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Do we understand performance dependencies, trade-offs, and robustness in dam design and operation?

Federica Bertoni (1), Andrea Castelletti (1,2), Matteo Giuliani (1), and Patrick M. Reed (3)

(1) Department of Electronics, Information, and Bioengineering, Politecnico di Milano, Milan, Italy (name.surname@polimi.it), (2) Institute of Environmental Engineering, ETH, Zurich, Switzerland, (3) Department of Civil and Environmental Engineering, Cornell University, Ithaca, NY, USA

Globally, many countries are actively seeking to maximize the hydropower potential of major river basins, yielding proposals for constructing approximately 3,700 major dams in the near future. At present, cost-benefit analyses are the dominant approach for evaluating candidate dam designs, where the typical problem framing has the following features: (i) a single objective, in which potentially conflicting and heterogeneous objectives are monetized and aggregated into a single Net Present Value (NPV) or Levelized Cost of Energy (LCE) metric; (ii) dam sizing using a pre-defined operating rule; and (iii) a limited accounting for potentially non-stationary external uncertainties. These features in standard cost-benefit analyses strongly bias dam design methods as they fail to explore the interdependent nature of reservoir sizing and operations. In particular, by neglecting a careful consideration of alternative reservoir operating schemes, standard design frameworks are likely to result in over-sized, underperforming dams. Moreover, deeply uncertain changes in hydro-climatic variability and human demands motivate the need for highly flexible assessment frameworks that capture the key tradeoffs between users, how dependencies in dam sizing and operations influence these tradeoffs, and the ultimate robustness of the infrastructure systems.

In this work, we combine MORDM (Multi-Objective Robust Decision Making) and EMODPS (Evolutionary Multi-Objective Direct Policy Search) with the specific focus on advancing coupled dam sizing (i.e. discrete reservoir volumes) and operation design (i.e. continuous release policy parameters) problems. We demonstrate the potential of this integrated, highly flexible assessment framework through an ex post analysis of the Kariba dam in the Zambezi river basin. The Kariba dam was built in 1960 and has struggled to follow its specified operational rule curve that originally claimed to maximize hydropower production, independent of irrigation users' demands. Our results show that careful exploration of the coupling of dam sizing and operations yields designs that strongly outperforms the performance achieved under current Kariba system. Moreover, we demonstrate that our integrated sizing and operations framework leads to a significant reduction in capital cost requirements (i.e. smaller reservoir sizes) while simultaneously improving system robustness with respect to changing hydro-climatology and human irrigation demands.