POLICY BRIEF

Hydropower in the Zambezi River basin at risk due to changing climate and increased irrigation

Key messages

- Kariba is highly vulnerable to potential future changes is climate, with a drying climate potentially reducing average electricity generation by 12%. The expansion of Kariba is unlikely to deliver the expected increases in production even under a relatively favourable climate.
- While Cahora Bassa's expansion is viable under a wetting climate, its potential is less likely to be realised under a drying climate. More importantly, prioritising irrigation demand in the upstream catchments could severely compromise hydropower output.
- The new Batoka Gorge hydropower plant may not be able to reach expected production levels under either a wetting or drying future climate.
- The new Mphanda Nkuwa run-of-river hydropower plant below Cahora Bassa can deliver the expected production levels under most climate and development scenarios, although production is affected by prioritising irrigation over hydropower.
- While climate change is the most important overall driver of hydropower potential, increased irrigation demand may also affect major Mozambique plants if it is prioritised over hydropower and urban demand.

The 'Climate Change and Upstream Development Impacts on New Hydropower Projects in the Zambezi' project is a research initiative designed to address the major uncertainties facing hydropower development in the region, and to deepen understanding among stakeholders of the risks to hydropower from changes in climate and increased upstream water demand. For 18 months, researchers from University of Cape Town, Centre for Energy Environment Engineering Zambia (CEEEZ), University of Zambia, OneWorld Sustainable Investments, University of Eduardo Mondlane, and Pöyry Management Consulting have been developing and applying a water supply and demand modelling tool for the Zambezi River Basin. The research was guided by a Steering Committee led by the Southern African Power Pool (SAPP) and including the Zambezi River Authority (ZRA), the Zambezi Watercourse Commission (ZAMCOM) Interim Secretariat, SADC Energy, UK Department of International Development (DfID) and Climate & Knowledge Development Network (CDKN). This model was applied to two climate futures, reflecting possible 'wetting' and 'drying' climates, and two futures for irrigation expansion in the region. The results of the analysis point to dramatic potential negative impacts on major existing and planned hydropower investments.

ERC ENERGY RESEARCH CENTRE University of Cape Town
THE UNIVERSITY OF ZAMBIA — SERVICE AND EXCELLENCE
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CEEEZ Centre for Energy, Environment and Engineering Zambia Limited

Introduction

Water is a key resource for development in Southern Africa. Beyond basic needs for human survival, increased agricultural yield from irrigation improves food security, and hydropower is critical to industrial development and trade in many countries. Many Southern African Development Community (SADC) countries (e.g. Mozambique, Zambia, Malawi, and Tanzania) are highly dependent on hydropower, and are already periodically under water stress during drought, even as water demand sectors continue to grow. Climate change affects both water supply and water demand. On the supply side, not only the change in average rainfall but also the seasonality of that rainfall affects water availability. Increasing temperatures increase evapotranspiration from plants as well as evaporation from reservoirs and wetlands. On the demand side, changes in rainfall patterns and increased temperatures can increase water demand from irrigation, as well as from industry and urban areas to a lesser extent. SADC has experienced numerous examples already of the negative economic impacts on both hydropower and irrigation from climatic variability.

The Southern African Power Pool (SAPP) generation expansion plans include more than 11,000 MW of new large scale hydropower up to 2018. The plans for these major investments (e.g. Mphanda Nkuwa and Batoka Gorge), however, do not include an assessment of long term climate change impacts (direct and indirect) on the technical and economic viability of these hydropower plants. Including climate change in the equation means taking into consideration how the upstream demand for water may increase because of climate change, particularly irrigation demands, not just how climate change may affect rainfall and reservoir evaporation. In addition, the impact of changes in hydropower on the overall energy economy, and the financial viability of the major transmission investments, can only be assessed by looking at upstream changes in the Zambezi River Basin.

A scenario approach

While future climate is subject to scientific uncertainty, the impact of irrigation is a policy uncertainty. This is because the level of irrigation investment is driven by political and economic priorities, but also because the priority given to irrigation demand versus hydropower demand for water is a political decision – and, in this case, an international political one as well, because of the different countries utilising the resources of the Zambezi. The first group of scenarios modelled therefore test the impact of different future climates and levels of irrigation development, assuming that hydropower is prioritised over irrigation. The 'wetting' and 'drying' climate futures are derived from two well-respected Global Circulation Models (GCMs) included in the WATCH climate dataset.1 Both climate futures include average temperature increases, meaning that reservoir evaporation and evapotranspiration from natural vegetation and agriculture will increase under both scenarios, reducing runoff.

Box 1. Scenarios used in the water supply and demand analysis

	Hydropower development	*Irrigation development*	*Future climate*
A	Historical	Historical	Dry
B	Historical	Historical	Wet
C	Business as Usual	Historical	Dry
D	Business as Usual	Historical	Wet
E	Business as Usual	Business as Usual	Dry
F	Business as Usual	Business as Usual	Wet
G	Business as Usual	BAU with highest demand priority	Dry
H	Business as Usual	BAU with highest demand priority	Wet
I	Optimistic	BAU with highest demand priority	Dry
J	Optimistic	BAU with highest demand priority	Wer

Medium- and long-term irrigation potential is based on the World Bank Zambezi Multi-Sectoral Investment Opportunity Analysis,[2] while hydropower development is based on estimates of commissioning dates of new plants from SAPP and individual utilities. The 'optimistic' development scenarios include more rapid commissioning of hydropower plants and new irrigated areas than under the 'business as usual' scenarios.[3] Additional scenarios then test the effect of prioritising irrigation over hydropower, while holding climate and absolute water demand levels constant. The purpose of exploring these alternatives was not to arrive at one 'right' answer, but to illustrate the implications of different decisions and possible futures.

Accessing the right data

To ensure that the water scenario analysis would be grounded in the best scientific and technical understanding, the study team worked extensively with stakeholders in the region when gathering data. All of the power utilities with existing or planned hydropower plants in the Zambezi River Basin were contacted, and most participated in review meetings and provided primary data. The ZRA was a critical source of information on the shared Zambian-Zimbabwe stretch of the Zambezi, and co-chaired the main review meeting, while the Mozambique National Directorate for Water provided detailed historical data for the Zambezi downstream in Mozambique. The historical and future estimated runoff inputs for each sub-basin came directly from the recently-completed Zambezi Decision Support System (ZDSS)4 hydrological model.

A user-friendly tool

The study team used the Stockholm Environment Institute's Water Evaluation And Planning (WEAP) simulation tool for the water balance analysis, and to test the effects of each scenario on existing and planned hydropower plants. WEAP providesd a user-friendly interface and scenario management capability with an intuitive graphic interface, which can be easily used not only for analysis and presenting results to stakeholders but also for training those stakeholders to do their own analysis. The model was calibrated against historical measured data at key points along the river (e.g. Victoria Falls) and at key reservoirs (e.g. lake levels at Kariba, discharges at Itehi-tezhi) and demonstrated a strong fit with both historical measurements. The analysis covered the major existing plants (i.e. Kariba, Cahora Bassa and Kafue Gorge Upper), extensions to existing plants (i.e. Kariba North and South bank, Cahora Bassa North Bank) and major new plants (i.e. Batoka Gorge, Itezhi-tezhi, Mphanda Nkuwa, Kafue Gorge Lower, and to a lesser extent Boroma and Lupata).

Key findings

Change in future climate is an overwhelming driver of future production at most hydropower plants. The difference in average generation in 2050-2070 versus 1960-1990 is 10 to 15% for all plants except Kafue Gorge Upper and Boroma (see Table 1 and Table 2). For Mphanda Nkuwa and Cahora Bassa, however, the impact of upstream irrigation exceeds the impact of alternative climates, particularly when irrigation demands are prioritised over hydropower demand.

An example of the impact of climate is Kariba, where average future generation under a drying climate is 12% below that under a wetting climate, before any changes in irrigation or new hydropower demand (see blue versus red lines in Figure 1). The reasons why Kariba production is not greater than historical production under a 'wetting' climate is that both climates include higher temperatures (which drive greater consumption by plants and reservoir evaporation losses) and that much of the additional precipitation underr the 'wetting' climate is downstream to Kariba.

More importantly, the expansion of the Kariba appears unlikely to reach the planned production levels. Even under a wetting climate, average generation in 2050-2070 is 10-15% lower than targeted production (i.e. historical production plus expected production from the extensions) (see green and purple lines versus the dashed orange target level in Figure 1).

Table 1: Summary results for existing hydropower plants

Scenario	*Kariba*	*Cahora Bassa*	*Kafue Upper*
2050-70 average generation / modelled historical			
A. Hydro hist, irrig hist, dry	88%	98%	106%
B. Hydro hist, irrig hist, wet	100%	107%	108%
2050-70 average generation / target*			
C. Hydro BAU, irrig hist, dry	76%	96%	107%
D. Hydro BAU, irrig hist, wet	90%	111%	109%
E. Hydro BAU, irrig BAU, dry	75%	92%	105%
F. Hydro BAU, irrig BAU, wet	88%	105%	107%
G. Hydro BAU, irrig BAU #1, dry	73%	76%	96%
H. Hydro BAU, irrig BAU #1, wet	85%	90%	104%

* Target is modelled historical generation plus expected generation from expansions at Kariba and Cahora Bassa.

Note: For scenario names, hist=historical, irrig=irrigation, BAU=business as usual, #1= irrigation prioritised

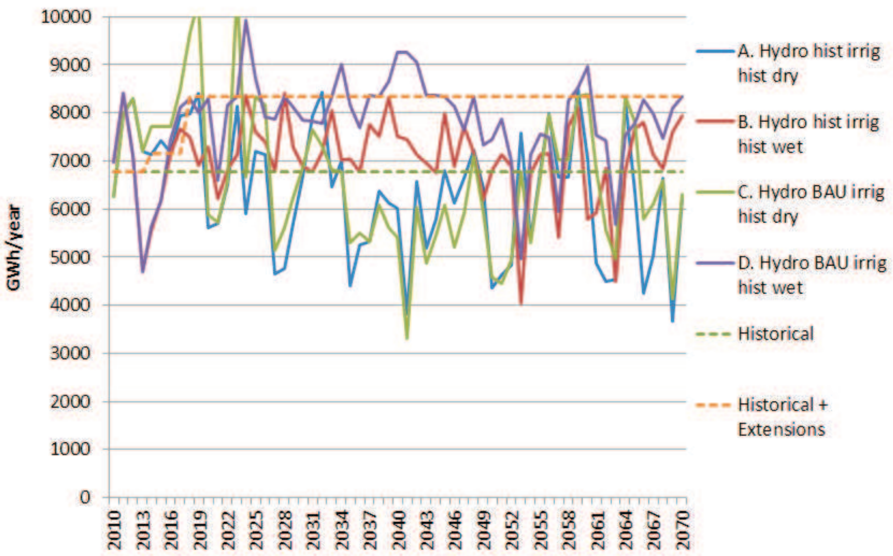

Figure 1. Future annual generation at Kariba

Cahora Bassa, on the other hand, could reach the target for the North Bank expansion under a wetting climate, but would often fall short under a drying climate (see purple and green lines versus dashed orange target line in Figure 2). Kafue Gorge Upper (not shown in figures) appears to be the exception in that future production levels could actually be higher than historical levels under both climates, which could be in part due to the increased regularity of Itezhi-tezhi releases once hydropower production commences in 2014.

Choosing the appropriate target for future generation for new plants is difficult, because feasibility studies are either under revision or incomplete in many cases. Compared to the values from the original feasibility study (which is currently being revised), however, Batoka Gorge is not able to meet the generation target under any of the scenarios (see Figure 3 and Table 2). Itezhi-tezhi, on the other hand, generates more than that stated target of 611 GWh/year in almost all scenarios and Kafue Gorge Lower generation levels are well above the targeted 2,400 GWh/year. Mphanda Nkuwa can also meet the stated targets under almost all scenarios except when irrigation is prioritised over hydropower in a drying climate (see Figure 4). For all new plants, the impact of different climate futures is still highly significant.

The impact of irrigation depends not just on the level of demand but, more importantly, on the prioritisation given to agricultural demand over hydropower production. For existing and new plants, including 'business as usual' irrigation growth only reduces average generation by up to 6%, with Cahora Bassa and Batoka Gorge under a wetting climate at the higher end of this range.

When irrigation is prioritised over hydropower, the impact on generation is significant across many plants. At Cahora Bassa, average generation drops 20% when irrigation is prioritised (see yellow versus green line

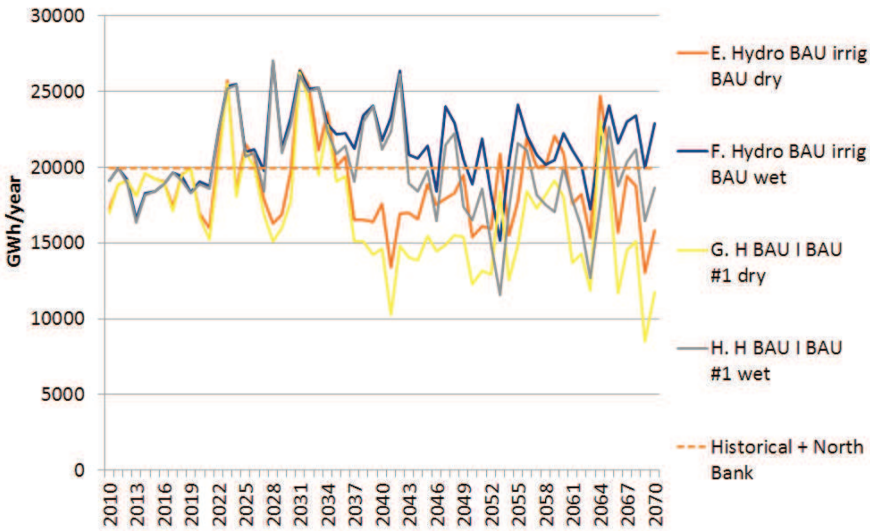

Figure 2: Future annual generation at Cahora Bassa

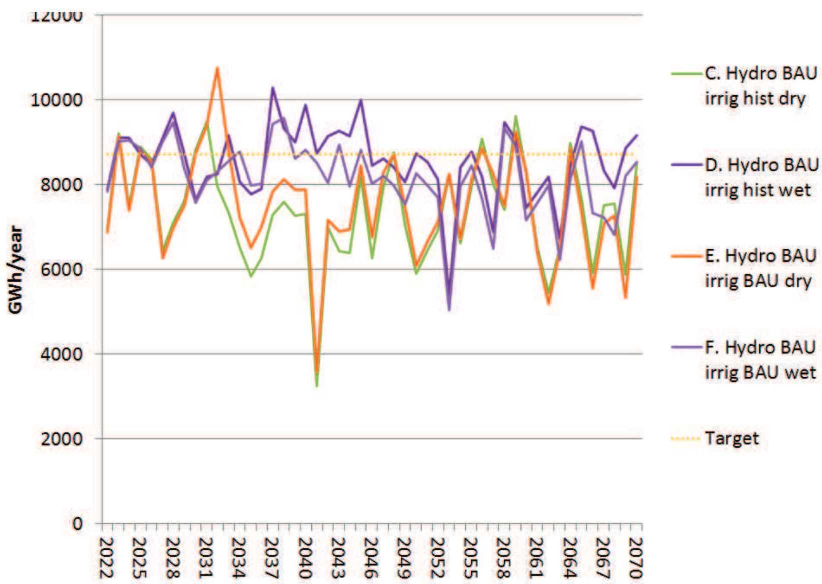

Figure 3: Future annual generation at Batoka Gorge

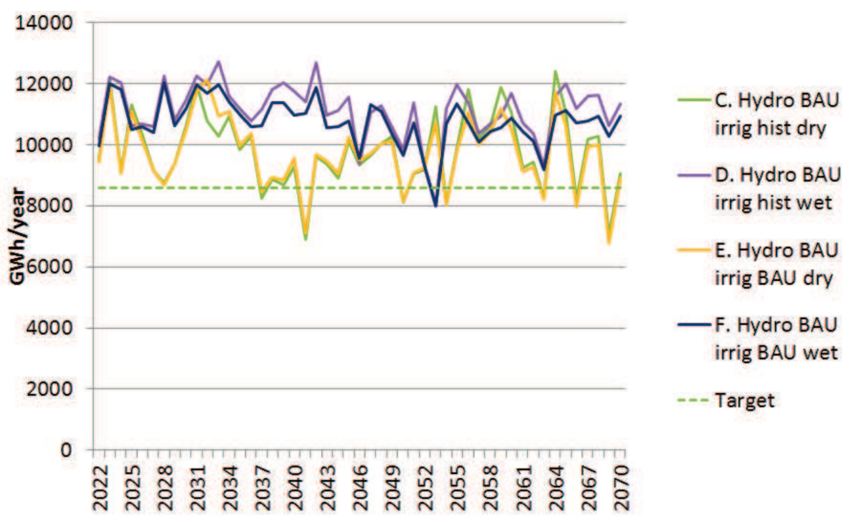

Figure 4. Future annual generation at Mphanda Nkuwa

and grey versus dark blue line in Figure 5). Mphanda Nkuwa loses 13–15% of average generation (see Table 2). This vulnerability at Mphanda Nkuwa reflects the fact that this plant is basically a run-of-river plant, with only a relatively small reservoir. Prioritising irrigation reduces average generation under a drying climate for Luptata, Kafue Gorge Upper and Kafue Gorge Lower by 17%, 11% and 11%, respectively. Lupata is not only a run-of-river plant, but is also downstream to one of the areas with largest irrigation potential – between Mphanda Nkuwa and the confluence with the Shire River. The impacts on Batoka Gorge and Itezhi-tezhi are very limited, given the small amount of irrigation upstream to these plants. Kariba also has a large enough reservoir to cope with the competing sectoral demands, so the prioritisation of irrigation does not result in significant additional losses of generation.

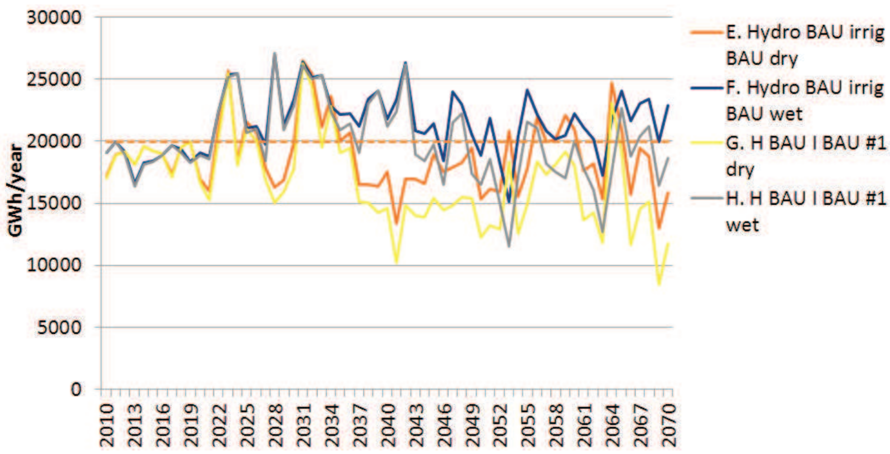

Figure 5: Future annual generation at Cahora Bassa under different irrigation priorities

Photograph by Randall Spalding-Fecher

Figure 6: Lake Kariba Dam

Conclusions

The relatively low consumption of water in the Zambezi River Basin in the past meant that explicit trade-offs across sectors and across countries, while important at a local level, posed less of a challenge for the basin overall. This is likely to change in the future, as increased demands from all sectors and major potential changes in climate will require more explicit agreements on how to best utilise a limited resource.

The dramatic potential impacts of climate change on hydropower potential in the Zambezi River Basin point to the need to explicitly consider climate change in both project planning and overall system expansion planning. This is even truer for future plants, where financial viability and loan repayments will depend on

Table 2: Summary results for new hydropower plants 2050-70 average generation (GWh)

Scenario	*Mphanda Nkuwa*	*Itezhi-tezhi*	*Batoka*	*Kafue Lower*	*Boroma*	*Lupata*
C. Hydro BAU irrig hist dry	9825	614	7387	3427	1403	4119
D. Hydro BAU irrig hist wet	10825	699	8251	3655	1420	4473
E. Hydro BAU irrig BAU dry	9564	613	7284	3366	1399	4019
F. Hydro BAU irrig BAU wet	10377	699	7725	3559	1419	4316
G. Hydro BAU irrig BAU #1 dry	8319	601	7032	3037	1283	3416
H. Hydro BAU irrig BAU #1 wet	9438	695	7637	3431	1385	3983
Target*	**8600**	**611**	**8728**	**2400**	**1168**	**4171**

* Target is from utilities or literature

Note: For scenario names, hist=historical, irrig=irrigation, BAU=business as usual, #1=irrigation prioritised.

the stability of generation and sales revenue. A key next step in this analysis should be to look at not just how climate and development affect individual plants, but how they affect entire national and regional energy systems. Although there is increasing cooperation in the basin, major decisions on investment and operations are not necessarily coordinated as effectively as possible, and this will be more complex with four or five major new plants in the basin in the coming 10 to 15 years. Linking the water modelling to an energy system model for the region would allow for more explicit modelling of the energy, water and economic trade-offs, and a deeper understanding of the real costs of a changing climate.


Photograph by Randall Spalding-Fecher

Figure 7: Discharge at Itezhi-tezhi dam

Acknowledgements

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Disclaimer

Notes

1. WATCH is the EU Integrated Project Water and Global Change (WATCH, 2007-2011), (www.eu-watch.org/) . The CNRM model represents a 'wetting' climate, because total average runoff in the Zambezi River Basin excluding the Shire/Lake Malawi sub-basin is 8% greater in 2071-2100 than in 1961-1990. The CNRM-CM3 global coupled system is the third version of the ocean-atmosphere model initially developed at CERFACS (Toulouse, France), then regularly updated at Center National Weather Research (CNRM, METEO-FRANCE, Toulouse) (www.cnrm.meteo.fr/scenario2004/references_eng.html). The ECHAM model represents a 'drying' climate, with a decrease in total average runoff of 6% in 2071-2100 versus 1961-1990. ECHAM is a comprehensive general circulation model of the atmosphere from the Max Plank Institute for Meteorology. www.mpimet.mpg.de/en/wissenschaft/ modelle/echam.html)
2. World Bank. 2010. The Zambezi River Basin: A Multi-Sector Investment Opportunities Analysis. Volume 4. Modeling, Analysis and Input Data. Washington, D. C.: World Bank
3. In most cases, the 'optimistic' commissioning date for a hydropower plant is 5-7 years earlier than the 'business as usual' date, and the current SAPP pool plan estimates are considered 'optimistic'. For irrigation, the 'business as usual' scenario included realizing all identified projects from the MSIOA study by 2030 and achieving the full 'high level potential' by 2060, while the 'optimistic' scenario reaches these two levels in 2020 and 2040, respectively.
4. The Zambezi Decision Support System (Zambezi DSS) of the National Institute of Disaster Management (INGC in Mozambique) (http://zdss.ingc.gov.mz/) is a web-based, interactive tool to analyse the impact of water resources development and climate change scenarios on future runoff in the Zambezi basin. The hydrological model has been peer reviewed is the most up-to-date source of historical and future runoff data for each sub-basin.