may have limited staff and expertise to access and work with climate information, conduct vulnerability and risk assessments and stress tests, perform complex systems analysis, develop and assess adaptation strategies, implement adaptation actions, and monitor and manage systems performance.

Coordinating plans, policies, and institutions in the Philippines through USAID's Safe Water project

More than 30 agencies in the Philippines are involved in the water sector, so planning and coordination can be challenging. In 2023, the Government of the Philippines created the Water Resources Management Office (WRMO), which is charged with leading and coordinating across national government agencies on water-related functions. At a sub-national level, USAID's Safe Water project supported the Provincial Integrated Water Security Plans, which have been adopted by the WRMO and enable local governments to contribute to achieving universal water supply access and strengthen water management. Coordination at the national and sub-national levels have helped the Philippines shape decisions, allocate more funding for water security activities, and create organizational structures to support the development of improvement programs and plans (USAID 2023).

USAID Philippines supported the Palawan government to develop a climate-resilient water intake structure to supply water. Credit: USAID

Attracting and retaining personnel is also a significant challenge because resource-constrained government agencies and research institutions compete with the private sector and global employers for trained staff (UNFCCC 2023). In some cases, donors and their country counterparts have overcome this constraint by engaging external specialists to conduct analyses and provide data products. However, while these products are valuable and provide a short-term benefit, this approach is costly (relying often on international staff) and often leaves no lasting staff capacity within the country, thus constraining development. This acts as a brake on the rapid replication and widespread use of highly technical analyses (Hallegatte et al. 2019; UNFCCC 2023).

Data gaps, fragmentation, and poor data quality—as well as limited access to data management and analysis tools—constrain the ability of technical staff to conduct robust assessments and informed planning. Information on the location, design, condition, use, and performance of infrastructure assets and network components is often incomplete and inaccessible. Constraints on data availability also include institutional issues such as data ownership, intellectual property, and sharing limitations. Data gaps can be particularly challenging for planners in difficult-to-access areas with the most vulnerable populations, including urban slums and rural areas with poor communication (UNFCCC 2023).

As the dynamics of climate change become increasingly frequent and complex, the technical challenges in understanding and managing climate risks increase as well. Climate uncertainty may interact with other stressors within a system; this dynamic combination of factors can be challenging to decision makers with limited technical resources and data to understand climate change. Traditional infrastructure systems planning has not adequately considered these evolving combinations of climate risks and uncertainties. Responses to these challenges require tailored information products for specific users and applications.

Stress-testing for climate risk to determine the most effective infrastructure investment needs at the systems level

Climate change poses risks to infrastructure systems in southern Africa, but the lack of data has made it difficult for donors and countries to know how to prioritize resilience investments. The World Bank assessed the region's energy and water infrastructure needs by stress-testing the connected electricity and water resource systems with different climate change scenarios to understand the most vulnerable components and most effective infrastructure investment needs. Working with country partners, World Bank used this analysis to plan robust new infrastructure and enhance the readiness of African countries to use climate finance to increase infrastructure resilience (Cervigni et al. 2015; ASCE 2018; ASCE 2022).

Data providers' ability to collect and integrate multi-hazard data and generate alerts is limited, and multiple U.S.-funded support programs are working to address these information gaps to support more robust country decision making (USAID 2020a). As multi-hazard events become more common, understanding the connections across systems becomes more critical to build resilience. Compound climate hazard events can lead to significant cascading impacts across systems and sectors, especially for vulnerable infrastructure, populations, and ecosystems. These compound climate hazards act as a threat multiplier that combines with existing stressors and exacerbates the impact on unprepared infrastructure systems (Sherri Goodman, Systems Workshop, 2023).

Strategies to address technical barriers include:

- Support data collection, management, and sharing across institutions.
- Use best international practices at a local level, including integration of performance metrics, standards, and codes.
- Use tools and frameworks to leverage data and comprehensively plan and manage assets.
- Integrate systems planning into the entire infrastructure life cycle.

Support data collection, management, and sharing across institutions

Implementing a data collection and management strategy will help institutions build critical datasets that can inform systems planning and adaptive management processes. Even better, organizations with similar data needs can coordinate to gather data and co-manage systems and share information to inform systems analyses. For example, a country's land use planning ministry can work with the transportation ministry to collect and share data on existing infrastructure, climate vulnerability, social demographics, and other common data needs when planning large transportation investments. This includes drawing on the knowledge and experience of communities and indigenous peoples to understand observed climate conditions, impacts, and resilience strategies. For instance, water service providers (WSPs) in Kenya during the COVID-19 pandemic were required to provide handwashing stations, and USAID's Water, Sanitation, and Hygiene Finance (WASH-FIN) program exposed the financial and data gaps for WSPs to meet this target (USAID 2020b).

Different sectoral ministries generate valuable data that can inform other sectors as they identify development objectives to which they could contribute. For example, USAID's Bureau of Humanitarian Assistance (BHA) is developing a geospatial database to track BHA's infrastructure projects by type and purpose and have data on dimensions, locations, costs, conditions, and capacities. These data can be leveraged to inform further development investments.

Watershed planning to develop projects and engage private investors in South Africa

With support from USAID, the C40 Cities Finance Facility (CFF) funds climate adaptation projects that embed systems thinking, helping cities finance inclusive and equitable projects that focus on climate change mitigation and resilience. In Durban, South Africa, funding from CFF is being used to develop a business case for a Transformative River Management Programme (TRMP). TRMP will adapt 7,400 km of streams and rivers to mitigate the impacts of flooding and drought projected in the future. The business case will use cost-benefit analysis to persuade a range of funders, including the municipality itself, businesses and property owners in Durban, and global climate funders, to make the investments required. The projects will have significant benefit in the riverine corridor, such as job opportunities, green economy, and natural open spaces for recreation that will promote private-sector engagement and investment.

USAID South Africa's water supply work in Cape Town aims to diversify the city's water supply and reduce risks from drought. Credit: USAID

The 50x2030 Initiative is working in 50 countries to build more robust data on agriculture, supported by multiple donors (World Bank Group 2023; USAID 2020b). These data can enrich systems thinking for infrastructure planning across energy, transport, water resources, and other sectors.

Working with common datasets, assumptions, and methodologies facilitates a coordinated planning process across government agencies and helps organizations optimize the information available. Even with limited data, this collaboration helps improve analysis and address systems-level challenges (Alfred Grünwaldt, Systems Workshop, 2023).

Use best international practices at a local level, including integration of performance metrics, standards, and codes

Using proven practices, such as performance standards and codes that enable enhanced climate resilience in infrastructure planning, design, and operation, can improve outcomes and build on tested approaches. Ongoing efforts and guidance by engineering professional societies, such as the American Society of Civil Engineers (ASCE) include sustainable resilience metrics for infrastructure (ASCE 2021).

Systems resilience assessment in Jamaica

The Coalition for Climate Resilient Investment (CCRI) worked with the Government of Jamaica to implement the CCRI Systemic Resilience Assessment Tool. The pilot project examined the exposure of Jamaica's transport, water, and energy sectors to physical climate risk and identified "hot spots" that indicated where investments in climate resilience would have the most impact. The analysis—supported by the University of Oxford, UK FCDO, and the Green Climate Fund—enabled Jamaica to prioritize investments, maximize socioeconomic value, and identify opportunities for nature-based solutions (Legacy Programme n.d.).

The World Bank's decision tree framework for resilient water systems in Mexico City

Stress-testing systems under a range of future scenarios helps pinpoint critical vulnerabilities under different conditions and prioritizes the most effective interventions.

The World Bank evaluated Mexico City's water supply through a comprehensive human-hydrologic modeling tool accounting for the human influence on the physical water cycle and implications for water supply in the city. Stakeholders from all sectors contributed to the cross-sectoral integration of the model, which integrated aspects of infrastructure, societal decision making and policy choices, natural resources, and climate change. The system was stress-tested to understand vulnerable points and results were used to prioritize infrastructure improvements to the city's water system that maximized reliability and resilience of the supply for all users. Investment opportunities uncovered during this process could alleviate water stress in Mexico City, including rainwater harvesting and other demand-side adaptations in addition to the implementation of large new infrastructure, such as water supply dams and pipe networks (St. George Freeman et al. 2020).

Urban centers like this one demonstrate critical nodes in system networks. Credit: Shutterstock

Use tools and frameworks to leverage data and comprehensively plan and manage assets

Building on existing frameworks, such as UNEP's International Good Practice Principles for Sustainable Infrastructure (UNEP 2021), can help countries begin to take a systems-level approach. Tools that have been successfully applied include the Coalition for Climate Resilient Investment (CCRI) Systemic Resilience Assessment Tool (see box on previous page for an application in Jamaica), Ghana's infrastructure assessment approach (GIZ and UNEP 2022), and the World Bank Decision Tree (St. George Freeman 2020 and Paltán n.d.). They include assessment and prioritization methods that can support a systems approach.

Countries are using coordination frameworks to build cross-sectoral institutional and technical capacity, develop processes, and define actions and responsibilities across ministries. In Ghana, as part of the country-wide climate infrastructure assessment, ministries co-developed a plan to address disjointed efforts and create synergies across sectors. As one measure, the roadmap prioritized a centralized climate risk data management system to provide more complete, efficient, and aligned data for decision makers. This improved data quality, streamlined data management, and improved access to data across infrastructure ministries and sectors (GIZ and UNEP 2022).

It is important to use tools and techniques that are feasible given a country's existing capacity and data constraints, accessible to in-country staff, and fit for use in the local context. For instance, in countries with daily power outages or regular road washouts during the rainy season, the tools to improve the energy sector or road transport resilience may be much simpler but still effective to improve conditions beyond the status quo (Stephane Hallegatte, Systems Workshop, 2023). In data-scarce environments, using simplified geographic information system tools to layer information onto maps (such as critical infrastructure nodes, climate risks, and utility connections) can help paint a clearer picture of system and network connections (Cervigni et al. 2015; ASCE 2018; ASCE 2022).

"It is very important to understand the whole picture of risk and to ensure that these risk considerations are understood across the entire life cycle of the infrastructure system."

— Arghya Sinha Roy, Senior Climate Change Specialist, Asian Development Bank, 9/26/2023

Integrate systems planning into the entire infrastructure life cycle

Systems resilience should be assessed and integrated at each stage of the infrastructure life cycle, from planning to construction, operation, and beyond. During the initial systems planning process, policymakers, planners, environmental and social experts, financiers, builders, engineers, local stakeholders, and community members should be engaged to ensure that all perspectives and life cycle phases are considered. As components of an integrated plan are constructed and move into operation, managers should maintain a systems perspective to ensure that operational decisions continue to support systems resilience. An ongoing monitoring and evaluation process to track systems performance and external conditions—including climate change—will support managers in optimizing systems resilience.

Financial barriers

Current public and private investment in resilient, quality infrastructure is far less than required, making it difficult for countries to plan and implement a strategic pipeline of projects. UNEP estimates that the annual difference between financing available for climate adaptation and total need in developing countries is $194 billion to $366 billion, increasing to $315 billion to $565 billion by 2050 (Standard Chartered et al. 2024; UNEP 2023). The Asian Development Bank (ADB) estimated financing needs for regional hard infrastructure to be $459 billion per year from 2017, or about 2.4 percent of developing Asia's GDP. When the expected need for funding "social" infrastructure (such as health and education) is included, the gap doubles to $907 billion (Ra and Li 2018). Moreover, in Latin America and the Caribbean, the Inter-American Development Bank (IDB) concludes that the region needs to boost investment in infrastructure from 1.8 percent of its regional GDP to 3.12 percent (Brichetti et al. 2021) to close the existing infrastructure gap. The unmet need for adaptation financing for urban infrastructure is partially driven by the focus on climate mitigation. Ninety-eight percent of total urban climate financing for the transport and building sectors in 2017 and 2018 went to investments in mitigation projects ($377 billion), while only 2 percent ($7 billion) was devoted to adaptation projects (Cities Climate Alliance 2021).

The lack of sufficient investment is driven by several factors. Investors cite an overall lack of bankable projects that meet their investment requirements. At the same time, the lack of analytic tools to quantify

Electrical technicians inspect and maintain solar panels on Karampuang Island, Indonesia, to extend the life cycle of the energy infrastructure. Credit: MCC

the physical risk of climate impacts to specific infrastructure investments makes it difficult for investors to assess the financial risks and prospective returns on potential investments. This can lead financers to make more conservative decisions about potential investment opportunities. Further, the timing and magnitude of climate impacts is uncertain, and the benefit of adaptation investments—such as increased resilience during a severe storm—may not be realized by the investor during the timeframe of their investment. The uncertainty inherent in climate projections grows larger for more distant future years, which is especially relevant for major capital investments where the anticipated service life of infrastructure spans decades. The lack of a clear market signal to potential investors discourages countries from incorporating the upfront costs of resilience into their infrastructure plans. Further, the lack of a clear physical and economic assessment of risks leaves investors with little confidence in the strength of their investment (Carmody and Chavarot 2021).

While inadequate capital investment is a major concern, the lack of financial resources to support institutional strengthening and upstream planning is also a significant constraint. Traditionally, donor funding has been focused heavily on capital investment but not on the enabling upstream capacity to conduct systems-level risk assessment, prioritization, and planning; build institutional frameworks; and conduct policy reform. This gap contributes to the inability of infrastructure agencies to develop a sound pipeline for infrastructure investments. These weaknesses are often compounded by lack of coordination among donors and investors with different funding objectives, along with donor/investor requirements that countries find challenging to meet, including demonstrating project readiness, meeting project performance criteria, assembling financial packages, and developing performance monitoring and management capacity.

Thermal power plants support a baseline energy supply, ensuring stability and resilience in energy systems. Credit: Shutterstock

Strategies to address financial barriers include:

- Revise government funding requirements to reflect and align with national policies for systems resilience.
- Promote donor investments that increase the resilience of country systems and align with country priorities.
- Strengthen financial risk management analysis and resources to support private-sector investment.
- Develop a stronger pipeline of bankable projects that contribute to systems resilience.
- Engage private companies operating within partner countries on shared infrastructure needs.

MCC Malawi's energy sector reform included investment in improving the capacity and financial viability of the national utility. Credit: MCC

Revise government funding requirements to reflect and align with national policies for systems resilience

Government funding and procurement processes should incorporate broader systems-level considerations and create incentive mechanisms to integrate systems-level planning both within individual ministries and across sectoral agencies. This process can be facilitated through the development of a multi-agency systems investment road map that lays out a plan for investments over time (Arghya Sinha Roy, ADB, Systems Workshop, 2023).

For example, the Government of Kenya has implemented requirements for mandatory disaster risk insurance coverage in power purchase agreements, which is used to help finance repairs and reconstruction after a disaster. This approach also creates an incentive for infrastructure owners and operators to reduce risks so they pay a lower premium for more resilient assets, which improves energy grid reliability (Hallegatte et al. 2019).

South Africa's Budget Facility for Infrastructure

South Africa's Budget Facility for Infrastructure (BFI) is a budgetary reform initiated by South Africa's National Treasury to deliver large infrastructure projects that consider climate, social, and economic objectives and align across government agency responsibilities. The BFI is a financing facility that is managed jointly by the National Treasury, Presidential Infrastructure Coordination Commission, the Departments of Planning, Monitoring and Evaluation, and the Department of Economic Development. The facility vets submitted infrastructure projects and prioritizes projects that meet submission requirements, including those that are clearly identified as a national priority and are very large and strategic interventions with long-term impacts (Global Infrastructure Hub 2018).

Promote donor investments that increase the resilience of country systems and align with country priorities

Developing agreements among donors and countries to support a strategic roadmap of prioritized investments over the long term will support countries in achieving robust and cost-effective infrastructure services. The effectiveness of this approach was demonstrated by the joint efforts of multiple donors with the Government of Thailand to develop a joint strategy for a Bio-Circular-Green economy (see box on page 37) (OPEC 2023). This coordinated support can be reinforced by donor efforts to streamline requirements for funding based on an overarching long-term agreement that articulates objectives, performance requirements, and processes for collaboration over time.

Strengthen financial risk management analysis and resources to support private-sector investment

Systems analysis of financial risks related to climate change can provide potential investors with more accurate information about exposure risks and an economic rationale for resilience measures that protect systems performance. It also supports the application of risk management products (such as parametric insurance, green revolving funds, and national disaster funds) to protect investors and enable government services. As risks are more effectively assessed and quantified, new models for climate-informed insurance are emerging. For example, the Climate Insurance-Linked Resilient Infrastructure Financing is providing long-term (10-year) municipal insurance to cities in South Africa and the Philippines, with plans to expand. A new guide for private-sector investors discusses mechanisms for private investment and offers an adaptation and resilience investment framework to assist investors in identifying and assessing eligible projects (Standard Chartered et al. 2024).

Develop a stronger pipeline of bankable projects that contribute to systems resilience

Together, the steps above will support countries in developing a stronger, prioritized list of projects ready for investment that clearly reflect the principles outlined above and will contribute to resilient infrastructure systems. In turn, this pipeline sets the stage for countries to engage both private- and public-sector investors.

Engage private companies operating within partner countries on shared infrastructure needs

Private actors often invest in infrastructure that directly affects their supply chain. Companies have invested in climate-resilient infrastructure to protect against flooding, extreme heat, and coastal hazards (Chau et al. 2023). Engaging with companies that are exposed to the same types of climate impacts as other stakeholders can be a useful way to identify where public investment is needed in relation to where private sources are planning to contribute, or instances in which public-sector concessional finance or risk insurance can help catalyze private-sector investments.

USAID Kenya's WASH-FIN program supports surveys and designs for water projects to inform commercial financing proposals. Credit: USAID

CHANGING THE MODEL OF DONOR AND COUNTRY PARTNER SUPPORT

Partner governments, donors, and investors can unlock the benefits of resilient infrastructure systems by strategically tackling the barriers identified above and investing in four areas:

- Support in-country partners' approaches to infrastructure systems resilience.
- Finance projects that contribute to systems resilience.
- Integrate resilient systems planning into donor and investor institutions.
- Collaborate across the development community and share good practices.

As precipitation patterns change, it is critical that water supply systems adapt accordingly. Credit: Unsplash

Donor Actions to Advance Systems Planning

- ☐ **Support in-country partners' approaches to infrastructure systems resilience.** Provide funding and technical support to countries to develop a strong enabling environment for climate-resilient systems planning. Example actions may include:
  - Invest in countries' systems-level climate vulnerability and risk assessments and network analyses, including gathering and applying data that enable systems-level analyses.
  - Provide extended technical support to build in-country capacity over time to conduct vulnerability assessments and design systems-level adaptation strategies.
  - Support countries in developing strategic plans for resilient infrastructure systems that build a pipeline of bankable projects and align with national development goals.
  - Fund institutional and policy assessments to pinpoint key barriers and identify priorities for capacity building, policy development, and organizational change to enable systems planning.
  - Provide extended technical support to design and implement institutional and policy reforms.

- ☐ **Finance projects that contribute to systems resilience.** Commit to funding and enabling projects that are part of countries' plans for climate-resilient infrastructure systems. Example actions may include:
  - Provide financial incentives to partner countries to conduct resilient infrastructure systems planning, including preferential investment in priority infrastructure.
  - Fund investments that countries have identified as pipeline priorities in their strategic infrastructure systems plans.
  - Assess the impact of project-level investments on systems resilience as part of standard due diligence in infrastructure investment decisions.
  - Support funding for countries to implement systems-level approaches throughout the infrastructure life cycle, including operations and maintenance.
  - Pursue opportunities for blended finance mechanisms to scale investment from the private sector.
- ☐ **Integrate resilient systems planning into donor and investor institutions.** Improve donors' internal processes and investment policies to support infrastructure systems resilience. Example actions may include:
  - Incorporate systems resilience analysis into investment decision making, including planning, programming, implementing, and evaluating programs and projects.
  - Develop and incorporate guidelines for climate-resilient infrastructure systems as part of the due diligence process.
  - Incorporate standardized procurement language in solicitations and contract agreements that requires partners and contractors to consider systems resilience when developing projects and activities and incorporate these requirements into procurements.
- ☐ **Collaborate across the development community and share good practices.** Create synergies across government, donor, and private-sector funders through aligned policies and coordinated investments. Example actions may include:
  - Strengthen donor coordination to align investment goals and priorities across funders.
  - Invest in joint studies or analyses to increase efficiency and scale.
  - Share country-level data, information, and studies to support resilient systems interventions across funders.
  - Identify joint opportunities to reduce administrative costs for country partners by aligning procurement and reporting requirements.
  - Share lessons learned and good practices to promote replication and scaling.
  - Promote awareness of the benefits of resilient systems thinking across the development community through forums, knowledge exchange, and communication platforms.

Support in-country partners' approaches to infrastructure systems resilience

Strong collaboration with country partners can help promote systems thinking for infrastructure planning while building technical and institutional capacity. The development community should engage closely with country partners to build awareness and inclusion of systems-level approaches, build the support of decision makers, and create an enabling environment that promotes systems planning and builds capacity. By supporting in-country champions, development agencies can help catalyze home-grown support and buy-in for systems approaches.

Support partner country capacity to conduct infrastructure systems planning

Collaboration between countries and donors can help countries more rapidly implement systems strategies. Collaboration can include both technical and financial support to strengthen planning and investment processes, setting the stage for direct investment in projects that contribute to resilient infrastructure systems. Specific strategies include:

- Provide financial and technical support to build in-country capacity to conduct systems analysis, identify adaptation priorities, and develop feasible funding strategies. This support includes planning and integration of systems principles into decision making throughout the infrastructure life cycle.
- Support climate literacy and technical capacity to process and use climate data from available in situ sources and global products (e.g., remote sensing), and develop and disseminate information that highlights tools and methods that are available to support countries in their planning efforts.

Improved stakeholder engagement and inclusive development practices

Stakeholder engagement plays a critical role in informing effective climate-resilient infrastructure systems. When governments and donors engage with stakeholders they gain insight into the community's knowledge, concerns, needs, and priorities, which inform the development of improved planning and implementation. By actively involving people who will be directly affected by the infrastructure, they also unlock a multitude of opportunities to enhance collaboration, participation, and resource mobilization.

Inclusive development practices are a crucial aspect of stakeholder engagement. By ensuring that diverse societal groups (e.g., women, LGBTQIA+, disabled, other marginalized groups) participate in climate resilience planning, planners and policymakers tap into a diversity of indigenous and local knowledge to reduce risks and unlock innovative solutions. These practices bridge the gap between policymakers and the public to foster better design and mutual trust. When diverse and local communities are part of the decision-making process, infrastructure systems gain community ownership, improved quality, and long-term sustainability.

- Invest in countries' climate vulnerability and risk assessments or network analyses, drawing on existing tools, methodologies, frameworks, and approaches whenever possible, while strengthening data and tools over time.
- Support countries in assessing and designing adaptation actions at the systems level.
- Support countries in developing strategic plans for resilient infrastructure systems that build a pipeline of bankable projects and align with national development goals.
- Build in-country technical capacity over time by funding and supporting in-country institutions, research entities, and professional staff.

Strengthen institutional policies, alignment, and coordination

Donors can also support partner countries in addressing institutional and governance barriers that inhibit their ability to work at a systems level. This support can start by funding and co-conducting an assessment of key policies and processes and institutional constraints across national, sub-national, and sectoral levels. The results of this analysis can help inform countries and donors about priority areas for investment to establish a stronger enabling environment that supports systems-level planning and action. Specific actions include:

- Support country assessments of institutional and policy barriers and gaps that inhibit systems approaches.
- Provide extended policy and institutional support to implement reforms, based on an analysis of priority needs at the institutional capacity, structural, and policy levels.
- Support country partners in coordinating systems approaches across sectors and broadening stakeholder engagement to promote a more just and inclusive understanding of the potential magnifying and cascading impacts of climate change on different communities and populations.

Applying a network analysis for transportation infrastructure in Tanzania

In Tanzania, the World Bank worked with the municipality of Dar es Salaam to conduct a network analysis of its transportation system that examined the impact of flood events on the reliability of infrastructure services, including the impact on residential mobility and supply chain disruptions. By focusing on critical flows across the whole system, the analysis could pinpoint key weaknesses in the road, transit, and port access networks, and recommend investment priorities to improve the reliability of transportation services by strengthening these chokepoints (Hellmuth et al. 2019).

Flooding can disrupt critical transportation nodes, paralyzing transportation systems. Credit: Shutterstock

Monitor progress and learn

Effective monitoring of systems performance is essential to enable countries to track progress, address gaps in performance, make adjustments, and identify priorities for future investments. This work includes an ongoing process of monitoring changing climate conditions and potential future scenarios and considering how best to adapt to changing risk profiles. Donors can support country partners through targeted investments and technical support. Specific strategies include:

- Work with country partners to design systems for monitoring and evaluation. This includes performance metrics to monitor and track adaptation and resilience, protocols for data collection, and country-led monitoring and tracking processes to gauge the improvement due to systems planning efforts (including after natural hazard events).
- Develop protocols to assess monitoring and evaluation findings, and incorporate lessons learned into future investments, policies, and processes.
- Support countries in sharing information with other partners and the development community about effective practices and lessons learned from programs and processes that can improve resilient systems planning.

Inter-agency coordination, innovative technical tools, and novel management authority in Niger

The Millenium Challenge Corporation (MCC) designed a Compact with the Government of Niger to increase rural incomes by improving water resources management for agricultural production. The country is highly dependent on rain-fed agriculture and is highly vulnerable to the changing climate. Farmers routinely experience flooding and drought extremes that impact agricultural output and exacerbate food insecurity. Shifting to groundwater use instead of relying on surface water would reduce the agriculture sector's susceptibility to impacts from extreme events that disrupt the water supply. However, data on groundwater resources are scarce. To fill these data gaps, MCC partnered with the U.S. Geological Survey to use remote sensing to map shallow and deep aquifer levels, improve site locations for groundwater-sourced agricultural investments, and calculate the available and renewable volumes of water in the aquifers. This interagency collaboration led to a ground-breaking discovery that Niger is the most groundwater-rich country in the Sahel region. The innovative data collection method improved the development of climate-informed investments in the agriculture sector.

With MCC's support, Niger also created a new water management authority to sustainably manage the resource, and better data on the country's groundwater resources will continue to help Niger reduce food insecurity. Increasing Niger's capacity to identify and utilize groundwater resources will have cascading impacts from the water sector to the agriculture sector and throughout the economy. The partnership between MCC and the National Aeronautics and Space Administration (NASA) did not end with the Niger compact. The technology and data are also easy for partner governments to own and continue to use beyond compact lifetimes (MCC 2022 and MCC 2023b).

Finance projects that contribute to systems resilience

Donors should commit to funding and enabling projects and activities that are part of countries' plans for climate-resilient infrastructure systems, sending a clear signal to country partners that systems resilience priorities will be supported.

Incentivize resilient systems planning

Supplying financial support for systems planning provides country partners with the means to develop a strong action plan for systems resilience.

- Provide financial incentives to partner countries to conduct resilient infrastructure systems planning, including preferential investment in priority infrastructure.

Fund priority projects that build systems resilience

Donors should commit to funding infrastructure projects that countries demonstrate will strengthen systems resilience and work to develop and deploy blended finance.

- Fund investments that countries have identified as pipeline priorities in their strategic infrastructure systems plans.
- Pursue opportunities for blended finance mechanisms to scale investment from the private sector.

Support systems-level approaches throughout the infrastructure life cycle

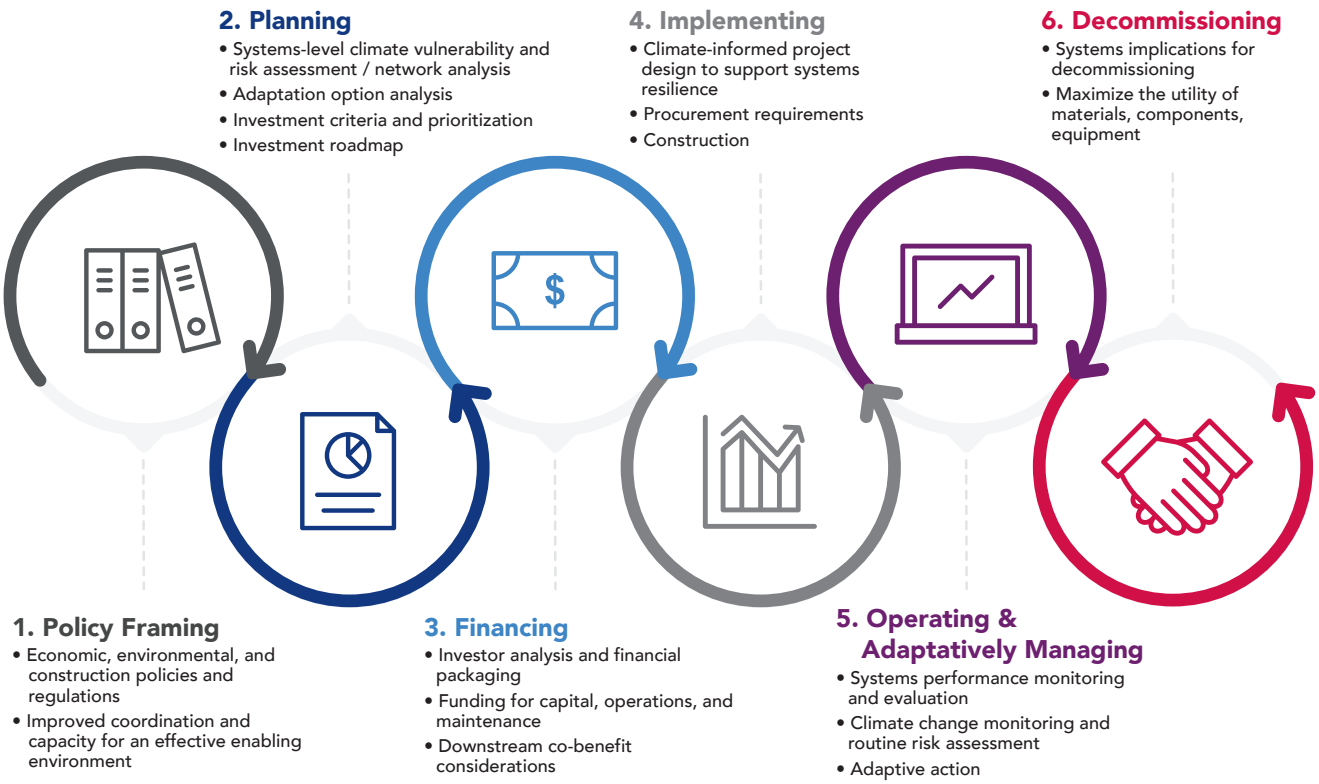
Donors can support the incorporation of systems resilience into each step of the infrastructure development, design, and implementation life cycle. This is particularly important given the long service life of most infrastructure. Absent ongoing monitoring, changing climate conditions over decades can result in unexpected and catastrophic impacts on systems resilience.

When designed well, natural systems and infrastructure systems can exist in harmony. Credit: Shutterstock

Opportunities include:

- For new assets, include provisions for ensuring resilience and estimated cost savings throughout the life cycle of a proposed project in the context of the broader infrastructure systems.
- For existing infrastructure, support countries in strengthening their operations and maintenance, performance monitoring, inspections, and emergency response to include larger systems-level considerations and improve climate resilience.
- Support countries in assessing climate risks to existing operations, focusing on risks to the performance of infrastructure systems to continue to deliver operational objectives, including the supply chain or trade route continuity of major export industries.
- Assist country partners in assessing systems adaptive capacity and using adaptive management approaches at both the asset and systems scales.
- Support countries in evaluating an asset's end-of-life impacts on the wider system and developing approaches to resolve adverse impacts.

Systems planning throughout the infrastructure life cycle



Through a public-private partnership, MCC assisted in the expansion of the As-Samra wastewater treatment plant in Jordan to increase its capacity and to provide freshwater to the water-constrained country's population. Credit: MCC

Integrate resilient systems planning into donor and investor institutions

Development institutions should improve their internal processes to support infrastructure systems resilience and ensure that their investment policies incentivize systems-level processes. While different donors have specific internal processes, individual organizations should review their processes and requirements to enhance their ability to support and catalyze systems approaches. This can have a magnifying impact in partner countries where various donors are engaged and could have strategic alignment across sectors and geographies. Integrating systems analysis and requirements into individual organization design, procurement, and implementation processes throughout the life cycle can improve the resilience and outcomes of investments. Specific strategies include:

Incorporate resilient systems analysis as part of investment decision making

Considering investments from a resilient systems perspective helps donors make strong investments that support greater resilience. Donors should:

- Assess the impact of project-level investments on systems resilience as part of standard due diligence in infrastructure investment decisions.
- Incorporate systems resilience into investment decision-making processes, including planning, programming, implementing, and evaluating programs and projects.

Develop standards and guidelines to promote systems approaches

Donors should strive to develop consistent, institution-wide practices that support and enable systems resilience across the organization. This will foster internal alignment across different sectors and programmatic investments. It will also communicate their commitment to systems approaches to country partners and other investors. Specific strategies include:

- Develop and incorporate standards or guidelines for climate-resilient infrastructure into project design that address systems-level resilience and uses systems-level metrics for addressing climate change factors throughout the project life cycle to optimize resilient systems performance.
- Incorporate standardized procurement language in solicitations and contract agreements that requires partners and contractors to consider systems resilience when developing projects and activities and incorporate these requirements into procurements.
- Develop and implement training and awareness building for organizational staff to promote internal understanding and support for resilient systems approaches.

MCC's investments in Benin's Port of Cotonou attracted over $200 million in private financing, helping triple the port's capacity. Credit: MCC

Collaborate across the development community and share good practices

Infrastructure developers and planners have an opportunity to collaborate and combine efforts to improve systems thinking for development projects. Sharing knowledge, data, and lessons learned can help increase the inclusion of systems approaches into development processes and climate resilience for infrastructure investments. Engaging with local communities, CBOs, and businesses is critical to better understanding local challenges and priorities, as well as information and past experiences that are critical to understanding how to develop resilient and appropriate infrastructure that responds to the diverse needs of all users.

In Kenya, for example, the U.S. embassy established an economic growth working group. With broad interagency membership, it was able to foster coordination on infrastructure investment among U.S. government agencies. USAID's participation facilitated the consideration of enabling conditions affecting infrastructure development from the earliest

Cross-sector investment in Thailand

The Organization of the Petroleum Exporting Countries (OPEC), ADB, and the governments of the Republic of Korea and Australia are providing technical assistance to the Government of Thailand to support implementation of a development strategy for a Bio-Circular-Green (BCG) economy integrated across sectors. Through awareness-raising campaigns, strengthened policies and regulatory frameworks supporting BCG, and finance opportunities from banks, private investments, and capital markets, government agencies and the private sector will be better able to execute BCG programs and prioritize BCG-sector investments, sectors, and themes to maximize climate resilience across sectors.

planning stages by the entire working group. This strong working group experience led to opportunities for multiple U.S. government agencies to provide complementary support to Kenya in the energy sector. This optimized U.S. government support for local access to reliable and cost-effective electricity supply, promoting economic growth and development.

Strengthen donor coordination to improve systems resilience

Donors can magnify the resilience impact of their individual investments by increasing the level of coordination across institutions working in the same country or region to achieve systems-level resilience. Specific actions include:

- Develop collaborative protocols to define investment goals and priorities that reinforce areas of mutual benefit across donor groups and support joint action to achieve greater resilience outcomes.
- Share country-level data, information, and studies to support strong resilient systems interventions across the donor and development practitioner community.
- Identify opportunities to reduce administrative burdens and costs for country partners, such as aligning application processes and reporting requirements.
- Invest in joint studies or analysis on systems-level climate vulnerability assessments or adaptation options analysis.
- Share information on lessons learned and good practices through communication resources that may include case study reports, blogs, webinars, or technical white papers, and convene discussions about potential good practice standards for coordinated investments.

Build awareness of the benefits of resilient systems thinking among the broader development community

In addition to cross-donor collaboration, donors can support resilient systems approaches by highlighting successful approaches, sharing best practices, and promoting dialogue throughout the development community. This may include:

- Hold in-person and virtual forums with country partners, donors, multilaterals, and private investors to discuss the benefits of systems planning, good practices, and lessons learned from early adopters.
- Develop and disseminate case examples of effective practices and lessons learned.
- Develop donor resources to facilitate systems-level climate resilience.

Primary roads should be designed with additional climate resilience measures to minimize travel disruptions. Credit: Shutterstock

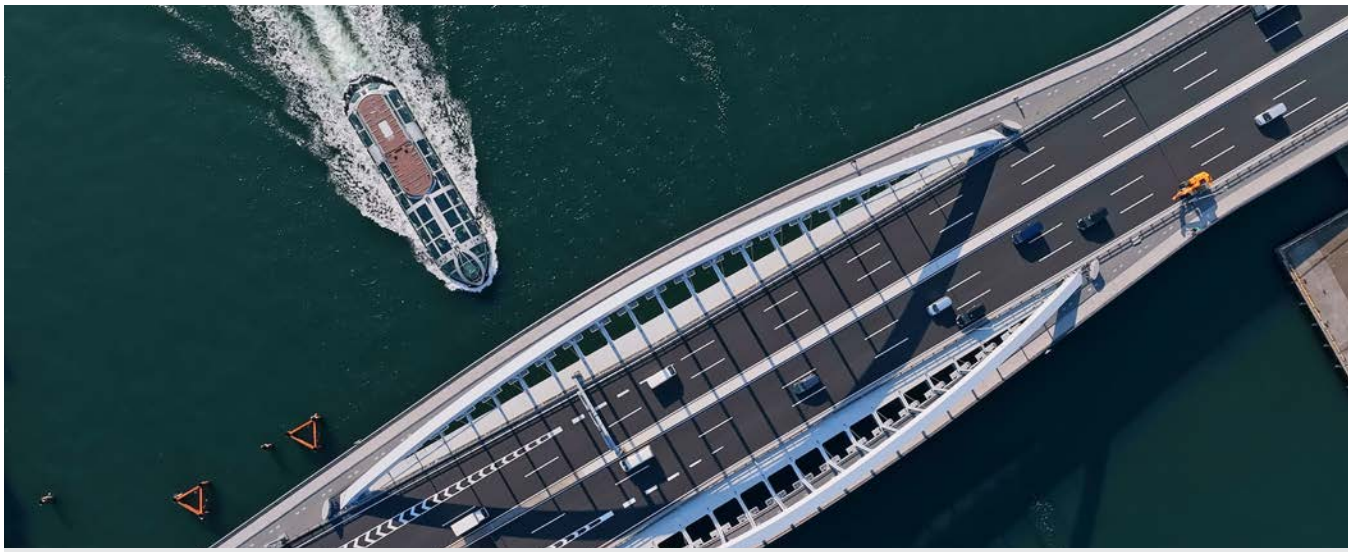
Communities and farmlands in the Senegal River Delta benefited from MCC's irrigation infrastructure rehabilitation and water resource management project. Credit: MCC

ACHIEVING INFRASTRUCTURE RESILIENCE AT SCALE

This paper has demonstrated the benefits of a systems approach to infrastructure resilience, identified strategies to remove various barriers to doing so, and described actions that donors, countries, and the broader development community can take to catalyze a more holistic approach to designing infrastructure. Transforming our approach to infrastructure development will enable countries and funders to invest more wisely and scale up investments to meet the enormous demand for resilient infrastructure services. Changing the model will not be easy or immediate but working together, donors and countries can take a constructive, step-by-step approach to create the right enabling conditions for systems approaches to take root. Ultimately, a systems-focused model for infrastructure development will reflect these core characteristics:

- **Useful information:** Decision makers and stakeholders have adequate information about climate risks at the systems level.
- **Joint decision making:** Mechanisms are in place for information exchange, joint analysis, and collaborative decision making across sectors and stakeholders.
- **Systems risk assessment:** Planners are able to analyze the impacts of climate change (and other hazards) on the reliability and resilience of infrastructure services for each system and the cascading effects of disruptions on other infrastructure services, ecosystems, economies, and people.
- **Systems-focused prioritization:** Priorities for investment reflect climate change risks to systems services, ecosystems, economies, and people.
- **Aligned financing:** Investors are able to support systems priorities and achieve their investment objectives through risk management and collaboration.
- **Integrated systems management:** Mechanisms are in place for infrastructure adaptive management that incorporate emerging information about infrastructure performance, changing climate conditions, and evolving environmental and social contexts.

An honest assessment of these conditions is the first step to scaling up climate-resilient infrastructure systems. Collaborating, sharing information, and building experience and capacity will be crucial to meet the urgent global need for resilient infrastructure in the face of climate change.



Multi-modal transportation systems can be overlaid to serve commercial and personal purposes simultaneously. Credit: Shutterstock

REFERENCES

Acuña-Coll, N., & Sánchez-Silva, M. 2023. Integrating Systems Thinking and Flexibility in Infrastructure Management. *Innovative Infrastructure Solutions, 8*(144). Available at: https://doi.org/10.1007/s41062-023-01106-9

Adshead, D.; Thacker, S.; Fuldauer, L.I.; Gall, S.S.; Chow, N.; Pant, R.; Russell, T.; Bajpai, A.; Morgan, G.; Bhikhoo, N.; Boroto, D.; Palmer, R.; Cançado, D.; Jain, N.; Klöttschen, V.; Lawal, H.; Dery, P.; Twum, E.; Mohammed, G.; Hall, J.W.; Agbesi, L. 2022. Ghana: Roadmap for Resilient Infrastructure in a Changing Climate. Ministry of Environment, Science, Technology & Innovation, Accra, Ghana. Available at: https://gca.org/wp-content/uploads/2022/03/Ghana_Roadmap-for-Resilient-Infrastructure-in-a-Changing-Climate.pdf

Amenc, N.; Blanc-Brude, F.; Gupta, A.; Jayles, B.; Orminski, J.; Marcelo, D. 2023. Highway to Hell: Climate Risks Will Cost Hundreds of Billions to Investors in Infrastructure Before 2050. EDHEC Infrastructure & Private Assets Research Institute. Available at: https://edhec.infrastructure.institute/wp-content/uploads/2023/12/p108_Highway-to-Hell.pdf

American Society of Civil Engineers (ASCE). 2018. Climate-Resilient Infrastructure, ASCE Manual of Practice 140. Reston, VA. Available at: https://ascelibrary.org/doi/book/10.1061/9780784415191

American Society of Civil Engineers (ASCE). 2020. Code of Ethics. Reston, VA. Available at: https://www.asce.org/-/media/asce-images-and-files/career-and-growth/ethics/documents/asce-code-ethics.pdf

American Society of Civil Engineers (ASCE). 2021. New ASCE Manual of Practice Provides Framework for Hazard-Resilient Infrastructure. Available at: https://www.asce.org/publications-and-news/civil-engineering-source/article/2021/06/16/new-asce-manual-of-practice-provides-framework-for-hazard-resilient-infrastructure

American Society of Civil Engineers (ASCE). 2022. Hazard-Resilient Infrastructure, ASCE Manual of Practice 144. Reston, VA. Available at: https://ascelibrary.org/doi/book/10.1061/9780784415757

American Society of Civil Engineers (ASCE). 2023. Standard Practice for Sustainable Infrastructure, ASCE 73-23. Reston, VA. Available at: https://sp360.asce.org/PersonifyEbusiness/Merchandise/Product-Details/productId/309314929

Ashoor, Abdelwanees. 2022. Estimation of the Surface Runoff Depth of Wadi Derna Basin by Integrating the Geographic Information Systems and Soil Conservation Services (SCS-CN) Model. *Sebha University Journal of Pure and Applied Sciences.* Available at: https://sebhau.edu.ly/journal/jopas/article/view/2137/1012

Asian Development Bank (ADB) and Global Center on Adaptation (GCA). 2021. A System-Wide Approach for Infrastructure Resilience. Manila, Philippines and Rotterdam, the Netherlands. Available at: https://www.adb.org/sites/default/files/publication/672501/system-wide-approach-infrastructure-resilience.pdf

Atamuratova, S.; Boudreau, L.E.; Clarke, D.J.; Mahul, O.; Signer, B.L.; White, E.J.; Yi, H.J. Financial Protection Against Natural Disasters: From Products to Comprehensive Strategies - An Operational Framework for Disaster Risk Financing and Insurance. World Bank Group, Washington, D.C. Available at: http://documents.worldbank.org/curated/en/523011468129274796/Financial-protection-against-natural-disasters-from-products-to-comprehensive-strategies-an-operational-framework-for-disaster-risk-financing-and-insurance

Ayyub, B.M., Mao, Y., Hamed, M., Elsibaie S., & Elsibaie, M. 2023. Topology-based Analysis of Freight Railroad Networks for Resilience: Unweighted and Weighted Using Waybill Data. Technical Report DOT/FRA/ORD-23/35, Federal Railroad Administration, Washington, D.C.

Becker, J., & Smith, D.B. 2017. The Need for Cross-Sector Collaboration. *Stanford Social Innovation Review, 16*(1), C2–C3. Available at: https://ssir.org/articles/entry/the_need_for_cross_sector_collaboration

Brichetti, J.; Mastronardi, L.; Rivas, M.E.; Serebrisky, T.; Solís, B. 2021. The Infrastructure Gap in Latin America and the Caribbean: Investment Needed Through 2030 to Meet the Sustainable Development Goals. Inter-American Development Bank. Available at: http://dx.doi.org/10.18235/0003759

Carmody, L., & Chavarot, A. 2021. Risk and Resilience: Addressing Physical Climate Risks in Infrastructure Investment. Coalition for Climate Resilient Investment (CCRI). Available at: https://storage.googleapis.com/wp-static/wp_ccri/6dea3e47-ccri_riskandresilience_nov2021.pdf

Cervigni, R.; Liden, M.J.R.; Neumann, J.L.; Strzepek, K.M. 2015. Enhancing the Climate Resilience of Africa's Infrastructure: the Power and Water Sectors. Africa Development Forum, Washington, D.C., World Bank Group. Available at: http://documents.worldbank.org/curated/en/857671468179354431/Enhancing-the-climate-resilience-of-Africas-infrastructure-the-power-and-water-sectors

Chau, V.; Qahir D.; Matthews, N.; Caines, C.; Stroman, T.; Gibbs, R.; Yee, M.; Fielding, P. 2023. From Risk to Reward: The Business Imperative to Finance Climate Adaptation and Resilience. Boston Consulting Group, Global Resilience Partnership, USAID. Available at: https://www.globalresiliencepartnership.org/wp-content/uploads/2023/12/from-risk-to-reward-report.pdf

Chavarot, A.; Sanchez, C.; van Dijk, N.; Nowosinska, D.; Philips, W.; Rabba, J. 2022. Guidelines for Integrating Physical Climate Risks in Infrastructure Investment Appraisal. The Physical Climate Risk Assessment Methodology (PCRAM). Coalition for Climate Resilient Investment (CCRI) and Mott MacDonald. Available at: https://storage.googleapis.com/wp-static/wp_ccri/c7dee50a-ccri-pcram-final-1p.pdf

Chinzara, Z.; Dessus, S.; Dreyhaupt, S. 2023. Infrastructure in Africa: How Institutional Reforms Can Attract More Private Investment. Working Paper, International Finance Corporation. Available at: https://www.ifc.org/content/dam/ifc/doc/2023/working-paper-infrastructure-in-africa.pdf

Cities Climate Finance Leadership Alliance. 2021. State of Cities Climate Finance Report. Available at: https://citiesclimatefinance.org/wp-content/uploads/2021/06/Part-1-l-The-Landscape-of-Urban-Climate-Finance-FINAL.pdf

Climate Reality Project. 2023. How the Climate Crisis Is Impacting Ghana. Available at: https://www.climaterealityproject.org/blog/how-climate-crisis-impacting-ghana#:~:text=Amid%20these%20heat%20waves%2C%20Ghanaians,13%25%20of%20the%20country's%20population.

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and United Nations Environment Programme (UNEP). 2022. Case Study: The Capacity Assessment Tool for Infrastructure (CAT-I): Ghana and its Roadmap for Resilient Infrastructure in a Changing Climate. Available at: https://sustainable-infrastructure-tools.org/wp-content/uploads/2022/12/Ghana.pdf

Dhawan, A. 2022. Climate Insurance-Linked Resilient Infrastructure Financing (CILRIF). Global Innovation Lab for Climate Finance. Available at: https://www.climatepolicyinitiative.org/wp-content/uploads/2022/10/CILRIF-overview.pdf

Duan, S., & Ayyub, B.M. 2019. Assessment Methods of Network Resilience for Cyber-Human-Physical Systems. *ASCE-ASME Journal of Risk Uncertainty in Engineering Systems, Part A: Civil Engineering,* 6(1). Available at: https://doi.org/10.1061/AJRUA6.0001021

Federal Highway Administration (FHWA). 2017. Vulnerability Assessment and Adaptation Framework, Third Edition. FHWA-HEP-18-020. U.S. Department of Transportation. Available at: https://www.fhwa.dot.gov/environment/sustainability/resilience/adaptation_framework/index.cfm

Gilbert, S., & Ayyub, B. 2016. Models for the Economics of Resilience. *ASCE-ASME Journal of Risk Uncertainty in Engineering Systems, Part A: Civil Engineering, 2*(4). Available at: https://doi.org/10.1061/AJRUA6.0000867

Global Infrastructure Hub. 2018a. Leading Practices in Governmental Processes Facilitating Infrastructure Project Preparation. Available at: https://ppp.worldbank.org/public-private-partnership/sites/ppp.worldbank.org/files/2022-03/gih_project-preparation_full-document_final_art_web.pdf

Global Infrastructure Hub. 2018b. TransMilenio Bus Rapid Transit Colombia Case Study. Available at: https://inclusiveinfra.gihub.org/case-studies/transmilenio-bus-rapid-transit-colombia/

González, O.; Camilo, J.; Suardí Gómez, A.; Benoit, L.; Rodriguez Porcel, M. 2022. Transporte resiliente al cambio climático: ¿cómo priorizar la inversión?: caso de República Dominicana. BID. Available at: http://dx.doi.org/10.18235/0004576

Green Climate Fund (GCF). 2019. GCF Working Paper No. 1 – Adaptation: Accelerating Action Toward a Climate Resilient Future. Available at: https://www.greenclimate.fund/sites/default/files/document/accelerating-action-towards-climate-resilient-future.pdf

Green Climate Fund (GCF). 2021. Thematic Brief: Climate Resilient Infrastructure. Available at: https://www.greenclimate.fund/document/thematic-brief-climate-resilient-infrastructure

Grünwaldt, A.; Glass M.; McCarthy, N. 2021. Identification of Climate Resilience Opportunities and Metrics in Financing Operations: Technical Reference Document for IDB Project Teams. IDB, New York. Available at: https://publications.iadb.org/en/identification-climate-resilience-opportunities-and-metrics-financing-operations-technical

Hallegatte, S.; Rentschler, J.; Rozenberg, J. 2019. Lifelines: The Resilient Infrastructure Opportunity. World Bank Group, Washington, D.C. Available at: https://openknowledge.worldbank.org/entities/publication/c3a753a6-2310-501b-a37e-5dcab3e96a0b

Hallegatte, S.; Shah, A.; Lempert, R.; Brown, C.; Gill, S. 2012. Investment Decision Making Under Deep Uncertainty: Application to Climate Change. World Bank Group, Washington, D.C. Available at: https://openknowledge.worldbank.org/server/api/core/bitstreams/24b2bb36-2aaa-597f-8ed1-de11183d7063/content

Hamed, M.; Mao, Y.; Ayyub, B.M.; Elsibaie, M.; Omar, T. 2022. Connectedness Efficiency Analysis of Weighted U.S. Freight Railroad Networks. *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part B: Mechanical Engineering, 8*(4): 041202. Available at: https://doi.org/10.1115/1.4054326

Hellmuth, M.; Pereira, S.; Papachristodoulou, N.; Potter, J.; Bhat, C.; Bruguera, M.; Frederiksen, L.; Pedersen, K.; Pedersen, K.S.; Buchanan, M.; Stilson, D. 2019. Strategic Assessment of the Climate Resilience of Dar es Salaam Transport Infrastructure. Volume A: Synthesis Report. World Bank Group. Available at: https://www.researchgate.net/publication/337154977

Hill, A.C.; Mason, D.; Potter, J.R.; Hellmuth, M.; Ayyub, B.M.; Baker, J.W. 2019. Ready for Tomorrow: Seven Strategies for Climate-Resilient Infrastructure. Hoover Institution, Washington D.C. Available at: https://www.hoover.org/sites/default/files/research/docs/hill-ready-for-tomorrow-seven-strategies-for-climate-resilient-infrastructure_0.pdf

Infrastructure Pathways. 2023. The International Coalition for Sustainable Infrastructure, The Resilience Shift, Delivered by Arup. Available at: https://infrastructure-pathways.org/

Kalra, Nidhi; Groves, David G.; Bonzanigo, Laura; Molina Perez, Edmundo; Ramos, Cayo; Brandon, Carter; Rodríguez Cabanillas, Ivan. 2015. Robust Decision-Making in the Water Sector: A Strategy for Implementing Lima's Long-Term Water Resources Master Plan. The World Bank. Climate Change Group Office of the Chief Economist. World Bank Group, Washington, D.C. Available at: https://www.rand.org/pubs/external_publications/EP50929.html

Koks, E.; Rozenberg, J.; Tariverdi, M.; Dickens, B.; Fox, C.; van Ginkel, K.; Hallegatte, S. 2022. A Global Assessment of National Road Network Vulnerability. *Environmental Research: Infrastructure and Sustainability, 3*(2). Available at: https://iopscience.iop.org/article/10.1088/2634-4505/acd1aa

Kumar, H., & Travelli, A. 2023. A Calamitous Flood Shows the Dangers Lurking in Melting Glaciers. The New York Times. Available at: https://www.nytimes.com/2023/10/06/world/asia/india-flood-sikkim-climate-change.html

Legacy Programme. Infrastructure Risk Assessment and Resilient Investment Prioritization in Jamaica [video]. Available at: https://resilientinvestment.org/what-we-do/systemic-resilience/

Millennium Challenge Corporation. 2022. MCC and NASA Push Agriculture Data to a New Frontier. Available at: https://www.mcc.gov/blog/entry/blog-111622-nasa-agriculture-data/

Millennium Challenge Corporation. 2023a. Indonesia Infrastructure and Finance Compact. Available at: https://www.mcc.gov/where-we-work/program/indonesia-infrastructure-and-finance-compact/

Millennium Challenge Corporation. 2023b. MCC-financed study finds Niger to be most groundwater-rich country in the Sahel region. Available at: https://www.mcc.gov/blog/entry/blog-032223-niger-groundwater-rich-country/

Mullan, M., & Ranger, N. 2022. Climate-Resilient Finance and Investment. *OECD Environment Working Papers*, No. 196, Paris. Available at: https://doi.org/10.1787/223ad3b9-en

Naadi, T. 2023. Ghana Floods: "My Entire Farm is Under the Water and So is My House." BBC. Available at: https://www.bbc.com/news/world-africa-67147541

National Infrastructure Commission. 2020. Anticipate, React, Recover. Technical Annex: Case Studies and Good Practice for Resilience. Available at: https://nic.org.uk/app/uploads/Technical-Annex-Good-practice-case-studies.pdf

Network Rail. 2021. Buckled Rail. Available at: https://www.networkrail.co.uk/running-the-railway/looking-after-the-railway/delays-explained/buckled-rail-and-summer-heat/

Nguyen, G.H.T. 2015. Vietnam - Ho Chi Minh City Flood Risk Management Project: Environmental and Social Impact Assessment. World Bank Group, Washington, D.C. Available at: http://documents.worldbank.org/curated/en/296891468330027063/Vietnam-Ho-Chi-Minh-City-Flood-Risk-Management-Project-environmental-and-social-impact-assessment

Nishimura, M.; Sieber, N.; Wang, S. 2018. Impact Evaluation of Road Improvements and Rural Poverty — Baseline Survey in the Ningxia Liupanshan Area of the People's Republic of China. Asian Development Bank (ADB), Manila, Philippines. Available at: https://www.adb.org/sites/default/files/publication/428996/eawp-013-impact-evaluation-road-improvements-rural-poverty-prc.pdf

OPEC Fund for International Development. 2023. Strengthening Thailand's Bio-Circular-Green Economy. Available at: https://opecfund.org/operations/list/strengthening-thailand-s-bio-circular-green-economy

Ouyang, M.; Hong, L.; Mao, Z.; Yu, M.; Qi, F. 2009. A Methodological Approach to Analyze Vulnerability of Interdependent Infrastructures. *Simulation Modelling Practice and Theory 17* (5), 817-828. Available at: https://www.researchgate.net/publication/220674369_A_methodological_approach_to_analyze_vulnerability_of_interdependent_infrastructures

Paris Committee on Capacity-Building (PCCB). 2019. National-Level Pilot Exercise on Capacity Gaps and Needs Related to the Implementation of Nationally Determined Contributions. Technical Paper. United Nations Framework Convention on Climate Change (UNFCCC), Bonn. Available at: https://unfccc.int/sites/default/files/resource/PCCB_TP_capacity%20gaps%20and%20needs_NDCs_final.pdf

Planning Climate Resilience Infrastructure Systems Workshop. 26 September 2023. Hosted by Millenium Challenge Corporation and USAID, Washington, D.C.

Ra, S., & Li, Z. 2018. Closing the Financing Gap in Asian Infrastructure. Asian Development Bank (ADB), Manila, Philippines. Available at: https://www.adb.org/sites/default/files/publication/431261/swp-057-financing-gap-asian-infrastructure.pdf

Ray, P.A., & Brown, C.M. 2015. Confronting Climate Uncertainty in Water Resources Planning and Project Design: The Decision Tree Framework. World Bank Group. Available at: https://documents1.worldbank.org/curated/en/516801467986326382/pdf/99180-PUB-Box393189B-PUBLIC-PUBDATE-8-19-15-DOI-10-1596-978-1-4648-0477-9-EPI-210477.pdf

Resurgence. 2023. Resurgence Unveils DARAJA: Africa's Boldest Urban Early Warning Initiative. Race to Resilience. Available at: https://climatechampions.unfccc.int/resurgence-unveils-daraja-africas-boldest-urban-early-warning-initiative/

Resurgence. 2024. DARAJA: The Inclusive City-Community Forecasting and Early Warning Service. Available at: https://www.resurgence.io/daraja/

Rodríguez, D.J.; Paltán, H.A.; García, L.E.; Ray, P.; St. George Freeman, S. 2021. Water-related Infrastructure Investments in a Changing Environment: A Perspective from the World Bank. *Water Policy, 23*(S1). Available at: https://iwaponline.com/wp/article/23/S1/31/85987/Water-related-infrastructure-investments-in-a

Roy, K. 2024. Glacial Lake Outburst Threats and Management: Insight from Sikkim's Flood Event. *Journal of Arts, Humanities, and Social Sciences, 7*(1). Available at: https://shikshansanshodhan.researchculturesociety.org/wp-content/uploads/SS202401005-min.pdf

Rozenberg, J., & Fay, M. 2019. Beyond the Gap: How Countries Can Afford the Infrastructure They Need while Protecting the Planet. Sustainable Infrastructure Series. World Bank Group, Washington, D.C. Available at: https://openknowledge.worldbank.org/handle/10986/31291

Satterthwaite, D.; Archer, D.; Colebrander, S.; Dodman, D.; Hardoy, J.; Mitlin, D.; Patel, S. 2020. Building Resilience to Climate Change in Informal Settlements. *One Earth Review 2*(2): 146-156. Available at: https://doi.org/10.1016/j.oneear.2020.02.002

Schlüter, L.; Kørnøv, L.; Mortensen, L.; Løkke, S.; Storrs, K.; Lyhne, I.; Nors, B. 2023. Sustainable Business Model Innovation: Design Guidelines for Integrating Systems Thinking Principles in Tools for Early-Stage Sustainability Assessment. *Journal of Cleaner Production, 387*. Available at: https://www.sciencedirect.com/science/article/pii/S0959652622053501

St. George Freeman, S.; Brown, C.; Cañada, H.; Martinez, V.; Palma Nava, A.; Ray, P.; Rodríguez, D.; Romo, A.; Tracy, J.; Vázquez, E.; Wi, S.; Boltz, F. 2020. Resilience by Design in Mexico City: A Participatory Human-Hydrologic Systems Approach. *Water Security, 9*. Available at: https://www.sciencedirect.com/science/article/pii/S2468312418300245

Standard Chartered, KPMG, UNDRR. 2024. Guide for Adaptation and Resilience Finance. Available at: Standard-Chartered-Bank-Guide-For-Adaptation-And-Resilience-Finance-FINAL.pdf (sc.com)

United Nations Environment Programme (UNEP). 2021. International Good Practice Principles for Sustainable Infrastructure – Integrated, Systems-Level Approaches for Policymakers. Nairobi. Available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/34853/GPSI.pdf

United Nations Environment Programme (UNEP). 2023. Adaptation Gap Report 2023: Underfinanced. Underprepared. Inadequate Investment and Planning on Climate Adaptation Leaves World Exposed. Nairobi. Available at: https://www.unep.org/resources/adaptation-gap-report-2023

United Nations Framework Convention on Climate Change (UNFCCC). 2023. Technical Dialogue of the First Global Stocktake: Synthesis Report by the Co-facilitators on the Technical Dialogue. UN Climate Change Conference – United Arab Emirates Nov/Dec 2023. Available at: https://unfccc.int/documents/631600

United States Agency for International Development (USAID). 2014. Climate-resilient Development: A Framework for Understanding and Addressing Climate Change. Available at: https://pdf.usaid.gov/pdf_docs/PBAAA245.pdf

United States Agency for International Development (USAID). 2020a. Resilience Assessment: Eastern and Southern Caribbean. Available at: https://pdf.usaid.gov/pdf_docs/PA00X73B.pdf

United States Agency for International Development (USAID). 2020b. Water, Sanitation and Hygiene Finance (WASH-FIN) Kenya. WSP COVID-19 Financial Stress Testing and Mitigation. Available at: Microsoft Word - WASH-FIN WSP COVID-19 Stress Testing Report_7-7-20.docx (usaid.gov)

UrbanLinks. 2023. Systems Thinking Offers a Locally Led Path to More Resilient Cities. Available at: https://urban-links.org/insight/systems-thinking-offers-a-locally-led-path-to-more-resilient-cities/

Van Steenbergen, F.; Arroyo-Arroyo, F.; Rao, K.; Hulluka, T.A.; Woldearegay, K.; Deligianni, A. 2021. Green Roads for Water: Guidelines for Road Infrastructure in Support of Water Management and Climate Resilience. World Bank Group, Washington, D.C., page 171. Available at: https://documents.worldbank.org/en/publication/documents-reports/documentdetail/102951623742853259/green-roads-for-water-guidelines-for-road-infrastructure-in-support-of-water-management-and-climate-resilience

World Bank Group. 2005a. Republic of Tajikistan: Ferghana Valley Water Resources Management Project – Environmental Assessment and Management Plan. Available at: https://documents1.worldbank.org/curated/en/372881468777577723/pdf/E11290TAJIK0FVWRMP0Draft0EAMP.pdf

World Bank Group. 2005b. Project Information Document – Ferghana Valley Water Resources Management Project. Available at: https://documents1.worldbank.org/curated/en/776841468777585188/pdf/PID1Appraisal0Stage0Feb251r.pdf

World Bank Group. 2010. The Zambezi River Basin: A Multi-Sector Investment Opportunities Analysis. Vol. 1, Summary Report. Washington, D.C. Available at: https://openknowledge.worldbank.org/entities/publication/3a71e957-07c3-513e-aa2a-03aa8c040b84

World Bank Group. 2018. Batoka Gorge Hydroelectric Scheme: A Macroeconomic Assessment of Public Investment Options (MAPIO). Washington, D.C. Available at: https://documents1.worldbank.org/curated/en/590121549348324473/pdf/134327-WP-P133380-PUBLIC-4-2-2019-13-15-41-W.pdf

World Bank Group. 2020. Resilient Water Infrastructure Design Brief. World Bank Group, Washington, D.C. Available at: https://www.greenpolicyplatform.org/sites/default/files/downloads/resource/Resilient-Water-Infrastructure-Design-Brief.pdf

World Bank Group. 2021. Inclusive Resilience: Inclusion Matters for Resilience in South Asia. World Bank Group, Washington, D.C. Available at: https://openknowledge.worldbank.org/handle/10986/35220

World Bank Group. 2023. 50 by 2030: Data-Smart Agriculture. Available at: https://www.50x2030.org/

Electric transmission lines face risks from extreme heat and other climate hazards. Credit: Shutterstock

ANNEX OF CONTRIBUTORS AND WORKSHOP PARTICIPANTS

The authors are indebted to the contributions from colleagues whose expertise has shaped the understanding of this issue through expert interviews and review. They are (in alphabetical order):

Expert Interviewees and Reviewers

Bilal Ayyub, Univ. of Maryland Professor and Director of the Center for Technology and Systems Management

Nathan L. Engle, World Bank, Senior Climate Change Specialist

Alfred Grünwaldt, IADB, Climate Change Lead Specialist

Stephane Hallegatte, World Bank, Senior Climate Change Advisor

Hope Herron, MCC, Associate Director, Environmental and Social Performance and Co-Lead for the PREPARE Infrastructure Working Group

Alice Hill, CFR, David M. Rubenstein Senior Fellow for Energy and the Environment

Nitin Jain, GCA, Senior Director of Programs

Jason Jones, MCC, Director, Environmental and Social Performance

Rob Kafalenos, FHWA, Environmental Protection Specialist

Rebecca Lupes, FHWA, Climate Change Resilience Team Leader

Ken MacClune, USAID, Environmental Officer

Doug Mason, MCC, Director, Environmental and Social Performance and Co-Lead for the PREPARE Infrastructure Working Group

John Matthews, AGWA, Executive Director

Michael Mullan, OECD, Programme Lead: Climate Adaptation Finance & Investment

Homero Alejandro Paltán Lopez, World Bank, Climate Specialist

Kara Reeve, USAID, Resilience and Climate Adaptation Advisor, Center for Resilience

Carlos Sanchez, CCRI, Executive Director

Arghya Sinha Roy, ADB, Senior Disaster Risk Management Specialist

Vladimir Stenek, IFC, Senior Climate Change Specialist

Amy Swers, USAID, Senior Climate Infrastructure Advisor and Co-Lead for the PREPARE Infrastructure Working Group

Marycel Tuazon, MCC, Associate Director, Infrastructure

The authors are also grateful to the following individuals and organizations who shared insights during the Planning Climate Resilient Infrastructure Systems Workshop in September 2023. They are (in alphabetical order):

Workshop Panelists or Participants**

Alice Albright, MCC, Chief Executive Officer

Bilal Ayyub, Univ. of Maryland Professor and Director of the Center for Technology and Systems Management

Ben Cambell, MCC, Director, Environmental and Social Performance

Paige Cowie, MCC, Program Officer, Environmental and Social Performance

Sarah Drew, MCC, Senior Advisor, Director, Infrastructure, Environment, and Private Sector

Nathan L. Engle, World Bank, Senior Climate Change Specialist

Patrick Francis, MCC, Practice Lead, Senior Director, Environmental and Social Performance

Neb Girma, MCC, Practice Lead Senior Director, Global Energy Infrastructure and Market Development

Sherri Goodman,* Woodrow Wilson Center, Secretary General, International Military Council on Climate & Security and Senior Fellow

Alfred Grünwaldt,* IADB, Climate Change Lead Specialist

Jeff Haeni, USAID, Director, Center for Energy, Infrastructure, and Cities

Stephane Hallegatte,* World Bank, Senior Climate Change Advisor

Heather Hanson,± MCC, Managing Director, Infrastructure, Environment, and Private Sector

Eric Haxthausen, USTDA, Senior Advisor for Climate, Partnerships, and Innovation

Camille Heaton, MCC, Senior Director Environmental and Social Performance

Hope Herron,* MCC, Director, Environmental and Social Performance and Co-Lead for the PREPARE Infrastructure Working Group

Kate Iovanna,± MCC, Director, Energy

Nitin Jain,* GCA, Senior Director of Programs

Allison Leidner, NASA, Program Manager, Energy and Infrastructure Applications, NASA Earth Science Division

Ken MacClune, USAID, Environmental Officer

* = Keynote speaker, panelist, or breakout group facilitator
** = Additional individuals participated remotely
± = Affiliation at the time of event

Shahid Mahmood, USAID, Senior Engineering and Infrastructure Advisor

Arif Mamun, MCC, Managing Director for Economic Analysis

Genevieve Maricele,± NSC, Director of Global Development

Doug Mason,*± MCC, Director, Environmental and Social Performance and Co-Lead for the PREPARE Infrastructure Working Group

Marissa McInnis, DOD, Climate Change Program Director and Co-Lead for the Climate Action Team

Michael Mullan,* OECD, Programme Lead: Climate Adaptation Finance & Investment

Suzanne Ozment,± WRI, Senior Associate, Natural Infrastructure Initiative and Cities4Forests

Stewart Sarkozy-Banoczy,± Precovery Labs, Founder & Lead Precoverist; Ocean Sewage Alliance, Steering Committee Chair

Arghya Sinha Roy,* ADB, Senior Disaster Risk Management Specialist

Amit Smotrich, USAID, Climate and Food Security Advisor

Vladimir Stenek,* IFC, Senior Climate Change Specialist

Meghan Stromberg, WRI, Urban Resilience Program Coordinator & Research Analyst II

Amy K. Swers, USAID, Senior Climate Infrastructure Advisor and Co-Lead for the PREPARE Infrastructure Working Group

Caitlin Wiley,± MCC, Rosenthal Fellow

Christina Wong, USAID, Senior Urban Resilience Advisor, Green Cities

* = Keynote speaker, panelist, or breakout group facilitator
** = Additional individuals participated remotely
± = Affiliation at the time of event

Bridges are critical nodes in transportation networks and require additional resilience planning. Credit: Shutterstock

ABBREVIATIONS

ADB	Asian Development Bank
AGWA	Alliance for Global Water Adaptation
CCRI	Coalition for Climate Resilient Investment
CFR	Council on Foreign Relations
DOD	U.S. Department of Defense
GCA	Global Center on Adaptation
IADB	Inter-American Development Bank
IFC	International Finance Corporation
MCC	Millennium Challenge Corporation
NASA	National Aeronautics and Space Administration
NSC	National Security Council
OECD	Organisation for Economic Co-operation and Development
USAID	United States Agency for International Development
USTDA	U.S. Trade and Development Agency
WRI	World Resources Institute

PREPARE

Resilience at Scale

A Systems Approach to Climate-Resilient Infrastructure Planning