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Hydropower capacity expansion in the African continent under different socio-economic and climate policy scenarios

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Hydropower and other renewable energy sources are experiencing new investments for capacity expansion to provide clean and accessible energy to a growing population in many world areas. As most of the untapped hydropower potential lies in developing countries, here, strategic dam planning is critical in supporting the design of capacity expansion with reduced impact on interconnected water, food, and climate systems.

This is true especially for Africa, where more than 300 new hydropower projects are under consideration, and future population growth projections and associated energy, water, and food demands are highly uncertain.

In this work, we investigate how to strategically plan hydropower capacity expansion at the African continental scale, providing an estimate of future hydropower capacity needs. Specifically, we model the energy system using The Electricity Base Model for Africa (TEMBA), based on the OSeMOSYS energy modelling framework, and we consider capacity factors for each hydropower project reported in the African Hydropower Atlas as derived from the hydrologic simulation of the SWAT model that accounts for irrigation demand. To explore different socio-economic and climate policy projections, we also downscale final energy demands projections at the country level from the SSP database. We then investigate two different planning approaches: first, using scenario analysis, we examine how the different individual projections influence hydropower and power system development; second, we adopt a two-stage robust optimization methodology to develop a robust capacity expansion plan common for all the socio-economic and climate policy scenarios until 2035. Finally, we hypothesize that uncertainty about the socio-economic scenario is resolved, and we model the adaptation of the capacity expansion strategy to each of the narratives considered in the period 2035-2050 by solving a new optimization problem.

Our results show that not all the 100 GW of hydropower projects considered in the African Hydropower Atlas are needed to satisfy the final energy demands. Furthermore, as we observe large variability in hydropower capacity expansion under different socio-economic projections, we produce a short-term robust plan extracting the most relevant hydroelectric projects via robust optimization. Finally, we show that adapting capacity planning decisions based on new information can strongly reduce the price of robustness.

Our work proposes a methodology for taking planning decisions in an integrated assessment context where scenarios are used to link different societal sectors and resources. When the uncertainty spanned by plausible future states of the world is large and diverging, a combination of robust optimization and adaptive planning can reduce the potential for bad societal outcomes.