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Integrating hydrological constraints for hydropower in energy models: the case of the Zambesi River Basin in the Southern African Power Pool

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Ensuring reliable supplies of energy and water are two important Sustainable Development Goals, particularly for Sub-Saharan African countries. The energy and water challenges are however not independent, and the interlinkages between them are increasingly recognized and studied using water-energy nexus approaches. Yet, most of existing modeling tools are not accurately reproducing this nexus and thus provide limited support to the design of sustainable development plans.

In this work, we contribute an integrated modeling approach by embedding the hydrological description of the Zambesi River Basin into an energy model of the Southern African Power Pool (SAPP). The SAPP is the largest African power pool in terms of installed capacity and coordinates the planning and operation of the electric power system among the twelve member countries (Angola, Botswana, DRC, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Tanzania, Zambia, Zimbabwe). Specifically, we use the Calliope energy model, which allows to form internally coherent scenarios of how energy is extracted, converted, transported and used, setting arbitrary spatial and temporal resolution and time series input data. As in many state-of-the-art energy models, hydropower production is poorly described by neglecting the water availability constraints and assuming hydropower plant produce at their nominal capacity in each timestep. Exploiting Calliope existing modeling components, we improved the hydrological description of the main reservoirs in the Zambezi River Basin as part of the overall SAPP model, namely Ithezithezi (120 MW), Kafue Gorge (990 MW), Kariba (1.8 GW) and Cahora Bassa (2 GW). Our improvements include the most relevant hydrological constraints, such as time-varying water availability as determined by inflow patterns, time-varying hydraulic head, evaporation losses, cascade releases and minimum and maximum storage value. The model outcomes, such as the storage timeseries of each reservoir and the power production by source of each country, are then evaluated for different hydrologic scenarios. Our results are expected to demonstrate the value of advancing the hydropower characterization in energy models by capturing reservoir dynamics and water resource availability. These improvements will be particularly valuable to support hydropower expansion in African countries that rely mostly on hydropower to satisfy their growing energy demand.