Report No: ____________

Enhancing the Climate Resilience of Africa's Infrastructure:

The Power and Water Sectors

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Economic Commission for Africa

Currency Equivalents

All currency values are in constant 2014 US$ unless otherwise specified.

Weight and Measures

Systeme Internationale (SI Units)

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Abbreviations and Acronyms

ACPC	Africa Climate Policy Center
AFD	Agence Francaise pour Developmment
AICD	Africa Infrastructure Country Diagnostic
AR4	IPCC Fourth Assessment Report
AR5	IPCC Fifth Assessment Report
BCSD	Bias Corrected Spatially Downscaling
BNPP	Bank-Netherland Partnership Program
CMI	Climate Moisture Index
CMIP3	Coupled Model Inter-comparison Project
CO_2	Carbon dioxide
DfID	Department for International Development
DRC	Democratic Republic of the Congo
EAC	East African Community
EAPP	Eastern African Power Pool
FAO	Food and Agriculture Organization of the United Nations
GCM	General / Global Circulation Model
GHCN	Global Historical Climatology Network
GIS	Geographic Information System
GW	Gigawatts
Ha	Hectare
ICA	Infrastructure Consortium for Africa
ICOLD	International Commission on Large Dams
IFPRI	International Food Policy Index
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
IPCC	Intergovernmental Panel on Climate Change
IQR	inter-quartile range
IRENA	International Renewable Energy Agency
ITRC	Irrigation Training and Research Center
IWMI	International Water Management Institute
KfW	Kredit Anstalt fur Entwicklung
LHWP	Lesotho Highlands Water Project
MSIOA	Multi-Sector Investment Opportunity Analysis
NBA	Niger Basin Authority
NDF	Nordic Development Fund
NGO	Non-governmental organization
NPV	Net present value
O&M	Operation and maintenance
PAP	Priority Action Plan
PF	perfect foresight
PIDA	Program for Infrastructure Development in Africa
PPA	Power Purchase Agreement
PV	Present Value
RCC	high roller compacted concrete
RCPs	Reference Concentration Pathways
RDM	Robust Decision Making

SADC	Southern African Development Community
SAPP	Southern African Power Pool
SDAP	Sustainable Development Action Plan
SEI	Stockholm Environment Institute
SI Units	Systeme Internationale
TDH	Turn Down the Heat
TFESSD	Trust Fund for Environmentally and Socially Sustainable Development
THI	Temperature humidity index
TOR	Terms of Reference
TWh	terawatt hours
UNFCCC	United Nations Framework Convention on Climate Change
WAPP	West African Power Pool
WEAP	Water Evaluation And Planning
WHO	World Health Organization
WMO	World Meteorological Organization

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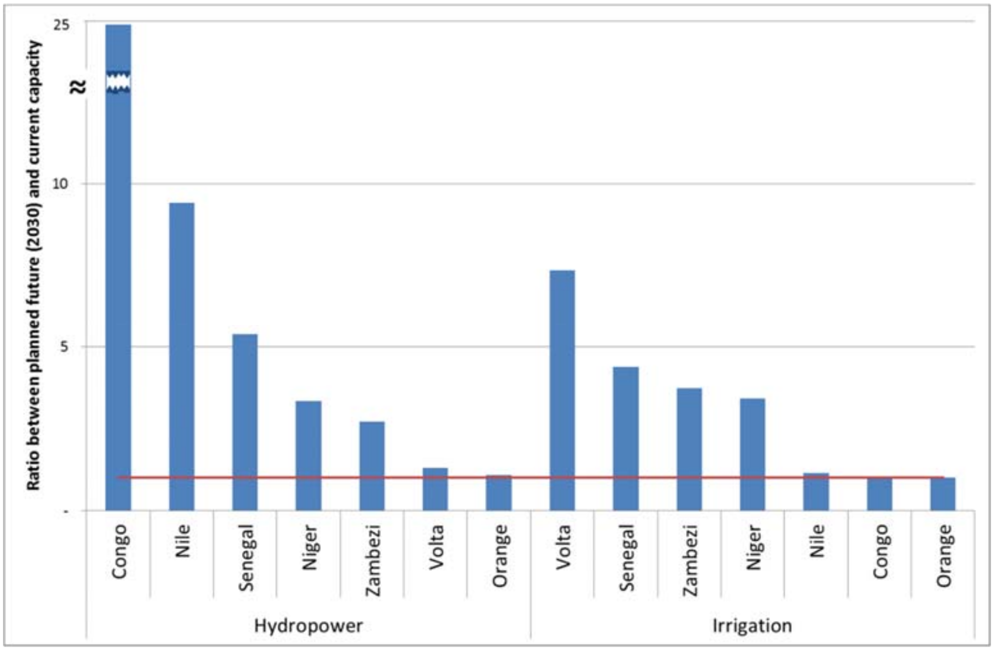
Executive Summary

Africa's Infrastructure: a key to development, potentially vulnerable to climate change

Africa has experienced economic growth of more than 5% per annum during the last decade, but to sustain this growth, investment in infrastructure is fundamental. In recognition of this, the Program for Infrastructure Development in Africa (PIDA), endorsed in 2012 by the continent's heads of State and Government, has laid out an ambitious long-term plan for closing Africa's infrastructure gap. In the water and power sector, PIDA calls for an expansion of hydroelectric power generation capacity by over 54,000 MW, and of water storage capacity by 20,000 Km^3.

Much of these investments will support the construction of long-lived infrastructure (e.g. dams, power stations, irrigation canals), which will be vulnerable to the potentially harsher climate of the future. Using for the first time a consistent approach across river basins and power systems in Africa, including a comprehensive, broad set of state-of-the-art climate projections, this report evaluates the risks posed by climate change to planned investments in Africa's water and power sectors. It further analyzes how investment plans could be modified to mitigate those risks; and it quantifies the corresponding benefits and costs, within the limits of a largely desk-based assessment.

Figure 0-1: **Planned expansion of hydropower and irrigation capacity (2010 capacity=1)**



Note: The Congo hydropower expansion includes a portion of the Grand Inga phased hydropower project expected to be constructed by 2050, but not full deployment, as the project is currently not expected to be fully operational until after 2050.

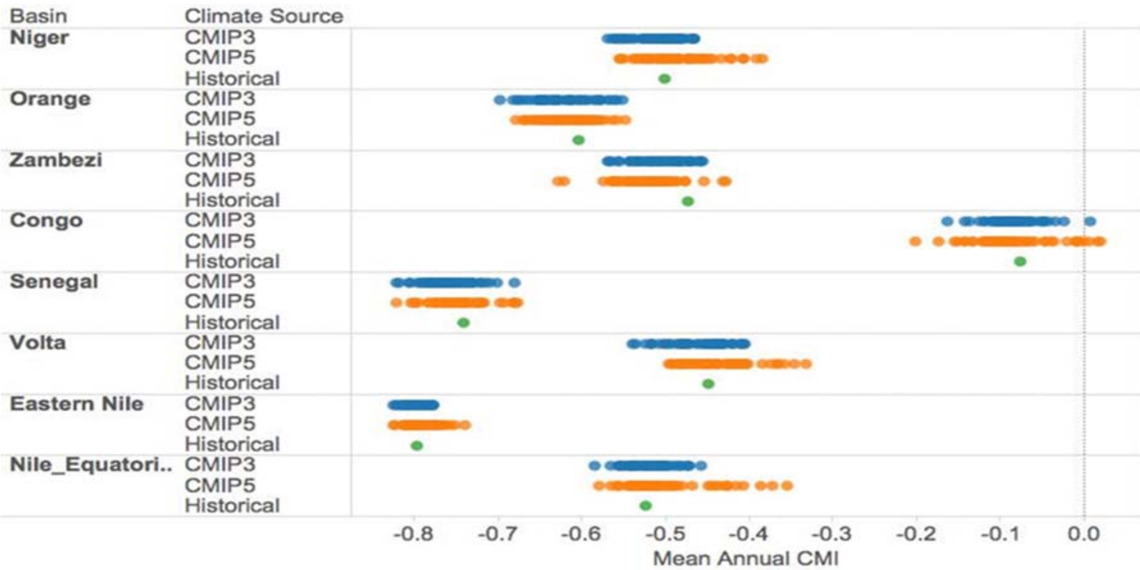
The scope of this study includes seven major river basins (the Nile, Niger, Volta, Senegal, Congo, Zambezi, and Upper Orange), and four power pools (Eastern, Western, Southern, and Central African

Power Pools). The study address all of the PIDA hydropower capacity enhancements in the subject basins, as part of the region's overall power generation plans; as well as additional investments in irrigation included in regional and national master plans.

The reference investment program against which climate effects are assessed (labeled in short PIDA+ in this report, to cover national masterplans not included in PIDA proper) calls for a major scale up of the stock of infrastructure capacity across the continent's major river basins (Figure 0-1): hydro-power capacity is planned to increase by a factor of six; irrigated area by 60%, but up to 700% in some basins. The total present value of the investment cost to achieve these goals is estimated to be $75 billion over the period 2015 to 2050. The window of opportunity for making investment more climate-resilient is considerable: we estimate that, of the roughly 80,000 MW of future additional hydropower capacity envisioned in PIDA+, only approximately 10 percent (or 8,500 MW) is in facilities already under construction. Most of the existing construction activity is accounted for by one large project, the 6000 MW Grand Ethiopian Renaissance Dam in Ethiopia.

This massive program of investment is, by and large, being designed on the basis of historical climate; but a vast body of scientific evidence indicate that the climate of the future will be very different from the past, although climate models often disagree on whether the future in any specific location will be drier or wetter (Figure 0-2). In addition, the range of uncertainty in climate projections has actually tended to increase over time – the earlier generation climate model results, in blue in the figure below, show a tighter distribution than the latest climate model results, shown in orange. The most recent advances in climate science, therefore, do not help narrow uncertainty, which on the contrary seems to be increasing. The conclusion provides another important rationale for adopting the robust decision-making methods used in this study in planning climate-sensitive infrastructure deployment.

Figure 0-2: Climate change projections across Africa's river basins

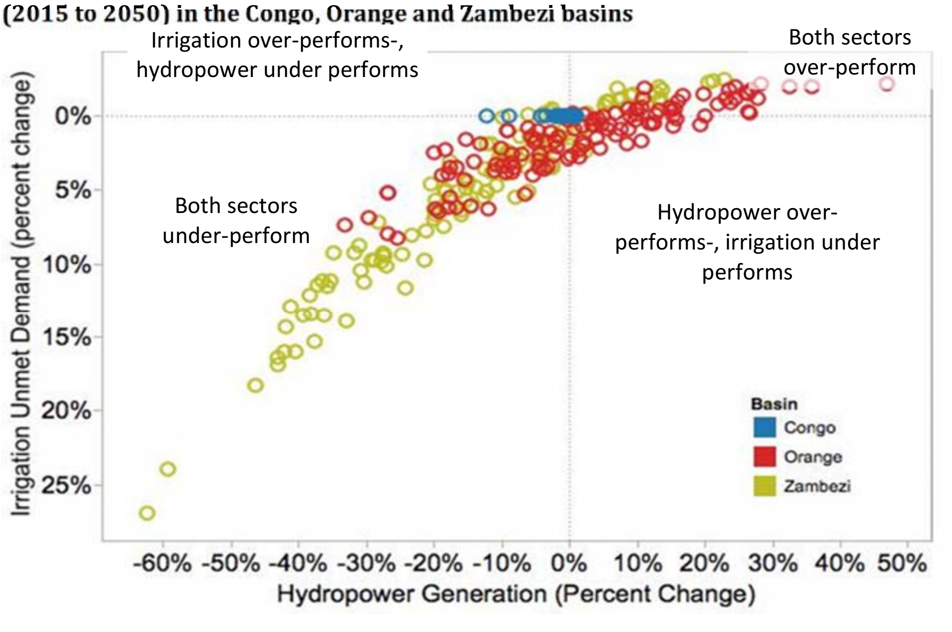


Note: the Climate Moisture Index (CMI) is a measure of aridity that combines the effect of rainfall and temperature projections – the effect of higher temperature is to increase evaporation. The index values vary between -1 and +1, with lower values representing more arid conditions. A CMI value greater than zero indicates that, for that basin, precipitation rates are greater than potential evapotranspiration rates. CMI is often a good proxy indicator for measures such as river runoff and irrigation demands. The chart reports CMI values (averaged over the period 2010-2050) projected by climate models included in the IPCC Fourth and Fifth Assessment reports. In each basin, the green dot denotes the average value of CMI in the historical baseline. Dots to the right of the historical value refer to projections of wetter climate; dots to the left, indicate projections of drier climate. CMIP3 corresponds to IPCC Fourth Assessment GCM results (published 2007); CMIP5 corresponds to IPCC Fifth Assessment GCM results (published 2013).The range of uncertainty in climate projections has actually tended to increase over time – the earlier generation climate model result (in blue), show a tighter distribution than the latest climate model results, shown in orange.

The Risk of Inaction

Climate change will bring about major variations in Africa's hydrological regimes: the total amount of annual rainfall, its monthly distribution over the year, and the way it will evaporate or contribute to runoff will all be quite different from the past. As a result, the amount of water available to key productive uses such as hydropower or irrigation will be very different: lower in dry climate scenarios, higher in wet scenarios. This will affect considerably the performance of infrastructure in physical terms. Climate change is likely to result in significant deviations from the amount of hydro-power or irrigated crops that would be produced under a stationary climate. For example in the case of the central and southern Africa basins (Congo, Orange and Zambezi basins), depending on the climate scenario considered, there could be under-performance by both sectors (occurring in many scenarios); over-performance by both sectors, occurring in some scenarios; and in fewer cases, under-performance by one sector and over-performance by the other (Figure 0-3).

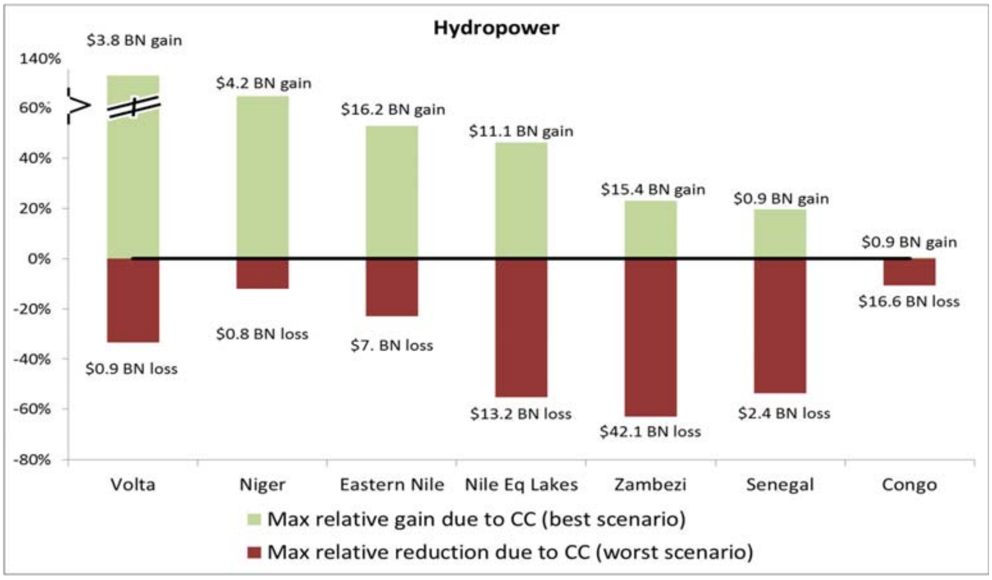
Figure 0-3: **Changes in physical performance of hydropower and irrigation under climate change (2015 to 2050) in the Congo, Orange and Zambezi basins**



Note: Every dot represents a particular climate scenario. Figures are expressed as percent difference from the value that would be expected under no climate change. Historical performance is approximated by the intersection of the two gray reference lines (at 0% change).

In economic terms, the impacts of climate change include lost revenues from underperforming hydropower or irrigation infrastructure in drier climate futures, and, on the other hand, the opportunity cost of not taking better advantage of an abundance of exploitable water resources in wetter climate futures.

Figure 0-4: **Changes in hydropower revenues from climate change (present value 2015 to 2050)**



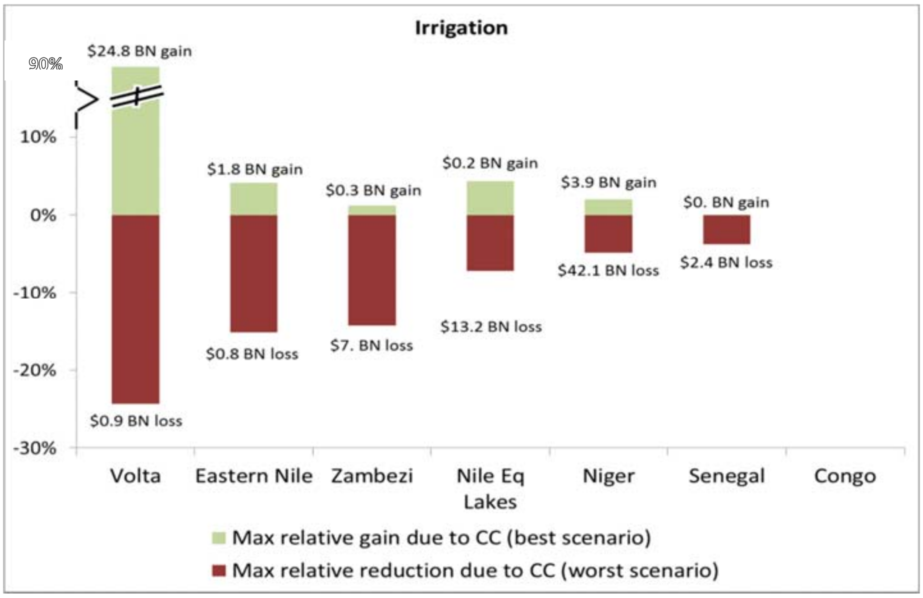
Note: The bars reflect, for each basin, the range of economic outcomes across all climate futures, i.e. the highest increase (green bars) and highest decrease (red bars) of hydropower revenues (discounted at 3 percent), relative to the no-climate change reference case. The outlier bar corresponding to the Volta basin has been trimmed to avoid distorting the scale of the chart and skewing the values for the other basins. Estimates reflect the range, but not the distribution, of economic outcomes across all climate futures. Each basin's results reflect the best and worst scenario for that basin alone, rather the best and worst basin across all basins.

When simulating the economic performance of infrastructure in the climate scenario at the end of the range, the deviations from the results expected under historical climate are dramatic. In hydropower (Figure 0-4), dry scenarios lead to revenue losses in the order of 10% to 60% of baseline values, with Zambezi, Senegal and Nile (equatorial lakes region) basins most affected. Wet scenarios result in potential revenue increase in the order of 20% to 140% (with Volta, Niger and Eastern Nile as the basin with larger gains).

In some wetter climate futures, infrastructure could perform better than expected, because for a given installed capacity more hydropower or more crops could be produced with the extra water. However, much of the corresponding gains could be only potential ones. This is so, since power systems would have been planned in anticipation of lower-than-actual generation from hydro-power; as a result the transmission lines and the power trading agreement needed to bring the extra hydro-power to the market may simply not be available; and without them, the gains from more abundant water might not be realized.

In irrigation, departures from the no-climate change baseline are also significant, but less striking (Figure 0-5). In dry scenarios, the largest loss in revenue is in the 10 to 20% range for most basins, corresponding to $1 to $40 billion in absolute terms; in wet scenarios, the largest gains are in the Volta basin (over 90%); but they are only in the range of 1% to 4% in the other basins. The figures in absolute terms are still significant, as the cases of the Niger or the Eastern Nile indicate (close, respectively, to $4 and $2 billion in present value terms).

Figure 0-5: Changes in irrigation revenues from climate change (present value 2015 to 2050)

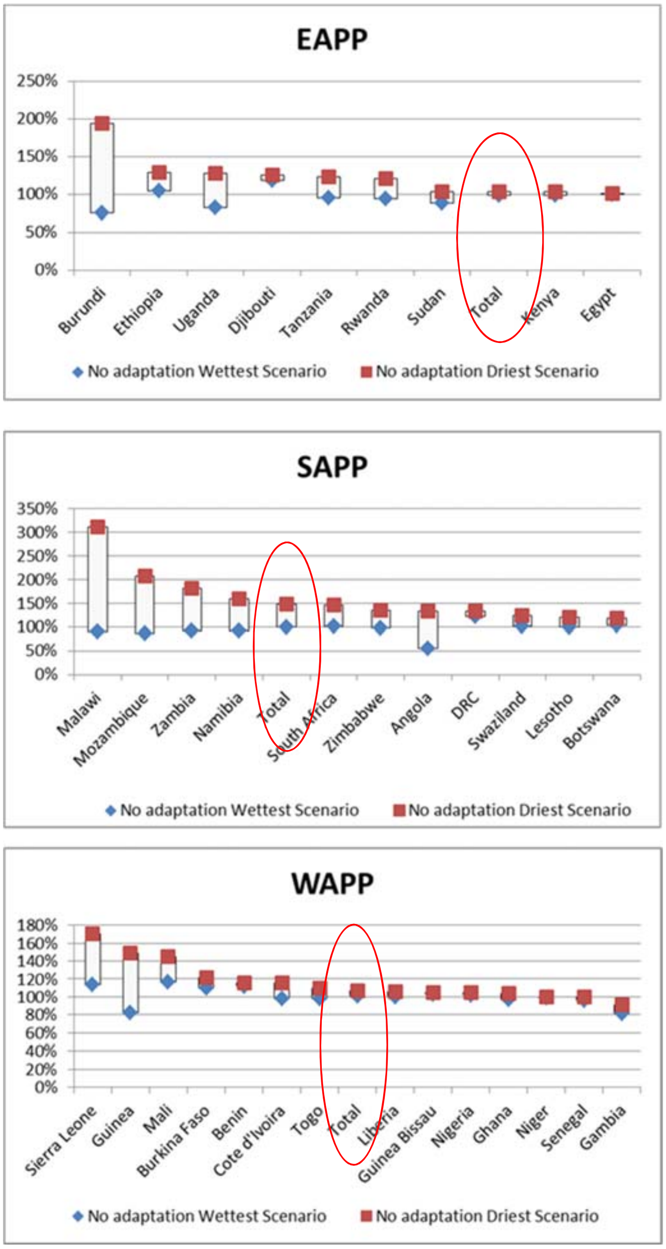


Note: The bars reflect, for each basin, the range of economic outcomes across all climate futures, i.e. the highest increase (green bars) and highest decrease (red bars) of irrigation revenues (discounted at 3 percent), relative to the no-climate change reference case. The outlier bar corresponding to the Volta basin has been trimmed to avoid distorting the scale of the chart and skewing the values for the other basins. Estimates reflect the range, but not the distribution, of economic outcomes across all climate futures. Each basin's results reflect the best and worst scenario for that basin alone, rather the best and worst basin across all basins.

Since a large part of the effects of climate change will materialize in the outer decades of the simulation period, the magnitude of impacts depends on how much decision makers care about the future. For example, using (as in most of this study) a 3% discount rate -which represents a considerable concern for how climate change might affect future well-being, the present value of hydropower and irrigation revenues expected in in the Southern African Power Pool basins (Zambezi, Orange and Congo) is in the order of $250 billion. But with a zero discount rate (no preference for the present over the future), this figure more than doubles, and so does the cost of losing revenues (in dry scenarios), or foregoing potential additional revenues (in wet scenarios). Conversely, when decision makers care more about the present (higher discount rates), the significance of climate change impacts decreases. For example, when using a 7 percent discount rate, baseline revenues in the SAPP basins decrease by 60 percent.

In addition to affecting producer revenues, climate change can also have large impacts on consumers. 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 also reduces overall prices. But in dry climates, less hydropower than planned is produced, and the difference will need to be made up for through more expensive power sources such as diesel generators. The results of the modeling simulations (Figure 0-6) for the Eastern (EAPP), Southern (SAPP) and Western Power Pool (WAPP) suggest that in general, the effects are asymmetric, with price increases in dry scenarios dominating the price decreases occurring in wet scenarios.

Figure 0-6: Cumulative consumer expenditure on electricity (no climate change case=100%)



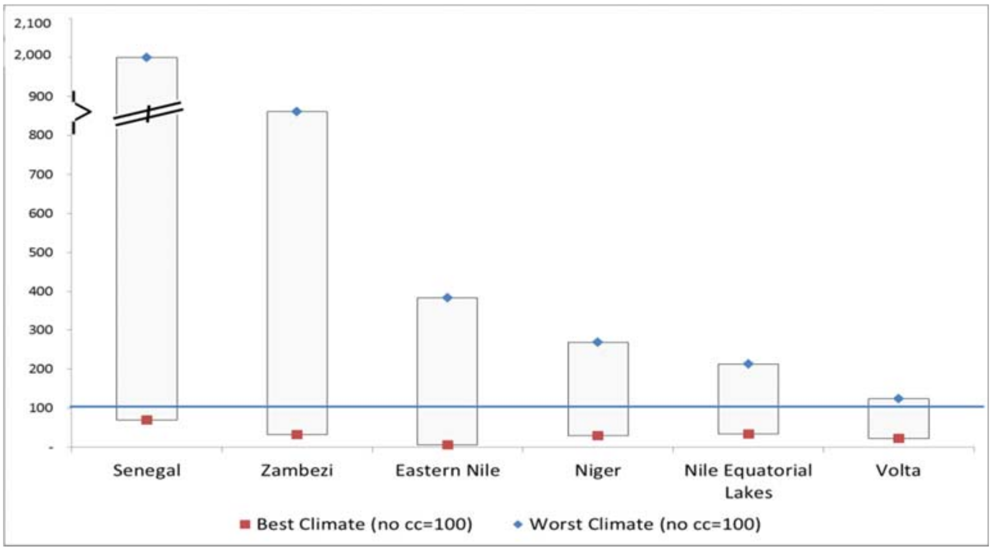
Note: the chart presents, for each country, the change of cumulative consumer expenditure on power over the simulation period 2015-2050, relative to the no-climate change reference case, and assuming no adaptation. Red dots represent expenditure change under the driest climate change scenario; blue dots, under the wettest one.

The effects on individual countries tend to be much larger than the power pool average. The dry scenario expenditure in Malawi, Burundi and Sierra Leone, is estimated to be, respectively, three, two and one half times larger than the no-climate change baseline. Other vulnerable countries include in Eastern Africa, Ethiopia (40% increase); and in Western Africa Guinea and Mali, which are in the 40% to 60% range of increase. In countries with large fossil "backstop" options –such as South Africa and Nigeria, the expenditure increase under dry climate is less noticeable. Climate change has a larger effect on consumer prices in the SAPP than in other power pools, owing to two factors:

transmission limitations; and the relatively high percentage of hydropower in most parts of the SAPP (outside of South Africa).

In addition to affecting expenditure on electricity, climate change can also have large effects on expenditure for agriculture imports. In dry scenarios, irrigation under-performs compared to the no climate change scenario, and the deficit in food production will need to made up for 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 (Figure 0-7).

Figure 0-7: Cumulative expenditure on agriculture imports (no climate change case=100)



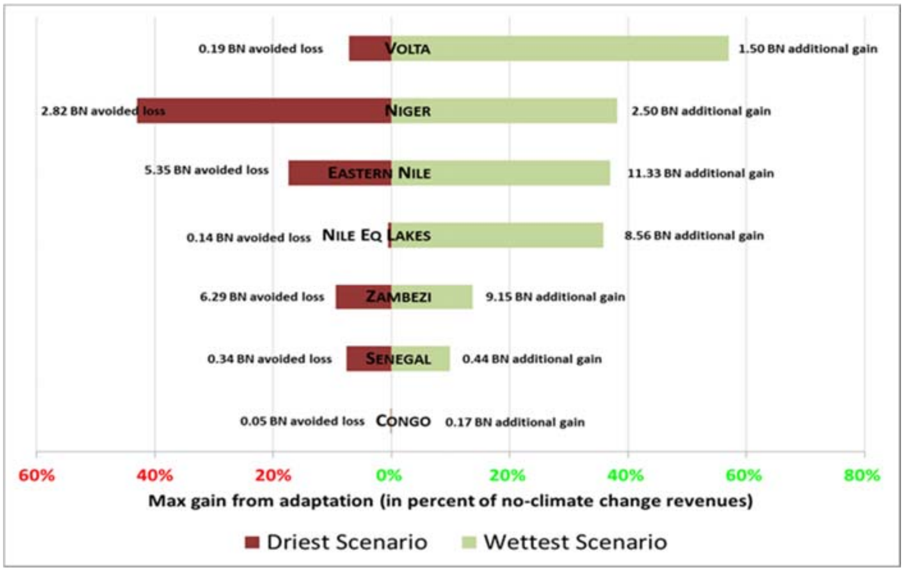
Note: The chart presents the change in cumulative (2015 to 2050) expenditure on crop imports, relative to the no-climate change reference case, for the driest and wettest climate change scenario. Values higher than 100 indicate an increase in expenditure on imports caused by the lower production that would result under drier climate; values lower than 100 indicate an increase in domestic production, leading to reduced need for imports. The outlier bar corresponding to the Volta basin has been trimmed to avoid distorting the scale of the chart and skewing the values for the other basins. Expenditures on imports are calculated with reference to the historical climate case. Imports are estimated as the additional need, or reduced need, to replace irrigated agricultural production that varies with climate scenarios. Estimates are for cumulative import requirements through 2050.

Adapting to climate change under uncertainty

To estimate the potential for adapting infrastructure capacity to either reduce damages or take better advantage of favorable climatic conditions, the study estimates the optimal response for each of six representative climate futures, chosen to span the full range of climate futures across the seven basins considered here. The adaptation strategies consist of combinations of basin- and farm-level design decisions (such as the size of reservoirs, turbine generation capacity, level of water use efficiency at the basin and at the field level). The resulting six adaptation strategies are equivalent to an optimal response to the corresponding climate future, which, as a first approximation, is assumed to be known in advance.

For example, knowing in advance that a wet future will materialize, it makes sense to expand generation capacity to produce more hydro-power; in a dry future, it is preferable to reduce generation capacity to avoid sinking capital in equipment that will end up being under-utilized. In this hypothetical "perfect foresight" situation, there is wide scope for improving the performance of infrastructure. In the case of hydro-power (Figure 0-8), dry scenario losses can be reduced in amounts equivalent to 5% to 40% of no-climate change revenues; in wet scenarios, additional revenues can be generated, in the order of 5% to 60% of baseline revenues.

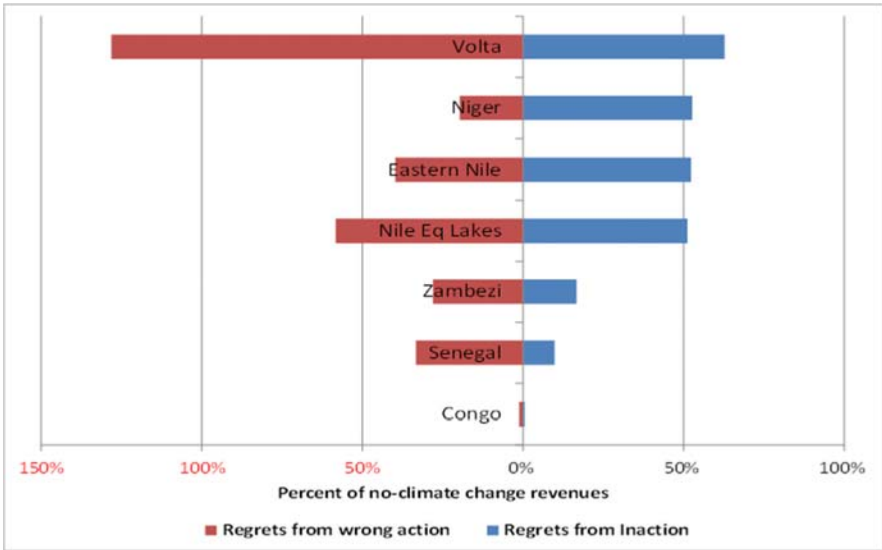
Figure 0-8: Gains from perfect foresight adaptation in hydropower



Note: Avoided losses (red bars in the chart) refer to the economic benefit of modifying investment decisions in anticipation of dry future climates. For example, reducing investments in turbines that would end being under-utilized would lead to cost savings. Additional gains (green bars in the chart) represent the gains that would accrue if planners correctly forecasted future wetter climate, and invested, for example, in expanded generation capacity to seize the opportunity of increasing hydropower production. Congo results exclude changes to the Inga III and Grand Inga projects, which are held fixed in this analysis.

But in fact 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.

Figure 0-9: Damage from not adapting or mis-adapting hydropower expansion plans



Note: The blue bars (regrets from inaction) indicate the largest damage (expressed as a percentage of the no-climate change revenues) that would be accrued when failing to consider climate change in investment planning. The damage could be a loss of revenues (in dry climates); or a foregone increase of revenues (in wet climates). The red bars (regrets from wrong action) refer to the damage incurred when a particular climate change is anticipated (e.g. a drier climate) and a very different one actually unfolds (e.g. a wetter one).

Each of the six optimal adaptation strategies identified in response to a particular climate future carries the risk of generating damages (or “regrets”) when a different climate materializes. In the Zambezi basin, for example, basin planners can ignore climate change when planning hydro-power and later regret that decision, as it can generate a loss of about 18% of baseline revenues; but if they adapt in the wrong way, they can face a regret of close to 30% of baseline revenues (Figure 0-9).

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 different possible preferences of decision makers and attitudes towards risks. A plausible representation of one such preference is to avoid the worst outcome. In this case, the robust adaptation strategy is to minimize, over all possible future climates, the maximum regret (where “regrets” are the damages –loss of revenue or missed opportunity to increase it- caused by not selecting the best response to any particular climate). In addition to the mini-max criterion, the study also considers alternative criteria (Box 0.1) for robust adaptations, which all suggest similar policy responses.

In the case of hydro-power, such robust adaptation cuts in half or more the initial regrets, i.e. those that would be faced in case of inaction against climate change (Figure 0-10) in all basins, except in the case of the Congo where initial regrets are small owing to an abundance of water.

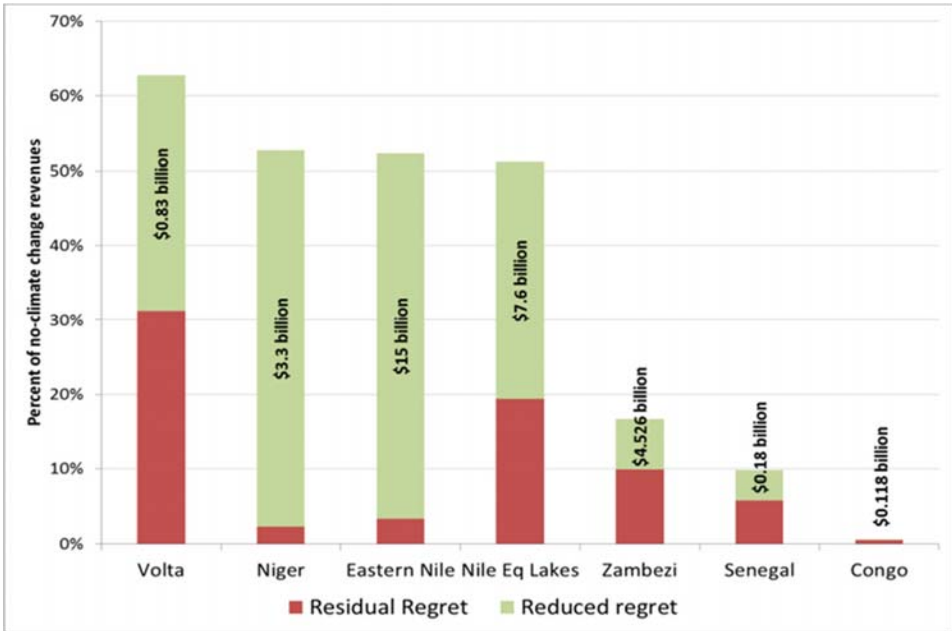
Box 0.1: Criteria Used for Robust Adaptations

The main criterion used in this study (called mini-max regret) is not the only that can be adopted for choosing robust adaptation strategies. When decision makers are uncertain about the future, the mini-max regret criterion suggests calculating the worst-case regret for each strategy over the full range of climate futures, and choosing the strategy with the smallest worst-case regret. The selection of the Mini-max criterion is justifiable when decision makers do not have a way to assess the relative likelihood of different outcomes, and have high level of risk aversion. But in situations where there are reasons to believe that some outcome are more likely than others; and where policy makers are risk neutral, other decision criteria could be used (e.g. the expected utility criterion); and this might lead to fairly different results.

To evaluate the sensitivity of the results of this study to alternative decision criteria, we considered three alternatives: mini-max regret; a criterion that selects the strategy with the smallest 90th percentile regret; and a criterion that selects the strategy with the smallest 75th percentile regret. In five of the six basins, all three criteria suggested the same robust adaptation strategy. In one basin (the Zambezi), there was a small difference between the strategies selected by the mini-max and the 75th percentile criterion.

In the case of the project level analysis, however, we considered three slightly more refined robustness criteria: mini-max regret; a criterion that selects the strategy with "small regrets" (i.e. not exceeding a certain threshold) over the largest number of futures; and a criterion that selects the strategy with small expected regret for a wide range of likelihoods. For most of the five projects considered, the three criteria suggest similar robust adaptations, but not in all cases – for example, in the Lower Fufu project in Malawi, the mini-max regret criteria would led to selecting the smallest diversion tunnel (with a maximum flow of 29 m3/sec). But the other two criteria would lead to larger sizes. The interpretation is that decision makers most concerned about very low flow, worst-case scenarios, should consider a design with small tunnels. However, decision makers less concerned with worst cases, and who consider all the futures equally likely might consider large tunnels (39 m3/sec). Finally, decision makers concerned with limiting their exposure to the extreme dry futures, but who believe those futures to be relatively unlikely, might consider tunnel size in between these extremes , and in particular in the range of 31-33 m3/sec, which by coincidence, is a capacity close to that which would be optimal based on historical climate.

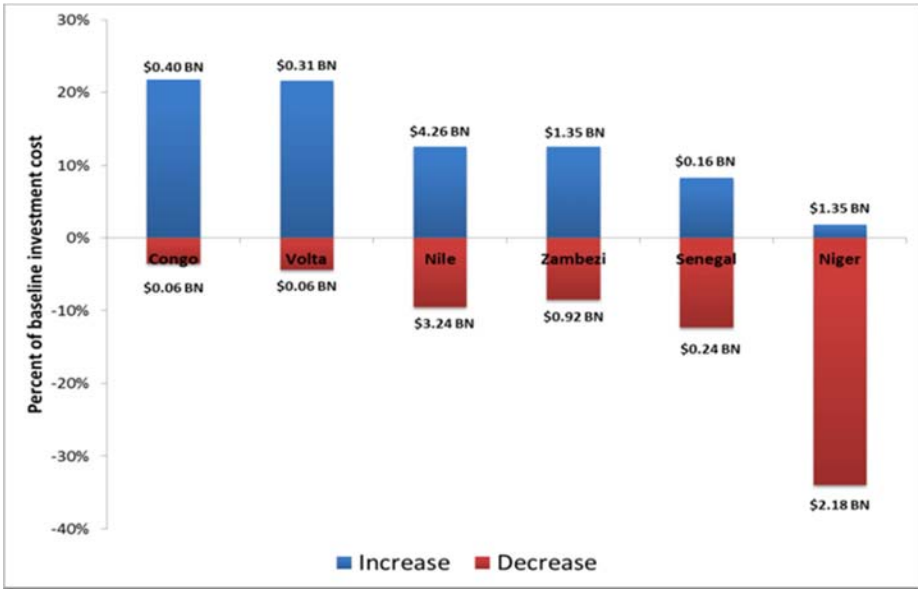
Figure 0-10: Reducing regrets through robust adaptation



Note: If decision makers ignore climate change, and plan investment based on historical climate, they are exposed to a maximum possible damage given by the sum of the red and green bars (expressed as percentage of reference, no-climate change revenues). By adopting robust adaptation, the worst-case damage is lower, and is represented by the red bars. The green bars thus represent the benefit of adapting, i.e. the reduction of worst-case damages. Numbers inside the bars indicate the discounted dollar value of adaptation (in terms of reduced maximum regret)

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 down-sized to avoid their under-utilization in dry climates. In hydro-power, cost increases and cost savings appear to be of similar orders of magnitude (Figure 0-11), mostly in the order of 10% to 20% 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 result, to different project developers.

Figure 0-11: Incremental cost of robust adaptation in hydropower



Note: The chart indicates the cost (expressed as a percentage of the baseline investment cost) of the adaptation strategy that minimizes the maximum regret (regrets are the damages –loss of revenue or missed opportunity to increase it- caused by not selecting the best response to any particular climate). For some of the facilities planned, adaptation will entail cost increases (blue bars); for some others, adaptation might lead to cost savings (red bars). Numbers inside the chart indicate the discounted dollar value of cost increases and of cost reductions.

Robust adaptation appears to be fully justified, even when only cost increases are considered (i.e. not considering the cost savings of downscaled investments). Comparing the latter with the benefit expressed as reduction of the maximum regrets, the benefit/ cost ratio comfortably exceeds one in all basins (Table 0.1). The exception is given by the Congo, confirming that in that basin the regrets from inaction may be too small to warrant significant departures from baseline investment plans.

Table 0.1: Costs and benefits of robust adaptation

Basin	Increased Cost (US$ Billion)	Decreased Cost (US$ Billion)	Reduced maximum regret (US$ Billion)	Benefit/ Cost ratio
Congo	$0.40	$0.06	$0.12	0.29
Niger	$1.35	$2.18	$3.30	2.45
Nile	$4.26	$3.24	$22.60	5.31
Senegal	$0.16	$0.24	$0.18	1.14
Volta	$0.31	$0.06	$0.83	2.64
Zambezi	$1.35	$0.92	$4.53	3.36

Note: the benefit/cost ratio column is given by the reduced maximum regret (i.e. the benefits of adaptation), divided by the incremental cost incurred by undertaking adaptation. Because the calculation does not incorporate the cost savings that adaptation brings about for some facilities, it should be considered as a conservative, lower bound estimate.

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, in order to reduce the cost of subsequently adding additional turbines.

Box 0.2: Illustrative Adaptation Results for the Zambezi River Basin

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

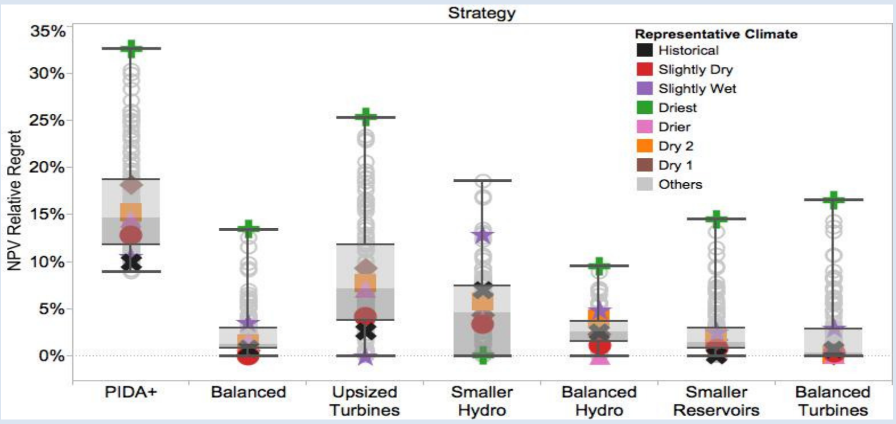
Step 1: Assess the potential for climate change adaptation to alleviate losses and expand opportunities

If river basin planners knew what future climate change would bring to their region, they could plan infrastructure with "perfect foresight". While 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 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.

Step 2: Assess regrets of choosing a single adaptation pathways from among the alternatives, and look to minimize those regrets

While 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, i.e. with 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 figure below compares the regret of six alternative specifications of an infrastructure investment plans 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 "Balanced Hydro" alternative, third from the right, 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.

Estimates of regret for different adaptation strategies in the Zambezi basin



Step 3: Evaluate the costs and benefits of a robust adaptation strategy

Once we chose 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 to the benefits of adapting. The last row of Table 0.1 in the text presents these results – note that the benefit/cost ratio in the table takes a conservative perspective and focuses only on the actual increased costs, but makes a compelling case that robust adaptation actions can provide economic benefits significantly larger than their expected costs.

The findings of the analysis indicate that it is possible, and economically advantageous, to modify investment plans to better handle the risks posed by climate change to the performance of hydropower and irrigation infrastructure (see Box 0.2 for a more detailed example of the process for the Zambezi Basin).

The specific way in which such modifications should be done, however, depends crucially on attitudes towards risks, on time preferences, on the relative priority assigned to physical performance vs economic performance of infrastructure, within and across sectors. These are choices that countries and regional organizations will need to make themselves; the results presented in this report are therefore indicative and should not be intended as substitute for assessments reflecting the full range of stakeholder perspectives and priorities.

Adaptation to Climate Change at the project level

To test the applicability at the project level of the approach used at the basin and power pool scale, the report evaluated the sensitivity to climate change of five case study projects, and the scope for identifying robust adaptation options.

Figure 0-12: Location of case study projects

Note

1. Lower Fufu Hydropower Project (Zambezi River Basin, Malawi);

2.Polihali Dam and Conveyance Project (Orange River Basin, Lesotho;

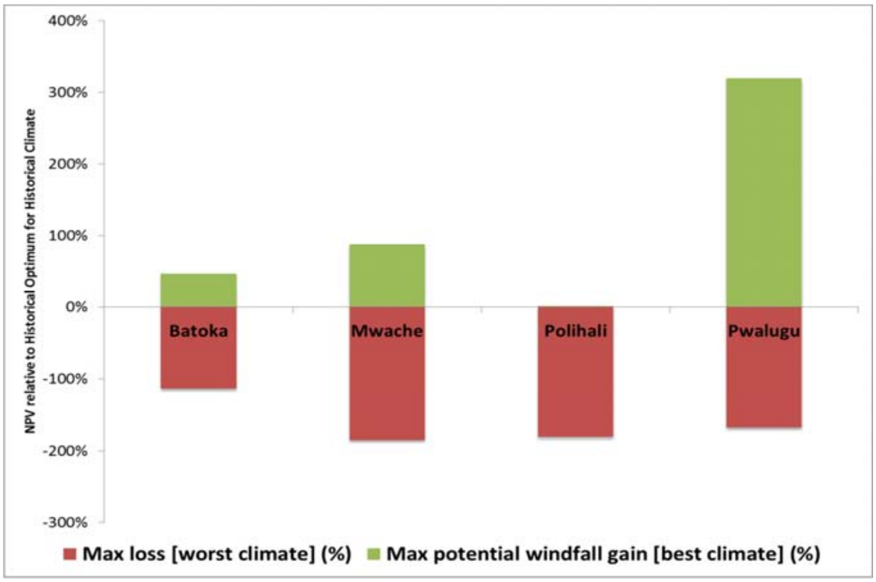
3. Pwalugu Multi-purpose Dam Project (Volta River Basin, Ghana);

4. Batoka Gorge Hydropower Project (Zambezi River Basin, Zambia/Zimbabwe);

5. Mwache Dam and Reservoir Project (Kwale District, Kenya)

The case studies analyzed span a wide range of geographic locations (Figure 0-12); of current and future climate conditions, and of design and management challenges. Project level performance was assessed over a wide range of plausible climate futures, to estimate the extent to which key technical and economic metrics of performance are affected. The analysis confirmed that existing designs may be considerably sensitive to climate change, both in terms of reduced performance under dry scenarios, and of potential extra revenues under wet scenarios (Figure 0-13).

Figure 0-13: Sensitivity to climate change of case study projects

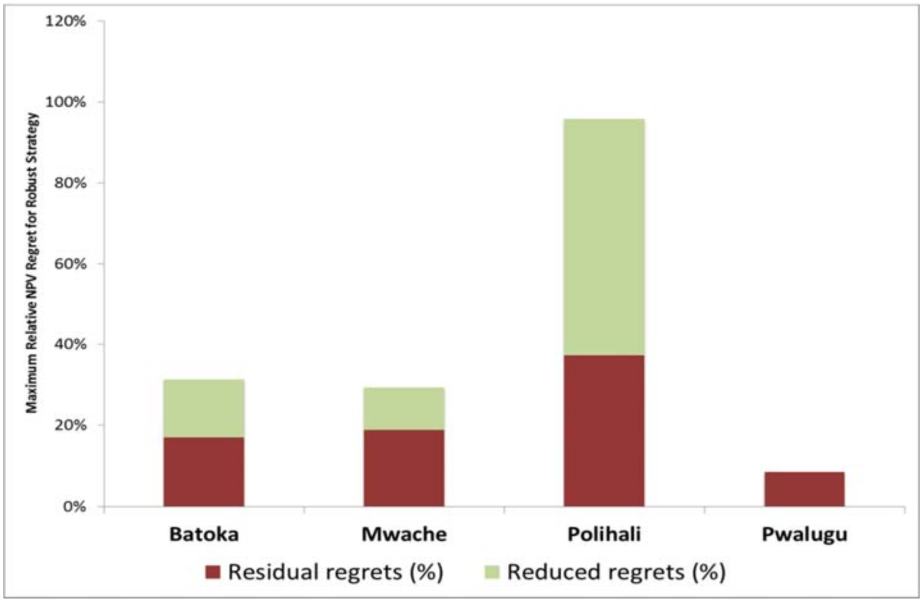


Note: The bars represent the net present value of revenues (for the period 2015 to 2050, discounted at 3%) measured relative the no-climate change case. Green bars indicate revenues increase (windfall gains) in the best future climate; red bars represent revenue losses in the worst future climate

But the value added of moving the analysis from the basin to the project level is that additional insights however can be obtained by utilizing more information on local circumstances. 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 risk of negative NPV are low even in extreme future climates. In fact, 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 : the maximum regret faced by project developers when using existing design can be cut by 30% or more by modifying selected design parameters in anticipation of climate change (Figure 0-14). But perhaps more importantly, the study 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. This is so in particular because at that stage it would be easier to evaluate the relative adaptation benefits of a wider range of interventions, including both "hard" engineering parameters (e.g. turbine capacity, size of canals, etc), as well as "soft" choices, such as length and terms of performance contracts (e.g. power purchasing agreements). See Box 0-3 below for more details on the analytic process, using the Batoka Gorge project as an illustrative example.

Figure 0-14: Reduction of regrets through adaptation in case study projects



Note: If decision makers ignore climate change, and plan investment based on historical climate, they are exposed to a maximum possible damage given by the sum of the red and green bars (expressed as percentage of reference, no-climate change revenues). By adopting robust adaptation, the worst-case damage is lower, and is represented by the red bars. The green bars thus represent the benefit of adapting. Reduced regrets are those which can be reduced through adapting the project design. Residual regrets are those which cannot be reduced through any adaptation studied for that project – other adaptations may be possible, however, including "soft" adaptations to contractual agreements such as Power Purchase Agreements (PPAs).

Box 0-3: illustrative Adaptation Results for the Batoka Gorge Project

The Batoka Gorge Scheme is a hydropower project in the Zambezi river basin, at a site 50 km 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 MW, a rated flow of 138.8 m^3/s, and produce on average 8,739 GWh/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 Project Scale
Analysis of the effect of climate change on the performance of Batoka Gorge in terms of hydropower production revealed significant sensitivity to climate change, with up to 33% decrease or 15% 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 in PV of revenues for the 30-year economic lifespan, assuming the average cost of power prevailing in the SAPP.

Robust Decision-making and Design at the Project Scale
Looking across a range of different possible designs of the Batoka Gorge project suggests the maximum regret of building the project a certain way can be reduced between 60-80% (depending on regional electricity price levels) compared to the maximum regret if the no-climate change design were chosen. In this case, as in the other studies in this report, the results are intended to be illustrative only – they 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 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 re-distribute the risks of overbuilding between providers and consumers of power.

Recommendations

Although climate change impacts in the mid 21st century may seem far away, they are going to be very real during the life span of the infrastructure that is planned now and will be built within the coming decade. If these impacts are not taken into account now, there is a considerable risk to lock the next generation of power and water infrastructure in Africa into designs that could turn out to be inadequate for the climate of the future; and costly or impossible to modify later. To avoid that risk, it is important to actively promote integration of climate change in infrastructure development, at both the planning and project levels. In terms of the latter, the approach outlined in this report could be applied beyond the five pilot test cases, considering that the data and analytical requirements are not particularly demanding (*Box 0.4*).

Box 0.4: What does it take to integrate climate change into project design

Implementing the approach proposed by this report at the basin scale -which involves many interactions among 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 report. The modeling components required for a project-level climate change analysis consist of a:

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.

The requisite sets of climate projections have become increasingly available, including those used for this report; and, as recommended here, they could be provided Africa-wide 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 excel spreadsheets that can be used as templates for a wide range of applications.

But in parallel to further testing of the approach in a wider range of locations, there is need to fully integrate climate change consideration into regular planning and project design processes. And this 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 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 report, to real-life infrastructure planning and design. The group would include representatives from the development community, relevant professional organizations in the engineering and consulting industries –which could be mobilized through vehicles such as the International Commission on Large Dams (ICOLD)-, and public sector stakeholders, at the regional –e.g. ACPC, NEPAD- and national level.

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. These could be hosted by African institutions (such as the Africa Climate Policy Center – ACPC) and should build on existing platforms (such as the World Bank's Climate Change Knowledge Portal). These knowledge repositories should be updated periodically as new information from the scientific and practitioner's communities become available. To ensure credibility of the information provided, suitable vetting mechanisms should be identified (for example, in collaboration with the World Meteorological Organization –WMO, and with the UNFCCC secretariat) so that users could have confidence that the data reflects the latest advances of climate science, hydrology, engineering, etc.

3. **Establish an Africa climate resilience project preparation facility**

Building on the seed resources made available for the present study, development organizations could mobilize funds to establish a facility that would provide technical assistance for the systematic integration of climate change in the planning and design of Africa's infrastructure. While eventually climate resilience analysis should become a regular part of program and project preparation, experience on the ground is limited and technical capacity is scarce; it is therefore not realistic that all existing project preparation outfits can rapidly integrate climate stress tests and adaptation analysis in their operation. Instead, it may be preferable to have a dedicated knowledge hub, which can provide technical assistance services across the continent for the assessment of climate impacts and particularly for the analysis of adaptation options in project design (including assessment of contracts of service), etc. The facility, to be adequately financed with grant or concessional resources, could have different windows to cater for the specific needs of different sectors, or for different stages of the infrastructure development cycle; for example, it could provide support to climate-resilient infrastructure masterplans; or to support the integration of climate resilience into individual projects.

4. Launch training programs for climate-resilient infrastructure professionals

To ensure the adequate strengthening of the technical skills 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. These could include technical staff of relevant public sector entities (e.g. ministries of water, power, transport; river basin organizations, power pools) as well as other professionals in the academic community and the private sectors.

5. Set up an observatory on climate resilient infrastructure development in Africa

To ensure that the work at the technical level discussed above on methodology, data, project preparation and training retains visibility and linkages with the policy level of decision-making, an observatory for climate resilient infrastructure development could be established. This could for example be part of the Infrastructure Consortium for Africa (ICA), which is a key platform to catalyze donor and private sector financing of infrastructure projects and programs in Africa, and which already includes Climate-Resilient Infrastructure in its list of priority topics. ICA could operate in partnership with ACPC to optimize the distribution of work across areas of comparative advantage.

The observatory could undertake the following activities:

a) keep track of program and projects featuring significant assessments of climate impacts and adaptation options;
b) monitor trends in financing for climate-resilient infrastructure;
c) help identify the technical, informational, financing and institutional bottlenecks that prevent progress in integrating climate consideration into infrastructure development, and
d) promote a high level dialogue on possible solutions among decision makers in Africa's national and regional organizations, and the international development communities.