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Integrated water-energy system modelling for optimal hydropower production planning under changing climate in the Zambezi River

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Most of Sub-Saharan Africa countries rely on hydropower to satisfy energy demand, and, as a consequence, their energy security is highly dependent upon water availability and spatiotemporal variability. Conversely, water and food security might be negatively affected by the development of large hydropower schemes potentially altering existing flow patterns. Projected changes in the hydrological cycle, driven by climate change, and population growth are triggering investment for expanding water storages and power generation capacity on major African rivers (Nile, Congo, Zambezi). In this context, novel modelling tools are required to support robust and reliable planning of new infrastructure accounting for the tight interconnection between water and energy, and the uncertainty stemming from the future co-evolution of these two domains. Focusing on the Zambezi River, this work contributes an expanded version of the well-known open energy system OSeMOSYS modelling framework including the main components of the hydrological cycle and their dynamics.

In the original OSeMOSYS setting, hydropower plants are represented as utilities characterized by a specific nameplate capacity reduced by a capacity factor, i.e. a proxy variable reproducing the temporal variability and availability of water in the real hydrological system to which the amount of energy that can be produced via hydropower is constrained. Within this framework, the energy produced by the hydropower plants is the control variable to optimize. In the innovative version of the model here proposed, the river and its tributaries are explicitly modelled as a network that flows into the hydropower reservoirs, hydraulically linking all the storage units, and more accurately accounting for all physical and operational constraints.

This modified OSeMOSYS model, calibrated over the last 20 years of hydrological and energy data, is used to explore alternative hydropower dam portfolios in the Zambezi river under different inflow distribution and population growth (i.e. energy demand) scenarios. Numerical results show that the explicit modelling of the system's hydrology in the modified OSeMOSYS reduces the error in predicting hydropower production w.r.t. the original version of the model when compared to historical data. Moreover, the explicit description of the hydrological system allows to assess the impact on hydropower production due to socio-economic and climate change, running simulations of the historical system configuration with future inflows. The optimal future expansion of the hydropower sector is then determined through optimization, providing useful insights for policy makers and stakeholders.