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Robust Infrastructure Sequencing and Management for Growing Food Energy and Water Demands in the Zambezi River Basin

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Fast population growth and economic development in several African countries is driving large infrastructure investments for growing energy, food and water demands which will likely strain existing ecosystem services. To minimize negative impacts and guarantee long-term success and sustainability of these investments, careful management and temporal planning of existing and new infrastructure is required. Our study focuses on the Zambezi River Basin (ZRB), a transboundary system supporting key economic growth and poverty reduction across its multiple riparian countries, while sustaining essential ecosystem services. The ZRB currently encompasses five hydropower dams, with three additional dams planned. The goal of this study is to generate efficient pathways that allow the temporal sequencing of planned dam projects along with robust management strategies that balance food, energy and environmental demands. A participatory approach is adopted at an early stage by running a Negotiation Simulation Lab (NSL) to elicit stakeholders' preferences and concerns supporting both model development and formulation of the optimization problem. Specifically, the pathway design is structured in three stages: first, optimal control policies are generated using Evolutionary Multi-objective Direct Policy Search for all possible combinations of dams projects; the time of construction is subsequently optimized, including the update of the system operation when a new dam is built, by balancing the benefits and the costs of additional infrastructure investments which are activated by projections of population growth triggering higher water and energy demands, finally promising policies are tested under a broad set of irrigation demand and streamflow scenarios. Our analysis shows that the rising demands cause all the planned dams to be built within the planning horizon from 2020-2060. The study also indicates that the operational preferences are key since they dictate the system's performance across multiple objectives and this behavior prevails under a larger suite of plausible future scenarios. Overall, our study provides a novel approach that integrates infrastructure investment planning that can be coupled with cooperative operations to meet growing regional demands while involving stakeholders in crucial stages of the decision making process.