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Optimal Infrastructure Sequencing and Management in the Zambezi River Basin

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Unprecedented population growth and fast economic development in several African countries is driving large infrastructure investments for growing energy, food and water demands. Massive infrastructure expansion required to support rising energy demands and extensive irrigation projects could stress the natural resources leading to social an geopolitical tension. In order to guarantee long-term success and sustainability and to minimize potential negative impacts of these investments, a carefully crafted temporal planning and management of existing and growing infrastructure is required. The challenges of long-term planning under uncertainty have been tackled in the literature through the use of dynamic adaptive pathways which provide a valuable scheme to include time and feedbacks for adaptive policy design. Additionally, a suite of robustness frameworks are now ubiquitous in the water resources field to better deal with planning and management under uncertainty gearing towards exploratory analysis to discover the combination of states that can cause water systems to fail rather than attempting to predict future behavior. We advance these concepts through an integrated approach for optimal time sequencing of infrastructure expansion and its corresponding management strategies. This approach is demonstrated in the Zambezi River Basin, this transboundary basin is key for economic growth and poverty reduction in the region sustaining the basic needs of nearly 30 million people. It provides important environmental services essential to regional food security and energy production. The Zambezi system currently encompasses four hydropower dams and plans to extend its capacity by adding four additional reservoirs. The goal of this study is to generate efficient pathways that allow the temporal and spatial sequence of planning and management alternatives. This refers to the optimization of expansion of hydropower dams and irrigation districts and its corresponding management strategy. For each candidate pathway, an optimal control policy is generated using Evolutionary Multi-objective Direct Policy Search (EMODPS), in which the operation policies are optimized with respect to their performance in meeting energy and irrigation demands as well as environmental requirements. Additionally, the pathways are optimized by balancing the benefits and costs of the additional infrastructure investments which are activated by future projections of growing population rates which are assumed to drive larger water demands. Since rising demands are projected, infrastructure elements will inevitably be added with time. Once the timing pattern is identified, a new selection of optimal operations based on the new system configuration is selected to maximize its benefit. A final step is to test the robustness of the optimal planning/management sequence against a suite of climate scenarios to determine their suitability under potentially pressing future states of the world. This study intends to provide guidance to crucial infrastructure investment planning in developing countries coupled with their optimal management to better absorb expensive infrastructure expansions while meeting growing regional demands.