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Climate change and hydropower in the Southern African Power Pool and Zambezi River Basin: System-wide impacts and policy implications

Randall Spalding-Fecher[a,*], Brian Joyce[b], Harald Winkler[c]

[a] Carbon Limits, AS, Øvre Vollgate 6, N-0158 Oslo, Norway
[b] Stockholm Environment Institute-US Center, 11 Curtis Ave, Somerville, MA, USA
[c] Energy Research Centre, University of Cape Town, Rondebosch, Cape Town, South Africa

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ABSTRACT

This paper examines climate change impact on hydropower will affect the expansion of the regional electricity system, as well as system costs and greenhouse gas emissions. The output from major Zambezi hydropower plants could decline by 10–20% under a drying climate, while wetting of the basin produces only a marginal increase. At a regional level, the increases in electricity generation costs are relatively small (less than 1% over the long term), but could reach 20–30% in the near term for hydro-dependent countries (e.g. Mozambique and Zambia). Because some hydropower could be displaced by coal, regional greenhouse gas emissions could increase by the equivalent of a large coal-fired power station. The risks to regional electricity systems highlight the need for strong cooperative governance arrangements to manage shared water resources in the region, which could be bolstered by recent political initiatives. Beyond the level of individual investments, a policy shift is needed to integrate climate change and upstream development considerations into national and regional electricity planning, supported by relevant tools. In addition, the potential for increased carbon emissions has implications for the commitments of southern African countries under the Paris Agreement to the UNFCCC.

1. Introduction

1.1. Background

With the population of the Southern African Development Community (SADC) region expected to increase from around 260 million in 2012 to more than 500 million over the next 30 years, and as the SADC region industrializes on its path to improved human development, the demand for power will increase dramatically. The electricity sector is therefore central to catalysing infrastructure projects that drive both regional integration and economic growth, with energy security increasingly important to continued development across Southern Africa.

The hydropower resources of the Zambezi River Basin (ZRB) are central to the long-term growth prospects and security of the Southern African Power Pool (SAPP). While hydropower remains an important but under-represented contributor to the SAPP, the significant resources are located in the ZRB, with more than 40,000 MW in generation potential (Spalding-Fecher et al., 2017). Hydropower accounts for roughly 40% of the regional hydropower capacity, with twice that amount planned under further development (Miketa and Merven, 2013; Spalding-Fecher et al., 2014). Securing the hydropower resources of the ZRB is therefore critical to ensuring regional energy security and stability. Increasingly, climate-related risks have the potential to further undermine the contribution of hydropower resources to the regional power pool and limit economic growth prospects (see, e.g., Spalding-Fecher et al., 2014). In addition, while hydropower can be part of the low carbon development strategies for the region, loss of output due to drying climate could shift generation to fossil fuels, making it more difficult for the southern African countries to meet their climate change mitigation commitments under the Paris Agreement to the United Nations Framework Convention on Climate Change (UNFCCC).

While previous research has examined the impacts of climate change on specific existing and new hydropower plants (Beck and Bernauer, 2011; Cervigni et al., 2015; Harrison and Whittington, 2002; Spalding-Fecher et al., 2014; Tilmant et al., 2010), they have not been linked to any electricity supply and demand scenarios for the region. This critical step is necessary in order to assess how climate change impacts on ZRB hydropower plants would affect the national energy balances of key ZRB riparian states, as well as the overall electricity system performance and evolution in the region.[1] The objective of this paper is to combine the analysis of climate

* Corresponding author.
E-mail addresses: randall.spalding-fecher@gmail.com (R. Spalding-Fecher), brian.joyce@sei-us.org (B. Joyce), harald.winkler@uct.ac.za (H. Winkler).

[1] At present, 2015, Kariba Dam is perilously low as a result of dry weather and over-production of electricity, with the result that production is being cut back, significantly affecting the Zambian and Zimbabwean economies.

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change impacts on hydropower plants in the ZRB with modelling of electricity sector supply and demand in the SAPP, to understand how the hydropower impacts of climate change will affect the expansion of the regional electricity system, as well as costs and greenhouse gas (GHG) emissions. This includes not only assessing the impacts but also considering the policy implications of these impacts. The water modelling inputs build on the outputs from the World Bank project "Addressing the Climate Vulnerability of African Infrastructure" (Cervigni et al., 2015), while the electricity modelling is based on analysis conducted under the World Bank project "Climate Change Assessment of the Energy-Water Nexus in the Zambezi River Basin" (Spalding-Fecher et al., 2017).

The next section presents the methodology, including the relationship with the previous studies upon which analysis builds. Section 3 presents the data and assumptions used in the modelling, with particular attention to the updates and modifications to the previously published water supply and demand model. Section 4 presents the results of the integrated scenarios, from changes in generation by technology to impacts on system costs and GHG emissions. Finally, Section 5 discussed the policy implications of the modelling results.

2. Methodology

The overall methodology for creating integrated power and water scenarios includes several components, as illustrated in Fig. 1, with the focus of the current paper highlighted in blue. The starting point for the water and electricity analysis is a set of development and climate futures, which are used to create internally consistent scenarios. The development futures lay the foundation for understanding future electricity and water demand, as well as electricity supply from the SAPP. The climate futures drive the supply of water in the ZRB model. These inputs, along with other relevant data, are used to analyse water supply and demand for the ZRB and electricity supply and demand for the SAPP. In turn, the results from the water modelling are used to revise the electricity scenarios, so that the integrated scenarios incorporate the impact of climate change on water availability and hydropower. The data and methodology for the water and electricity modelling have been presented in other publications, so that only the updates to these datasets are presented in this paper. The focus of this paper is the integrated scenarios.

2.1. Development futures

Given the long time-frame (i.e. 2010–2070) of this analysis, and the scientific, economic and political uncertainties within the ZRB, and SADC more broadly, this research utilizes a scenario approach for developing alternative forecasts of future energy and water demands. Because the future is uncertain, we cannot rely on only one forecast from which to predict future energy and water demand. The range of socio-economic futures that drive electricity and water demand, as well as the availability of capital to invest in infrastructure, were explained in a paper on the electricity modelling (Spalding-Fecher et al., 2017), and are summarised below. The scenarios draw on the Shared Socio-economic Pathways developed by the Intergovernmental Panel on Climate Change (IPCC) (Dellink et al., 2015; Ebi et al., 2014; Jiang, 2014; Jiang and O'Neill, 2015) and the International Futures modelling system (International Futures, 2014). Key features of the scenario are as follows:

- "Business as Usual" (BAU) is a continuation of current and recent historical trends in the region without major policy changes or major changes in the external (global) environment. Technology development is slow, as is the rate of increase in energy efficiency. Trade within the region remains relatively limited. Electricity sector integration in the region improves only slowly, with continued delays in major investments, as has been the case in recent years. Population growth is higher than in other scenarios, because the lower rate of GDP per capita is generally associated with lower total fertility and therefore lower population growth. This future is analogous to the IPCC Share Socioeconomic Pathway SSP2 ("Middle of the Road" or "Current Trends Continue").
- "SADC Integration" describes a future where the region takes the initiative to move forward more rapidly on the development of shared resources – particularly in the energy sector – even without major changes in the external (global environment). The bottlenecks to major regional projects (including new power plants) are removed through stronger political cooperation and joint financing of major infrastructure investments that benefit many countries. Resource development outside of the energy sector is more rapid than in BAU, but still constrained. The GPD trajectory is derived from the International Future's model "Base Case", which, although the name implies moderate "baseline" growth, in fact forecasts relatively rapid economic development for the region within that scenario (International Futures, 2014).
- In contrast to the first two scenarios, which assume no major changes in global trends, "Grand Deal" is characterized by a significant global commitment to sustainable development, which further supports regional efforts at economic integration and shared development. Rapidly falling clean technology prices (for energy efficiency as well as renewable energy supply) and mobilization of climate finance lead to both greater investments in low-carbon development and more rapid growth in economic and human development in the SADC. The scenario includes the lowest population growth, highest economic growth, and most rapid investment. This scenario is analogous to the IPCC Shared Socioeconomic Pathway SSP1.

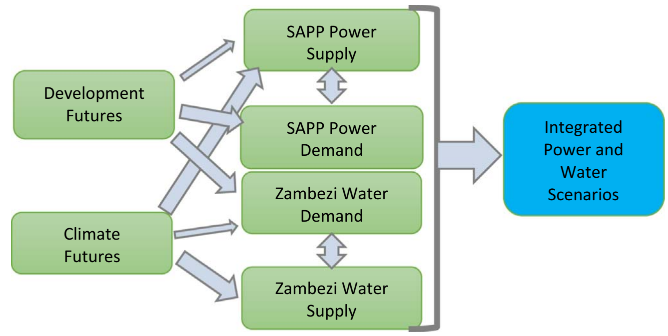

Fig. 1. Overview of methodology.

2.2. Climate futures

The climate futures were developed as part of the project, "Addressing the Climate Vulnerability of African Infrastructure", mentioned above, and published by Cervigni et al. (2015: Chapter 3). This project included analysis of data for the two most recent assessments of the IPCC: the Fourth (AR4) and Fifth (AR5) Assessments, published in 2007 and 2013 respectively. From AR44, 22 global circulation models (GCMs) were applied to three emissions scenarios, and the results were then downscaled to monthly time series on a 0.5 by 0.5 degree spatial resolution using bias-corrected spatial disaggregation (BCSD).[2] From AR5, 23 GCMs were applied to two emissions pathways, namely representative concentration pathway (RCP) 4.5 and RCP 8.5, corresponding respectively to medium and high emissions scenarios, and these were also processed using BCSD. An additional 22 climate futures (11 GCMs driven by the 4.5 and 8.5 RCP emissions pathways) were then produced with an alternative downscaling technique, the empirical-statistical downscaling methods developed by the

[2] The BCSD method is a development of pattern scaling, incorporating quantile mapping to account for GCM biases in rainfall intensity distributions. The strengths of this method are that the projections show strong agreement with GCM projected changes on a large scale, and that the method produces a de-biased future projected time-series, which greatly eases the application to impact modelling, particularly hydrology (Cervigni et al., 2015).

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