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Climate Change, Hydro-Dependency, and the African Dam Boom

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Summary. — We examine Africa's increasing reliance on hydropower in light of climate change-induced variations in rainfall and the potential power outages that may result. We use a continent wide riverflow model and IPPC climate change scenarios and show that current plans for African dam building are fairly well matched with river-flow predictions so that fears that international donors and national governments are making a series of expensive and environmentally damaging investments may be overstated. However, predictions of an increase in extreme events and reduced rainfall for certain countries mean there are still viability concerns for certain planned hydropower investments.

Key words — hydropower, climate change, Africa, energy

1. INTRODUCTION

In recent years the African economy has enjoyed a period of rapid expansion with real GDP growth rates in Sub-Saharan Africa averaging 5.5% per year during 2003–13 (IMF, 2013). Despite this recent success it is estimated that 69.5% of the population of Sub-Saharan Africa (585 million people) does not have access to electricity (IEA, 2011). A common perception is that this lack of access together with the inefficient and unreliable nature of Africa's power sector has impeded past economic growth and will act as a brake on future growth (Foster & Steinbuks, 2009; IEA, 2011; Khennas, 2012). [1]

One proposed solution to the energy problem in Africa is to significantly increase investment in hydropower which, it is argued, can provide clean, reliable, and affordable energy (IEA, 2012a). As a result, numerous large dams are being built or are under consideration with significant support from international donors. [2] One implication of this renewed interest in hydropower plant construction is an increase in Africa's already relatively high dependence on hydropower (World Bank, 2012). This is a concern because of the close relationship between hydropower generation and climate change-induced weather variability. If changing rainfall patterns lead to reduced river flow then the price of energy may increase and power outages may occur resulting in significant costs to the African economy. [3]

The focus of this paper is on this potential impact of climate change on hydropower production. In reality the impact of climate change on hydropower is only one of many potential risks associated with hydropower investment in Africa with others including political instability, civil conflict, or changes in energy prices. Nevertheless, the impact of climate change on hydropower has received little attention within the academic literature and it is also unclear to what extent climate change-induced variations in rainfall and temperature are incorporated into the decision-making process during the planning stages of dams. Both Pottinger (2009) and Iimi (2007) claim that climate change impacts are rarely explicitly considered when planning hydropower projects. It would appear that the siting of dams is often a process dominated by political and fiscal considerations, lobbying, corruption, and compromise. As the Economist (May 6th, 2010) points out, when planning dams "*the standards set in 2000 by the World Commission on Dams…are often ignored in Africa. Projects are rushed. Huge contracts are open to corruption. Engineering can be shoddy…*". In this context it seems possible that future changes to the African climate may not have been fully taken into account when locating current and planned African dams and hence it is reasonable to examine how such changes will affect hydropower production.

The contribution of this paper is threefold. First, we construct an extensive spatial dataset for Africa from geographically based information on daily precipitation, soil conditions, power plants, and energy network grids dividing Africa into 7,131 6-digit hydrological basins. Second, we employ econometric techniques and two alternative climate change scenarios to examine historic and predicted patterns of hydropower production. The results from our econometric analysis provide us with a set of quantitative estimates of the impact of weather-induced hydropower production disruptions. Using hydrological river flow modeling for the whole of Africa we are then able to identify shocks to hydrological production due to weather (rainfall and temperature) and the spatial extent of these shocks. Since it is unclear to what extent climate change-induced variation in rainfall is incorporated into the planning stages of dams, we use these results in conjunction with spatial level climate prediction data for Africa generated from our climatic models. This allows us to assess how well matched the current plans for dam building appear to be with predictions of river flow over time under two different climate change scenarios, one under large and one under small warming of the African continent.

The potential impact of climate change on hydropower production has been acknowledged by the IEA (2012b) who point

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out that although the *global* impact of climate change on hydropower is uncertain as a result of regional changes potentially canceling each other out, the impact on "*a river basin or a region could…be quite substantial*" (IEA, 2012b, p. 37). Similarly IEA-ETSAP (2010) point out that "*future hydropower production could be affected by climate change. The potential impact is not yet well understood and must be investigated in more detail.*" (IEA-ETSAP, 2010, p. 1). The World Bank also recognizes the risks associated with hydro-dependency in a changing climate. The World Bank (2013) points out the need to diversify the energy mix to ensure that energy supplies are sustainable given that "*an overreliance on hydropower energy makes the economies vulnerable to hydrological conditions*" (World Bank, 2013, p. 80) while the World Bank (2011) stresses that adapting to climate change will require an energy infrastructure that is more resilient to climate risks. Iimi (2007), in a World Bank Policy Research Paper, also points out that hydropower is one of the most vulnerable sectors to a changing global and regional climate. The World Bank's proposal is to build more dams linked to electricity grids across basins which should reduce regional energy risks. The aim of this proposal is to offset the future risk to Africa from a more volatile climate. The Worldwatch Institute (2010) however sounds a note of caution stating that "*New African dams are being built with no examination of how climate change will affect them, even though many existing dams are already plagued by drought-caused power shortages.*" [4] In a similar vein Beilfus (2012) calls for a halt to the recent growth in African dam construction due to the potential impact of climate change on future hydropower production.

Previous research into this important question has been made more difficult by the fact that predicting inter-annual, inter-decadal, and multi-decadal variations in climate is a major challenge to researchers. Furthermore, climate models provide predictions for a much larger geographical scale than the locations of dams and their watersheds and hence climate change effects will be subject to significant local variation. The climate of Africa as a whole is extremely varied and encompasses humid equatorial, seasonally-arid, and tropical and sub-tropical Mediterranean climates. Widespread extreme temperatures and heavy precipitation events are said to have increased with arid and semi-arid areas in northern, western, eastern, and some of Southern Africa are becoming steadily drier (Conway, Persechino, Ardoin-Bardin, Hamandawana, Dieulin, & Mahe, 2009; Goulden, Conway, & Persechino, 2009; IPCC, 2007). Several studies have examined the link between climate and hydropower in an African context. Yamba, Walimwipi, Jain, Cuamba, and Mzezewa (2011) predict a gradual reduction in hydropower generation over the next 60 years for the Zambezi River Basin although a large variability is expected. Beyene, Lettenmaier, and Kabat (2010) look similarly at the Nile River Basin and predict increasing precipitation and temperature with an overall positive effect on production from the Aswan Dam although this becomes an overall negative effect toward the end of the century. Finally, Harrison and Whittington (2002) study the Batoka Gorge hydro project and predict that a 35% fall in the flow of water over the Victoria Falls would cut annual power production by 21% and dry season production by 32%. Such a fall they argue would make the Batoka Gorge uneconomic (an internal rate of return of less than 10%).

Returning to our own analysis, our main finding is that current plans for African dam building appear to be reasonably well matched with predictions under scenarios of both high and low warming of the continent. Thus, although climate change is likely to impact river flow in Africa, the current planned dam locations mean that production estimates may be met contrary to the scenarios predicted by commentators such as Beilfuss (2012) and Worldwatch Institute (2010). However, the predicted performance of planned dams is not as good as that for existing plants. Moreover, certain countries are predicted to experience significantly lower river flow and an increase in weather variability which calls into question some planned dam investment.

The rest of this paper is organized as follows. Section 2 reviews the literature on the economics of hydropower and the role of hydropower in Africa respectively. Section 3 describes the research design and methods concentrating on the river flow modeling and climate change scenarios for Africa and our econometrics methodology. Section 4 presents the results and Section 5 concludes.

2. HYDROPOWER AND CLIMATE CHANGE IN AFRICA

To understand the renewed appetite for hydropower investment in Africa it is useful to provide an outline of the arguments in favor of hydropower compared to other sources of energy. First, hydropower is fairly reliable and not subject to international price fluctuations that can affect oil and gas markets. It can also deliver base-load power to meet peak demand or be used as a storage system that is quick-start meaning that it can help with fluctuations in supply or demand. Second, dams are used to store, use, and divert water for consumption, irrigation, cooling, transportation, construction, mills, power, and recreation. Third, from a cost perspective hydropower is generally considered to be competitive with other electricity sources, particularly so in the case of large hydropower plants (IEA, 2012a). [5] Finally, as a renewable resource, hydropower could play a dual role in a world of an uncertain future climate as a result of the clean nature of the energy produced and also because hydropower can be used as an adaptation strategy, by storing water, in the face of growing weather variability. For these reasons the hydropower sector is expected to "*play a strong, multidimensional role in sustainable development and poverty alleviation*" (World Bank, 2009).

Hydropower is currently the globally dominant source of renewable energy producing over 16% of global electricity production in 2011 (IEA, 2013). During 1973–2011 global hydropower generation increased by 175% (IEA, 2013) and the IEA's 2012 Hydropower Technology Roadmap sees global hydropower capacity more than doubling from 2011 levels by 2050 (IEA, 2012a). The majority of future hydropower expansion is predicted to occur in Africa, Latin America, and Asia (IEA, 2012a,b). In 2011, Sub-Saharan Africa possessed 13 GW of installed hydropower capacity and generated 20% of its electricity from hydropower (World Energy Council, 2013). However, many Sub-Saharan African countries are highly dependent on hydropower with some such as Angola, Cameroon, and Sudan generating over 70% of their electricity through hydropower while the extreme cases of Mozambique, the Democratic Republic of Congo, and Zambia produce more than 99% of their electricity through hydropower (World Bank, 2013).

The IEA (2013) reports that installed hydropower capacity in Africa produced 102 TWh/yr in 2009 although the continent has a technical potential output of 1,174 TWh/yr (IEA, 2013). This represents an undeveloped capacity of 91% and an exploitation rate of 9% compared to a global average exploitation rate of 25% (IEA, 2013). Estimates from the World Bank suggest that if Africa made appropriate