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Advancing Small Hydropower Design: A Novel Framework for Robust and Sustainable Solutions

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Small hydropower plants (SHPs) present an eco-friendly and economically viable alternative to conventional dam-based plants. With only 36% of their worldwide capacity currently tapped, there is potential for substantial global expansion including in industrialised nations. Most SHPs follow run-of-the-river (RoR) scheme, depending on the fluctuating flow of rivers because of their negligible storage capacity. They are deployed in a world characterised by a changing hydro-climate and unpredictable socio-economic evolutions. Due to their inability to regulate discharge fluctuations as well as their dependency on selling energy at higher rates, these plants are significantly vulnerable to these changes. Design alternatives are generated through traditional approaches relying on cost-benefit analysis that use past hydroclimatic conditions and disregard operational considerations, without assessing investment robustness in the face of changes. What is more, optimization and robustness analysis of these systems typically require a significant amount of computing time and resources necessitating high performance computing.

We introduce a new framework for robust hydropower system design to address these issues. This framework uses and extends HYPER, a state-of-the-art toolbox that computes technical performance, energy production, maintenance and operational costs of a design. It combines HYPER with many-objective robust decision making (MORDM) to define robust alternatives. Our implementation involves a systematic four-step process: (1) Introducing a two-objective formulation to identify design parameters balancing cost and revenue. (2) Creating alternative futures by sampling deeply uncertain factors, encompassing socio-economic (electricity prices, interest rate, cost overrun) and hydroclimatic factors (median, coefficient of variation, the 1st percentile of flows). These streamflow statistics are then transformed into flow duration curves using an innovative approach. (3) Robustness quantification of alternative designs using two newly introduced financial robustness metrics based on the probability of making the plant financially viable. (4) Identify the most critical parameters influencing robustness through sensitivity analysis and scenario discovery. We then employ a computationally efficient approximation approach to streamline resource-intensive steps in optimisation and robustness analysis.

Results indicate that employing the MORDM approach in the design of RoR hydropower plants offers valuable insights into the trade-offs between cost and revenue, while supporting design with a range of viable alternatives aiding in the determination of the most robust and reliable

design. Maximising the benefit cost ratio yields more robust and financially viable solutions than maximising NPV, as it leads to less costly designs that generate slightly less revenue on average but tend to better exploit low flows. Traditional design approaches employing identical turbine configurations and focusing on NPV maximisation, have proven to be less effective when compared to designs incorporating non-identical turbines. Moreover, such designs have demonstrated greater vulnerability to climate change, primarily attributable to their less flexible configuration.

Combined optimization and robustness analysis of a RoR design, initially taking 120 hours, is also made computationally inexpensive through a novel method involving strategic data input reduction. This innovation resulted in a significant 95% reduction in processing time, while maintaining nearly identical outcomes in both steps. An open-source Python version of this methodology is scheduled to be available by July 2024.