A Risky Climate for Southern African Hydro: Assessing hydrological risks and consequences for Zambezi River Basin dams

Executive summary

Africa is highly vulnerable to the impacts of climate change. Numerous climate change models predict that the continent's weather patterns will become more variable, and extreme weather events are expected to be more frequent and severe, with increasing risk to health and life. Within the next 50 years, an estimated 60 to 120 million people in Southern Africa will face water stress.

Across the continent, African leaders are under pressure to grow their national economies, and to raise standards of living for their people, which translate into increased demands for energy. Hydropower is generally being promoted as a source of large-scale energy capacity for the continent. Numerous large dams are being built or under consideration.

However, Sub-Saharan Africa (excluding South Africa) is already 60% dependent on hydropower for its power supply, and many individual countries are much more dependent. The continent has experienced recurring drought in the past quarter century, which has become a leading contributor to power shortages in numerous hydro-dependent countries. Drought-induced power shortages come at a great cost to local economies. Large hydropower schemes also harm the wealth of ecological services provided by river systems that sustain human livelihoods and freshwater biodiversity. These impacts are being compounded by climate change.

Despite these concerns, large dams are being built or proposed typically without analysis of the risks from hydrological variability that are already a hallmark of African weather patterns, much less the medium- and long-term impacts expected from climate change. Likewise, ecosystem services are rarely given much weight in the energy-planning process.

This report presents an evaluation of the hydrological risk of hydro-dependent power systems in the face of climate change, using the Zambezi Basin as a case study. The future of the Zambezi Basin exemplifies the challenges faced by decision-makers weighing potential benefits of hydropower development against the risks of hydrological change. The Zambezi River Basin is the largest in Southern Africa, with a total drainage area of approximately 1.4 million km^2. The basin currently has approximately 5,000 MW of installed hydropower generation capacity, including the massive Kariba (whose reservoir is, by volume, the largest in the world) and Cahora Bassa dams. An additional 13,000 MW of hydropower potential has been identified. None of these projects, current or proposed, has seriously incorporated considerations of climate change into project design or operation. The report discusses hydrological variability and uncertainty in the Zambezi Basin, the impact of climate change on basin hydrology and hydropower, and the risks for current and future hydropower developments. The need for incorporating climate change into energy planning is highlighted and recommendations to reduce the risks are proposed.

Hydrological Variability and Hydropower in the Zambezi River Basin

An understanding of the hydrological variability in the Zambezi River Basin is fundamental to assessing the risks, uncertainties, and consequences of hydro-dependent power systems.

The Zambezi River Basin has one of the most variable climates of any major river basin in the world, with an extreme range of conditions across the catchment and through time. Average annual rainfall varies from more than 1600 mm per year in some far northern highland areas to less than 550 mm per year in the water-stressed southern portion of the basin.

Runoff is highly variable across the basin, and from year to year. The entire Zambezi River Basin is highly susceptible to extreme droughts (often multi-year droughts) and floods that occur nearly every decade. Droughts have considerable impact on river flows and hydropower production in the basin. For example, during the severe 1991/92 drought, reduced hydropower generation resulted in an estimated $102 million reduction in GDP, $36 million reduction in export earnings, and the loss of 3,000 jobs. Extreme floods have resulted in considerable loss of life, social disruptions, and extensive economic damage. Hydropower operators and river basin managers face a chronic challenge of balancing trade-offs between maintaining high reservoir levels for maximum power production and ensuring adequate reservoir storage volume for incoming floods.

The natural variability of Zambezi River flows is highly modified by large dams, particularly Kariba and Cahora Bassa dams on the mainstem, as well as Itezhi-Tezhi and Kafue Gorge Upper dams on the Kafue River tributary. Zambezi hydropower dams have profoundly altered the hydrological conditions that are most important for downstream livelihoods and biodiversity, especially the timing, magnitude, duration, and frequency of seasonal flood pulses. More than 11% of the mean annual flow of the Zambezi evaporates from large reservoirs associated with hydropower dams. These water losses increase the risk of shortfalls in power generation, and significantly impact downstream ecosystem functions.

With the dams in place, overbank flood pulses now occur only during major floods in the basin, and are of inadequate volume and duration to sustain healthy functioning floodplain systems which are of global importance, such as Kafue Flats, Mana Pools, and the Zambezi Delta. High flood pulses, when they occur, are often mistimed – they are generated during emergency flood releases or the late dry season in response to required drawdown releases. Dry season flood-recession, essential for river-dependent agriculture, fisheries, and wildlife, is replaced by constant dry-season flows generated from hydropower turbine outflows. The economic impact of the loss of these and other ecosystem services is an important factor in the overall financial risk of hydropower development, especially in a changing climate.

Climate Risks in the Zambezi Basin

The Intergovernmental Panel on Climate Change (IPCC) has categorized the Zambezi as the river basin exhibiting the "worst" potential effects of climate change among 11 major African basins, due to the resonating effect of increase in temperature and decrease in rainfall. The Zambezi runoff is highly sensitive to variations in climate, as small changes in rainfall produce large changes in runoff. Over the next century, climate change is expected to increase this variability, and the vulnerability of the basin – and its hydropower dams – to these changes.

The future picture for Southern Africa's climate is increasingly clear, based on observed trends over the past century and increasing confidence in the range of climate change scenarios developed. Overall, the Zambezi will experience drier and more prolonged drought periods, and more extreme floods. The following are key risks predicted for the Zambezi River Basin over the next century:

- The basin is expected to experience a significant warming trend of 0.3 -0.6 ^{o}C.
- Increases in temperatures across the basin will result in an increase in open-water evaporation.
- Multiple studies cited by IPCC estimate that rainfall across the basin will decrease by 10-15%.
- Significant changes in the seasonal pattern of rainfall across the basin are predicted, including delayed onsets, as well as shorter and more intense rainfall events.
- All Zambezi Basin countries will experience a significant reduction in average annual streamflow. Multiple studies estimate that Zambezi runoff will decrease by 26-40% by 2050.
- Increasing water stress is a serious concern in the semi-arid parts of the Zambezi Basin.

Hydropower's Climate Risks

These staggering climate change predictions, based on the average (not extreme case) of many climate models, have profound implications for future hydropower in the Zambezi River Basin. Climate change has the potential to affect hydropower operations in at least five important ways:

- Reduced reservoir inflows, due to decreased basin runoff and more frequent and prolonged drought conditions, will reduce overall power output.

- Increased extreme flooding events, due to higher rainfall intensity and more frequent cyclones, will increase the risk of worse flood impacts from uncontrolled releases, and risks to dam safety.
- A delayed onset of the rainy season could result in less predictable power production and more uncertainty and complications in using reservoirs for flood management.
- Increased surface-water evaporation could reduce power production.
- Increased sediment load to reservoirs, resulting from higher rainfall intensity and corresponding erosion, will lead to a decrease in reservoir capacity and greater difficulty in managing floods.

Numerous studies have indicated that hydropower economics are sensitive to changes in precipitation and runoff. Most hydropower projects are designed on the basis of recent climate history and the assumption that future hydrological patterns will follow historic patterns. However, this notion that hydrological systems will remain "stationary" in the future (and thereby predictable for the design and operation of hydropower schemes) is no longer valid. Under future climate scenarios, a hydropower station based on the past century's record of flows is unlikely to deliver the expected services over its lifetime. It is likely to be over-designed relative to expected future water balances and droughts, and under-designed relative to extreme inflow events. Extreme flooding events, a natural feature of the Zambezi River system, have become more costly downstream since the construction of large dams, and will be exacerbated by climate change. The financial and social impact of a major dam failure in the Zambezi River Basin would be nothing short of catastrophic.

The design and operation of the Batoka Gorge and Mphanda Nkuwa dams now under consideration for the Zambezi illuminate these concerns. Both dams are based on historical hydrological records and have not been evaluated for the risks associated with reduced mean annual flows and more extreme flood and drought cycles.

Ecosystem Services Undervalued

The wealth of ecological services provided by river systems that sustain life on earth are rarely given much weight in the energy planning process. The current course of dam building in Africa is not being evaluated with respect to the impact of dam-induced hydrological changes on the ability of rural populations to adapt to new flow regimes, much less on their ability to adapt to climate change's impacts more generally. Ecosystem services are of critical importance for adaptation to climate change. The Millennium Ecosystem Assessment concluded that efforts to reduce rural poverty and eradicate hunger are critically dependent on ecosystem services, particularly in Sub-Saharan Africa. Continued dependence on hydropower systems will exacerbate the economic impact of reduced ecosystem services already associated with river development.

The value of the ecosystem services threatened by hydropower development in the Zambezi River system is astonishing. A recent economic valuation study estimates that the annual total value of river-dependent ecosystem services in the Zambezi Delta is between US$930 million and $1.6 billion. Agriculture, fisheries, livestock, tourism, and domestic water supply are all affected. Cumulatively, the economic value of water for downstream ecosystem services exceeds the value of water for strict hydropower production – even without valuation of biodiversity and cultural uses of the river system.

Recommendations

Reducing the economic risks of climate change in hydro-dependent systems must address current as well as planned infrastructure. The report recommends the following:

Assess hydropower in the context of comprehensive basin-wide planning: Planners need to carefully consider dams in the context of how climate change will shape water supply, and how future river flows must meet competing demands for power, conservation, and water for domestic use, agriculture, industry, and other services. Community- and ecosystem-based adaptation approaches that integrate the use of biodiversity and ecosystem services into an overall strategy aimed at empowering people to adapt to climate change must be central to any comprehensive planning efforts.

Incorporate climate change scenarios into dam design: The major implication of climate change for dams and reservoirs is that the future is uncertain, and can no longer be assumed to mirror the past. Until reliable data series are available for the design and operation of new hydropower dams, projects should be approached with extreme caution. Climatic uncertainty must be incorporated into dam design, to avoid the hazards of over- or under-designed infrastructure and financial risk.

Diversify the regional power pool to reduce hydropower dependency: Creating a diverse energy supply is critical for climate-change adaptation in water-stressed regions. The Southern African Power Pool (SAPP) provides an excellent framework for diversifying power production and reducing dependency on hydropower. In practice, however, SAPP has emphasized large-scale coal and hydropower development to feed the regional grid, without serious consideration of climate change impacts and risks. SAPP can play a key leadership role in adapting the regional power grid to the realities of climate variability and water scarcity through promotion of decentralized energy technologies, energy efficiency standards, demand-side management, and feed-in tariffs to support renewable technologies.

Improve existing hydropower capacity rather than investing in new infrastructure: Existing hydropower structures should be rehabilitated, refurbished, renovated, or upgraded prior to the construction of new hydropower facilities. Adding new or more efficient turbines is almost always much lower impact than building new dams.

Prioritize investments that increase climate resilience: Climate models warn about the impact of changing rainfall and runoff patterns on grain yields, water availability, and the survival of species. Yet large hydropower dams threaten to decrease, rather than enhance, climate resilience – especially for the rural poor – by prioritizing power generation over water supply, eliminating natural flood pulses which supports food production, and increasing evaporative water loss. Investments should aim to enhance climate resilience by helping poor and vulnerable communities prepare for, withstand, and recover from the negative effects of climate change.

Implement environmental flows for climate adaptation: Environmental flows are an important policy and management tool for restoring river systems. Environmental flows will be critical to help communities living downstream of dams to adapt to a changing climate, and should be incorporated into existing hydropower operations, as well as future dam design. Environmental flows have a vital role in maintaining and restoring key ecosystem services, especially for the Kafue Flats, Mana Pools, and the Zambezi Delta Wetlands of International Importance. Collaborative e-flow efforts among water authorities, dam operators, power companies, NGOs, and regional universities should be supported.

Ensure that monitoring and evaluation systems support adaptive management: These systems are essential to any strategy to adapt hydropower to climate change. They should help society understand clearly whether current water management practices are delivering on their promised outcomes, and enable decision-makers to apply any lessons learned to improve present and future management.

Rethink flood management strategies: Many hydropower projects are justified on the basis of providing flood control in addition to energy generation. However, allowing for flood storage means the reservoir must be drawn down to provide flood capture space at the very time that this water is most needed to supply energy. Alternative operating scenarios for existing dams and better approaches to flood management should be adopted, including the use of natural or enhanced floodplain storage in the river basin in conjunction with run-of-river operation of large hydropower dams.

Allocate hydropower revenues to compensate for dam impacts: The regulation of rivers for strict hydropower generation is associated with adverse impacts to river systems and the ecosystem services they provide. New financial mechanisms are needed to reallocate revenue from hydropower sales to directly compensate affected downstream water users for losses caused by dam operations to agriculture, grazing, and fisheries. At a basin level, hydropower revenue could be used to reduce pressures on river systems, including removal of exotic invasive species and negative impacts from land-use changes such as clear-cutting riparian forests, which directly threaten the viability of hydropower schemes.

Ensure best social and environmental practices: Dams in the Zambezi Basin are being planned under a variety of standards, with very little public input, and with very little if any attention to the broad social and environmental impacts that these projects may bring. Given the importance of well-functioning river systems to climate adaptation efforts in Africa, standards must be improved and become mandatory to minimize these risks and properly evaluate all alternatives.

Develop strong institutional capacity for water resources management: This may be the single most important factor in the successful adaptation of existing hydropower systems to cope with climate change, as many of the above recommendations would be impossible to implement with strengthened institutional capacity. Significant technical, financial, and social capacity is required across the spectrum of agencies dealing with water management. Those responsible for hydropower management at all levels must be trained in new modes of dam operation and equipped with models and tools for implementation.

The ecological goods and services provided by river basins, which are key to enabling societies to adapt to climate change, are under grave threat from climate change as well as existing and planned hydropower development schemes. Successful adaptation in a highly vulnerable region such as the Zambezi River Basin requires a major shift in thinking, planning and designing water investments for the future. Many major hydropower developers, utilities and lenders acknowledge these concerns, but continue to recommend large-scale investments in hydropower development, at the expense of alternative energy systems that would pose less of a climate risk, and be better suited to adaptation needs. An alternative pathway, focused on climate-smart investments that explicitly factor in financial risk and the ecological functions and the values of river systems, is urgently needed. It is hoped that this report will assist basin countries to make informed decisions on incorporating hydrologic variability and adaptation strategies into long-term planning and investment decisions for the Zambezi River Basin and beyond.