Enhancing the Climate Resilience of Africa's Infrastructure

A new method enables project managers to manage the risk that future climate could be wetter or drier than historical averages.

To sustain Africa's economic growth and accelerate the eradication of extreme poverty, investment in infrastructure is fundamental. The Program for Infrastructure Development in Africa (PIDA), endorsed in 2012 by the continent's heads of state and government, lays out an ambitious long- term plan for closing Africa's infrastructure gap, including through major increases in hydroelectric power generation and water storage capacity. Much of this investment will support the construction of long-lived infrastructure (for example, dams, power stations, and irrigation canals), which may be vulnerable to changes in climatic patterns—yet the direction and magnitude of climatic changes remain uncertain.

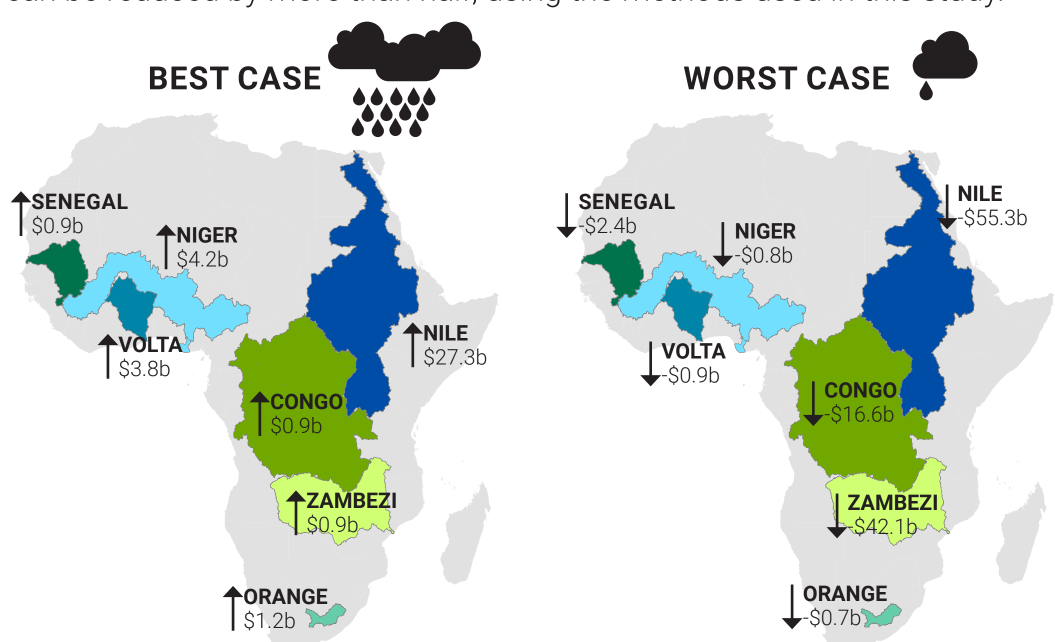
This recently completed effort evaluates—using for the first time a single consistent methodology and a wide range of state-of-the-art future climate scenarios—the impacts of climate change on hydropower and irrigation expansion plans in Africa's main river basins (Congo, Niger, Nile, Orange, Senegal, Volta, and Zambezi), as well as the effects on the electricity sector across four power pools. A key message that emerges is that failure to integrate climate change in the planning and design of power and water infrastructure could entail, in the driest climate change scenarios, significant losses of hydropower revenues and increases in consumer expenditure for energy. In the wettest climate scenarios, business-as-usual infrastructure development could lead to substantial forgone revenues if the larger volume of precipitation is not used to expand the production of hydro-power.

The main message of this effort is that **proper integration of climate change in the planning and design of infrastructure investments supported by PIDA, regional, and national plans can reduce the risk posed by the climate of the future to the physical and economic performance of hydropower and irrigation investments.**

The Risk of Climate Change to Hydropower Revenues: An Uncertain Future

With careful analysis and planning, projects can take climate change into account. In most basins, the risks of not adapting can be reduced by more than half, using the methods used in this study.

$83 billion
in African hydropower generation could be lost to climate change, if the driest future prevails. The wettest future could yield gains of $53 billion, but only if hydropower facility designs are altered to take advantage of the potential water windfall.



APPROACH

Integration of climate change in infrastructure investment needs to properly address the challenge posed by the large and persistent uncertainty surrounding climate projections. If it were known in advance that a wet future would materialize, it would make sense to expand generation capacity to produce more hydropower; in a dry future, it is preferable to reduce generation capacity to avoid sinking capital in equipment that will end up being underutilized. But the climate of the future is not known in advance. While ignoring climate change entails serious risks of planning and designing infrastructure that is not suited for the climate of the future, there is also a risk of adapting to climate change in the wrong way, which could be as significant as the risk of incurring damages when not adapting. A wrong adaptation decision takes place, for example, when it is based on the expectation that the future will be drier, when in fact, it turns out to be wetter.

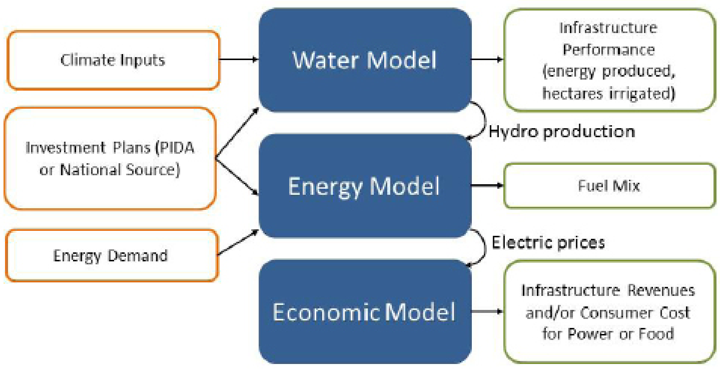
The solution to this dilemma is to identify an adaptation strategy that balances the risk of inaction with the risk of wrong action, taking into account the preferences of decision makers and attitudes toward risks. In the case of hydropower, this approach to adaptation under climate uncertainty can cut in half (or more) the maximum climate change impact (loss of revenue or missed opportunity to increase it) that would be faced in the case of inaction. The analysis further suggests that the benefits in terms of reduced risks significantly exceed the cost of modifying baseline investment plans.

What Does It Take to Integrate Climate Change into Project Design?

Implementing the approach proposed by this book at the basin scale—which involves many interactions among the components of a water resource system—is likely to remain complex for some time. But implementation at the project scale has grown more tractable, as suggested by the experience of conducting the case studies presented in this book. The modeling components required for a project-level climate change analysis consist of the following:

1. **A set of downscaled climate projections for the project's relevant geographic region.**
2. **A hydrologic model of the relevant region, calibrated to local observational records and linked to climate projections that can estimate project inflows and operations for alternative design specifications.**
3. **A simple project design and cost model that can reproduce any existing cost estimates from a pre-feasibility study and can estimate how costs would vary with alternative design specifications. If the complexity of the design precludes the development of a simple design and cost model, several estimates of alternative designs could be developed using more detailed tools.**

Schematic of Model Interactions to Estimate the Cost of Climate Change Infrastructure



The requisite sets of climate projections have become increasingly available, including those used for this book. As recommended here, the sets could be provided Africawide through a central data repository. Appropriate hydrological modeling platforms have also become increasingly available and can be calibrated using the same data utilized in feasibility studies. Finally, this study has generated a set of project designs and cost models embodied in spreadsheets that can be used as templates for a wide range of applications.

REGIONAL LEVEL APPLICATION

Typically, the regional, basin-scale water resource and power system is sized and expanded to meet each country's water and power needs. This plan usually relies on historical climate information, and infrastructure is built and fixed power purchase agreements are made to develop the water supply and energy power plants needed. The risk of this type of planning, if climate change dries the continent, is heavy economic damage – and the risk if climate change brings more water is a lost opportunity to make productive use of that windfall.

Regional scale planning can be improved, by tuning the designs throughout the basin to take best advantage of potential future water windfalls, while simultaneously hedging against potential future water deficits. The specific way in which infrastructure planning and design should be modified depends crucially on attitudes toward risks, time preferences, and the relative priority assigned to the physical performance versus the economic performance of infrastructure—within and across sectors. These are choices that countries and regional organizations will need to make themselves. Because this method involves both technical skill and stakeholder engagement, the World Bank and UNECA are currently working to implement the Afri-Res Facility, which will provide on-demand support, the most relevant data, and focused capacity building to regional planning organizations.

Illustrative Adaptation Results for the Zambezi River Basin

The study provides results for seven basins. It is useful to illustrate the analysis by walking through the key steps and results for a single basin, such as the Zambezi.

1 **Assess the potential for climate change adaptation to alleviate losses and expand opportunities.** If river basin planners knew what future climate change would bring to their region, they could plan infrastructure with "perfect foresight." Although such perfect foresight is not possible in reality, it is a useful way to evaluate the potential gains from adaptation efforts. Adaptation in the Zambezi basin has great potential to alleviate losses—avoiding $6.3 billion of potential losses in the driest scenario and adding $9.1 billion in gains in the wettest one.

2 **Assess the regrets of choosing a single adaptation pathway from among the alternatives and look to minimize those regrets.** Although the results of Step 1 usefully demonstrate the potential value of adaptation, it is nonetheless important to look at the outcomes of each of these perfect foresight strategies as the planner would, that is, from the perspective that the infrastructure that is built now could ultimately face any of the many possible climate futures. The goal should be to build in a way that minimizes the regret of these choices—the regret of an infrastructure strategy in any future is the difference between its revenues and the revenue of the strategy that performs best in that future. The study compares the regret of six alternative specifications of an infrastructure investment plan and the no-climate change specification in the Zambezi basin, across a very wide range of climate futures, including those wetter and drier than the historical climate. In this case, the option which minimizes regret - the "balanced hydro" alternative - implies an upsizing of some hydropower projects in the basin and a downsizing of other projects. This combination has the lowest range of regret for each investment alternative, and so represents a robust choice.

3 **Evaluate the costs and benefits of a robust adaptation strategy.** Once we have chosen a robust strategy, we can look behind the strategy to estimate the combination of increased costs and cost savings (savings coming from cases of strategic infrastructure downsizing) and compare those with the benefits of adapting. The detailed study document presents these results; note that the benefit/cost ratio estimated for adaptation in the Zambezi (benefits are 3.36 times greater than costs) takes a conservative perspective and focuses only on the actual increased costs, but it makes a compelling case that robust adaptation actions can provide economic benefits that are significantly larger than the expected costs.

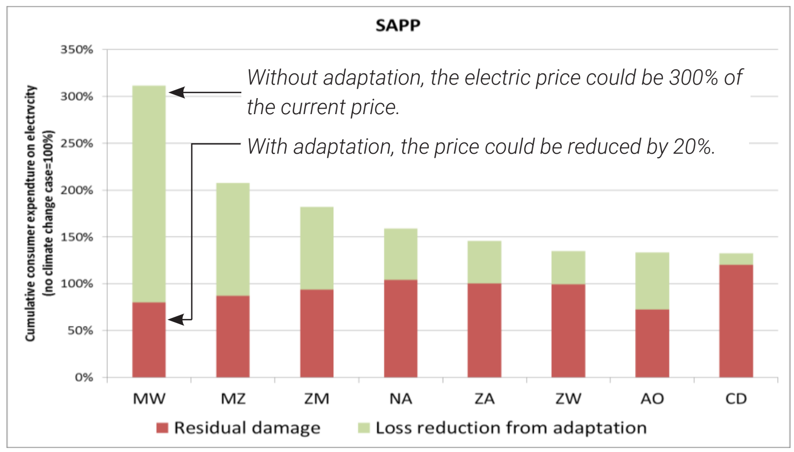
BENEFITS OF ADAPTING TO ELECTRICITY CONSUMERS

Climate change can have large impacts on consumers of electricity. In wet climate futures, hydroelectric facilities generate larger amounts of electric power without any additional investment (more water spinning the same turbines faster), which in turn allows hydro to replace fossil fuel–based energy generation and reduces overall prices. But in dry climates, less hydropower than planned is produced and the difference will need to be made up through more expensive power sources, such as diesel generators. The results of the modeling simulations for the East Africa Power Pool (EAPP), South African Power Pool (SAPP), and West African Power Pool (WAPP) suggest that, in general, the effects are asymmetric, with the price increases in dry scenarios dominating the price decreases occurring in wet scenarios.

But there is good news - compared with the no-adaptation case, electricity expenditure in dry scenarios decreases in virtually all countries as a result of adapting. The effects are most noticeable in the Southern African Power Pool (SAPP) (see figure below). The figure compares consumer electric expenses in the no climate change case (costs = 100% in the graphic) with the "worst case" results for a dry scenario in each country in the SAPP, and shows how the losses can be mitigated by adapting the hydropower system to be better tuned for future climate change, though a systemwide optimization of storage capacity, turbine capacity, and facilitated trans-boundary power trade.

Interestingly, at a power pool level, there are key countries that have potential alternatives to hydropower that allow adaptation to climate risks at lower costs. In SAPP, South Africa has the potential to switch to coal to adapt to lower levels of hydro imports from the Democratic Republic of the Congo's planned Grand Inga dam. In the West (WAPP) and the East Africa Power Pool (EAPP), Egypt and Nigeria have potential gas alternatives. In other instances, such as in EAPP, interconnections play an important role, allowing other low-cost, abundant renewables, such as geothermal power, to make up a potential shortfall in supply and trade in the region.

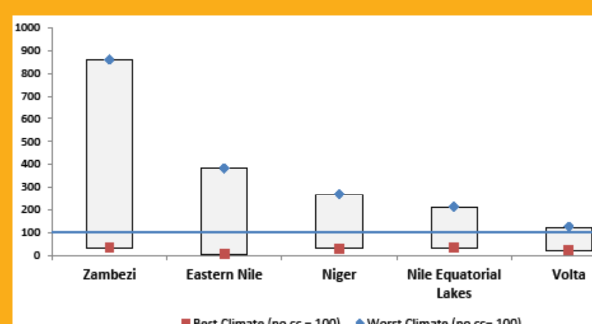
Adaptation has Great Potential to Reduce Consumer Costs of Electricity



Figures show results for countries in the South African Power Pool (SAPP): AO = Angola; CD = Democratic Republic of Congo; MW = Malawi; MZ = Mozambique; NA = Namibia; ZA = South Africa; ZM = Zambia ; ZW = Zimbabwe

Cumulative Expenditure on Agricultural Imports

In addition to affecting expenditure on electricity, climate change can also have large effects on expenditure for agricultural imports. In dry scenarios, irrigation underperforms compared with the no-climate-change scenario, and countries will need to make up for the deficit in food production by increasing expenditure on crop imports. In the driest scenario, imports could be 1.5 to 20 times larger than in the baseline, depending on the basin (see figure to the right).



Note: The chart presents the change in cumulative (2015 to 2050) expenditure on crop imports, relative to the no-climate-change reference case, for the driest and wettest climate change scenarios. Values greater than 100 indicate an increase in expenditure on imports caused by the lower production that would result under a drier climate; values lower than 100 indicate an increase in domestic production, leading to reduced need for imports.

PROJECT LEVEL APPLICATION

For seven planned projects, the study estimated performance over a wide range of plausible climate futures. The analysis confirmed that existing designs may be sensitive to climate change, in terms of reduced performance under dry scenarios and potential extra revenues under wet scenarios.

Two messages emerged, first, although project performance is in general sensitive to climate change, the project's worthiness is not necessarily affected. In some cases, the benefits and revenues of the project are so high that the risks of poor performance are low even in extreme future climates. In some cases, variables other than climate may have an even more significant effect on net returns (e.g., price and demand for power or water).

Second, the analysis confirmed that adjustment in project design can reduce regrets, by 30 percent or more, by modifying selected design parameters in anticipation of climate change. The study also found that the scope for adaptation can be considerably broadened if the analysis of climate change impacts is undertaken early in the project design process.

Illustrative Adoption Approach for the Batoka Gorge Project

The Batoka Gorge Scheme is a hydropower project in the Zambezi river basin, at a site 50 kilometers downstream of Victoria Falls, whose main benefit would be electricity production to supply markets in Zambia and Zimbabwe, within the Southern African Power Pool (SAPP). The resulting power station would have a total installed capacity of 1,600 megawatts, a rated flow of 138.8 cubic meters per second, and produce on average 8,739 gigawatt hours per year, under historical hydrological conditions. This study used Batoka Gorge as an illustrative case study to show the benefits of a robust decision making approach.

Sensitivity and Vulnerability to Climate at the Project Scale

Analysis of the effect of climate change on the performance of Batoka Gorge revealed significant sensitivity to climate change, with up to 33 percent decrease or 15 percent increase in average power production possible, depending on the climate future. The corresponding dollar value of this range of output variation between the worst and best scenarios is $4 billion over a 30-year economic life span.

Robust Decision Making and Design at the Project Scale

The potential regrets of over- or under-building the Batoka Gorge project can be reduced by 60–80 percent (depending on regional electricity price levels) with adjustments to the project design, compared with the the no-climate-change design. In this case, as in the other studies in this report, the results are intended to be illustrative only—the results do not imply that the choices made in feasibility studies are incorrect or suboptimal.

For Batoka Gorge, the results also suggest that the design appropriate for the historical climate may be robust over a wide range of climate futures, if the design is paired with flexibility in the choice of power contracts. In particular, more nuanced contracts can be used to recoup the costs of larger designs under wet futures and, in dry climates, to redistribute the risks of overbuilding between providers and consumers of power.

ADDITIONAL PROJECT LEVEL APPLICATIONS

Mwache

Urban water needs in Mombasa, Kenya, are projected to grow rapidly in the coming decades. The 2013 Water Supply Master Plan for Mombasa identifies a range of water supply projects to meet these demand increases, including a dam on the Mwache River. The Mwache Dam is designed to provide 186,000 cubic meters (m^3)/day of supply, with excess supply to be used for irrigation in nearby areas (for a total of 220,000 m^3/day). The reservoir was initially designed at a height of 85 meters above ground level, for gross capacity of 200 million cubic meters (MCM) and a dead storage volume of 4 MCM. After discussions with World Bank experts, the dam height, gross capacity, and dead storage volume were adjusted to 65 meters, 120 MCM, and 20 MCM, respectively. The climate change adaptation options analyzed included a revised reservoir capacity.

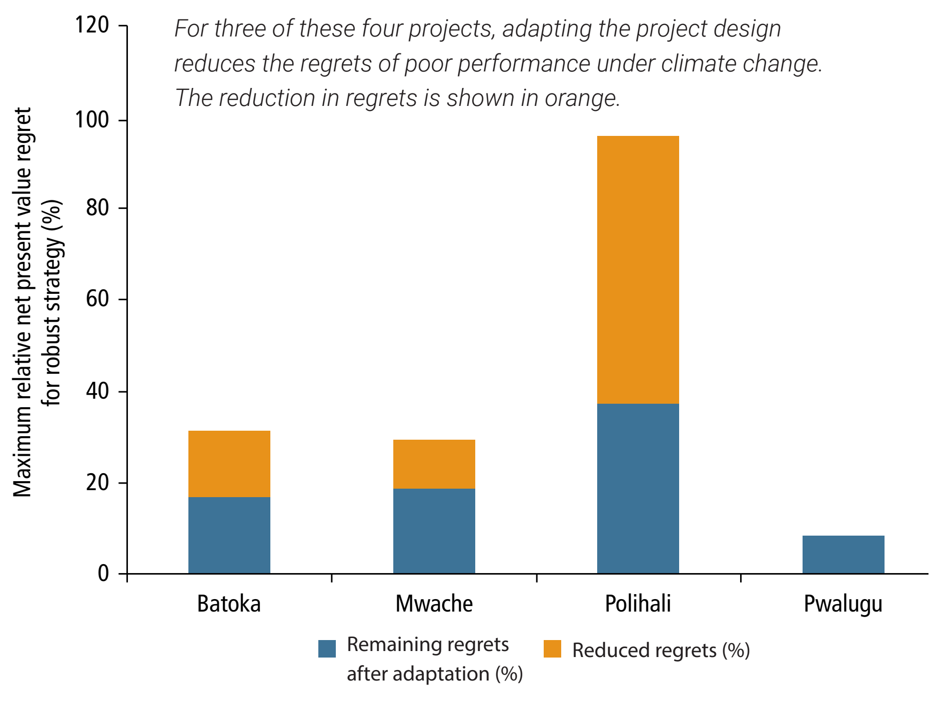
Polihali

The Polihali dam is part of the second phase of the Lesotho Highlands Water Project (LHWP). The Polihali dam would be located downstream of the Khubelu and Senqu Rivers. The main objective of the project is to transfer water from Polihali Reservoir to the existing Katse Reservoir. The LHWP has been found to be the least-cost alternative for supplying the growing water demand of the Gauteng area in South Africa. The Republic of South Africa and The Kingdom of Lesotho have thus agreed on the development and shared benefit of the LHWP. The first phase (the Katse and Mohale Dams, and water transfers) has already been completed and the second phase (Polihali) is under preparation. The Polihali dam and reservoir proposed has gross reservoir storage of 2,322 MCM. A 38.2 kilometer tunnel from Polihali to Katse Reservoir is sized to convey a maximum flow of about 35 m^3/s to ensure an average yield of 14.75 m^3/s over a year, or 465 MCM/year. Adaptation options analyzed in the study included an alternative pipe capacity.

Pwalugu

In 1992, the Volta River Authority assessed the economic and technical viability of three potential sites along the Volta River in Ghana for multipurpose dam projects—Pwalugu, Kulpaen, and Daboya. The study recommended the Pwalugu site, located 30 km southwest of Bolgatanga, as the most viable investment. The main benefits of the dam and reservoir project would be electricity production, irrigation water supply for new agricultural lands, and development of a lake fishery industry. The proposal is for a dam that is 41 meters high, to limit the flooded area and extent of community displacement and forest inundation. The reservoir would have gross storage of 4,200 MCM. Electricity would be produced using two generating units with a combined capacity of 48 megawatts (MW). The power station would have a maximum turbine flow of 170 m^3/s, with average annual hydropower generation of 184 gigawatt hours (GWh)/year. Irrigation water yield from the reservoir would be 2,200 million m^3/year, supporting roughly 110,000 hectares (ha) of irrigated land, including over 20,000 ha of rice farmland and 68,000 ha of improved pastoral land. Climate adaptation options analyzed included altering the reservoir size, hydropower turbine capacity, and irrigation water allocations.

Potential for Robust Adaptation to Reduce Regrets



THE COSTS OF ADAPTING TO CLIMATE CHANGE COULD BE LESS THAN EXPECTED

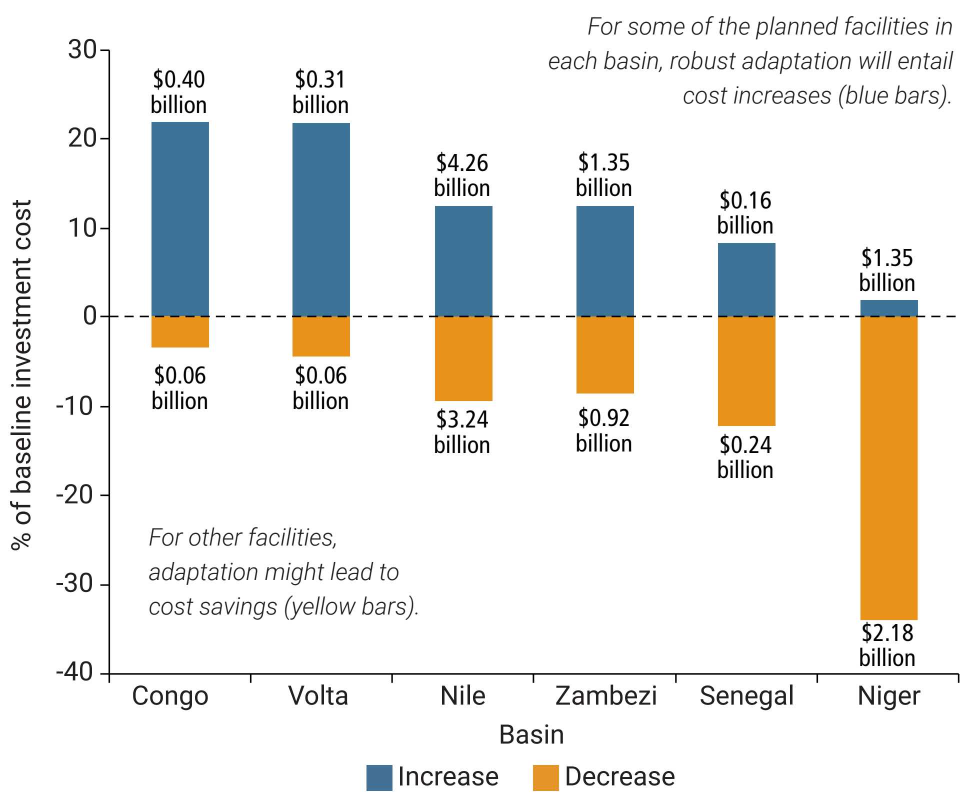
Robust adaptation will lead to cost increases when it entails investment in additional generation capacity or enhancements in water use efficiency; but it could also result in cost savings, for facilities that will be downsized to avoid their underutilization in dry climates. In hydropower, cost increases and cost savings are, at the basin level, of similar orders of magnitude (see figure below), mostly on the order of 10 to 20 percent of baseline investment costs (with the exception of Congo and Niger). But cost savings and cost increases do not cancel out, as in general they will accrue to different facilities within each basin and, as a result, to different project developers.

Most important, the costs of robust adaptation are fully justified in all but one basin, even when only cost increases are considered (i.e., not considering the cost savings of downscaled investments). Comparing only the cost increases with the benefit of adapting, expressed as reduction of the maximum regrets, the benefit/cost ratio comfortably exceeds one in these basins. The exception is Congo, confirming that in that basin the regrets from inaction are likely too small to warrant significant departures from baseline investment plans.

A comprehensive climate change response strategy might include not only ex ante adjustments to investment plans, but also elements of adaptive management, which might help identify additional ways to avoid regrets, through learning as climate change unfolds. For example, in the Volta basin, such an approach would entail an initial reduction in turbine capacity (consistent with expectation of a dry future), but with the option of adding turbine capacity later, if subsequent information suggests the climate will be wetter. Planners might create such an option by designing the powerhouses and tunnels larger than needed for the initial turbines, to reduce the cost of subsequently adding additional turbines.

> “The main message is that proper integration of climate change in the planning and design of infrastructure investments supported by PIDA, regional, and national plans can reduce considerably the risk posed by the climate of the future to the physical and economic performance of hydropower and irrigation investments.”

Incremental Cost of Robust Adaptation in Hydropower



NEXT STEPS

The results of the study provide a powerful motivation for changing the way water and power infrastructure is designed, to take better account of climate change. Making this change will require strong support of governments, project developers, and financiers. That is why the World Bank, the UN Economic Commission for Africa, the African Development Bank, and key donors have announced a cooperative effort to develop the Africa Climate-Resilient Investment Facility. The facility's activities will be based in Addis Ababa, Ethiopia, have regional Centers of Excellence throughout Africa, and will meet the need for expert assistance, high-quality climate and water resource data, and practical on-demand consulting support to enhance the resilience of new infrastructure.

> "African countries do not need to slow down the pace of infrastructure investment. As long as climate risk analysis is fully integrated in the project cycle and in pre-feasibility studies of individual investments, climate risks can be significantly mitigated in a cost-effective manner."

What comes next?

Promoting adaptation to climate change in the planning and design of infrastructure is likely to require a change in mindset, away from consolidated behavior and practices, with the goal of better integrating the expertise of the relevant professions, such as climate scientists and design engineers. Because such a paradigm shift is likely to have a considerable gestation time, the time to act is now, with priority assigned to the following selected areas of interventions.

1 **Develop technical guidelines on the integration of climate change in the planning and design of infrastructure in climate-sensitive sectors.** A multi-stakeholder technical working group could be established to develop voluntary technical guidelines on how to apply the notions of climate resilience, discussed at length in this book, to real-life infrastructure planning and design.

2 **Promote an open-data knowledge repository for climate-resilient infrastructure development.** To bring down the cost of the analysis needed to integrate climate considerations into infrastructure development, there is a need to establish common data sources (on climate scenarios, hydrology, standard construction costs, etc.), which could be made available to the public on open-data platforms and hosted by African institutions (such as UNECA's African Climate Policy Center).

3 **Establish an Africa climate resilience project preparation facility.** The facility, which would be adequately financed with grant or concessional resources, could have different windows to cater to the specific needs of different sectors or for different stages of the infrastructure development cycle. For example, the facility could provide support to climate-resilient infrastructure master plans or to the integration of climate resilience into individual projects.

4 **Launch training programs for climate-resilient infrastructure professionals.** To ensure adequate strengthening of the technical skills that are required to enhance the climate resilience of infrastructure, one or more training programs could be established for professionals involved in the planning, design, and operation of climate-sensitive infrastructures.

WORLD BANK GROUP United Nations Economic Commission for Africa

afd Agence Française de Développement · BANK-NETHERLANDS BNPP PARTNERSHIP PROGRAM · NDF Nordic Development Fund · KfW Bankengruppe · UKaid from the British people