Sustainable hydropower systems

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Re-operating dams in the Mekong

Yadu Pokhrel and Amar Deep Tiwari

Hydrological alterations caused by booming hydropower dams in the Mekong River basin are disrupting aquatic ecosystems and local livelihoods, calling for an urgent rethinking of hydropower development. Alternative operating strategies of existing Mekong dams could help restore the natural hydrological regimes without affecting power generation.

Hydropower development has altered the natural hydrological regimes of many global regions. The Mekong River basin (MRB), one of the world's largest and most biodiverse river basins, is among such regions undergoing rapid hydropower development that has directly impacted natural hydrological dynamics, riverine ecosystems and local livelihoods. More than 100 hydropower dams have recently been constructed across the MRB, dramatically increasing reservoir storage capacity from ~5 to ~70 cubic kilometres[1] (Fig. 1). Observational[2] and modelling[3] studies have demonstrated that the existing dams have caused substantial impacts on the seasonal patterns of Mekong River flow and the associated flood pulse — an important ecological phenomenon involving a strong seasonal flow pattern that drives periodic inundation and the exchange of water and nutrients between rivers and surrounding floodplains. Dam impacts have extended beyond the mainstream Mekong, also altering the unique flow reversal and inundation dynamics of the Tonlé Sap Lake in Cambodia. As dam building continues, there are fears that the existing and future dams may cause irreversible changes to the basin's hydrology[4], directly impacting agricultural production, fishery yield, wetland extents and sediment delivery to the delta, among others. Writing in *Nature Sustainability*, Galelli et al.[5] suggest that re-operating existing dams could help partially restore the natural seasonal hydrological variability — without affecting hydropower production — and support ecosystem services.

The research specifically discusses alternative dam management strategies in the MRB with related limits and opportunities. A viable strategy the authors propose is to consider dam re-operation in the lower MRB (excluding China); in this area, the existence of institutional support (for example, the Mekong River Commission) and a history of power purchase agreements could facilitate the implementation of re-operation strategies. Moreover, such a strategy would not undermine hydropower generation; for instance, some strategies could partially restore natural flows while increasing hydropower revenue in Laos by almost US$150 million per year, which amounts to one-third of the country's hydropower revenues.

Expansion of hydropower to help increase renewable energy generation must consider safeguarding of both ecosystems and livelihoods. Dams certainly have many societal benefits. In addition to generating power, dams can protect downstream areas from flooding, provide water for drinking, industrial and irrigation purposes, and create opportunities for navigation and recreation. The energy

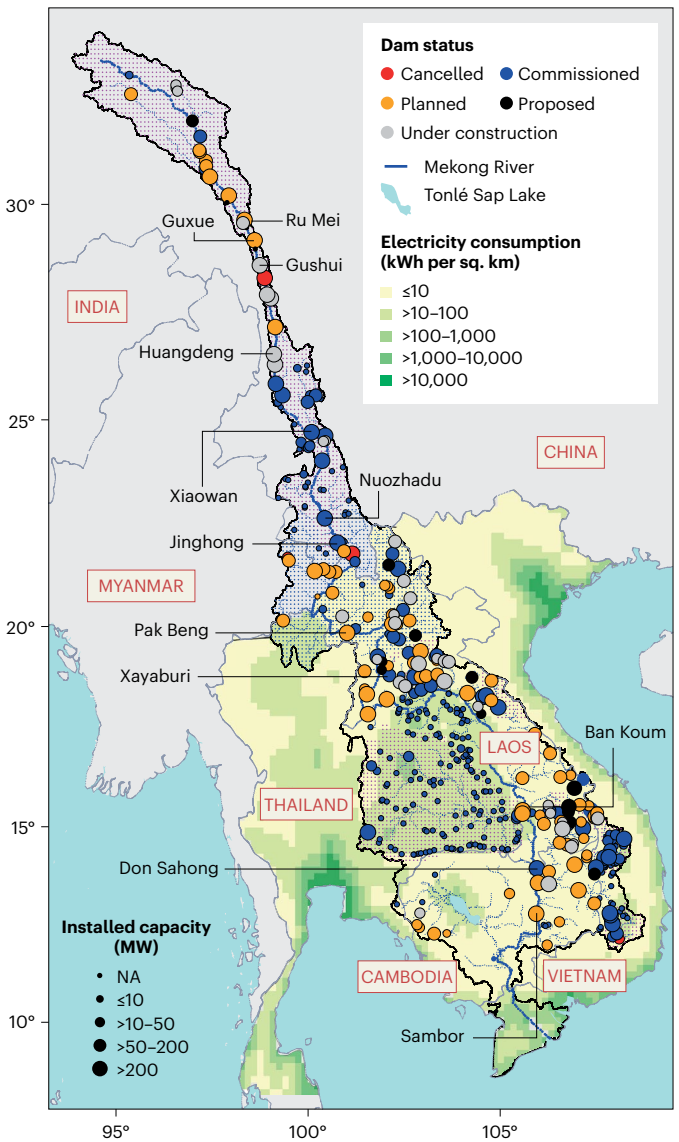

Fig. 1 | Dams and electricity consumption in the Mekong River basin. The background image shows electricity usage for the year 2015 (data from ref. [11]) for Lower Mekong countries: Thailand, Cambodia, Laos and Vietnam. The blue hatches show areas obstructed by the Xayaburi dam while the magenta hatches show areas obstructed by other dams (data from ref. [12]). Selected large dams — commissioned, under construction or planned — are labelled. The dam data — taken from ref. [4] — are based on the database of the Research Program on Water, Land and Ecosystems (WLE), Greater Mekong. Dam status is colour-coded whereas the installed capacity (megawatts) is marked by circle size. The basemap data are from ESRI. NA, data not available.

benefits are particularly attractive to the least developed countries in the Mekong region such as Laos, and especially in light of rapidly growing energy demands and the need for revenue generation. However, the benefits often come with high environmental costs and far-reaching implications on ecosystems and societies. Dams generally alter natural flow regimes, affect sediment and nutrient delivery, and obstruct migration routes for aquatic species. In the case of the MRB, a particularly critical aspect of such alterations is the dampening of the flood pulse, a crucial lifeline for riverine ecosystems and riparian communities[6]. Therefore, it is imperative that we rethink new hydropower development as well as the operation of existing dams. Replacing hydropower with solar energy[7] or employing hybrid options[8] could be an alternative to restore the hydrological regime without affecting energy generation. However, as Galelli et al. note, dam removal is not an option in the MRB as most dams are relatively new, and in fact many more are planned. Therefore, the use of optimal operational strategies is crucial to sustain hydropower production while minimizing adverse ecological impacts.

To address this issue, Galelli et al. evaluated the trade-offs between hydropower production and the preservation of natural hydrological variability in the case of 108 existing hydropower reservoirs across the MRB. They used a hydrological model to simulate river flow, also considering the storage and water release patterns of the reservoirs, including the Lancang portion in China. By examining a scenario under which all 108 reservoirs would be re-operated, they concluded that to fully restore the seasonal hydrological variations, a basin-wide coordination for dam re-operation would be essential — currently not feasible given the lack of coordination between China and Lower Mekong countries. Then, the authors investigated re-operation of the 20 major hydropower dams located in the Lower Mekong, considering 28 different optimized re-operation strategies that balance average annual hydropower production, firm hydropower production, and the average annual ratio between the monthly-averaged maximum and minimum flows (a proxy of the annual flood pulse). These strategies would substantially decrease the deviation of river flow from natural conditions, and ensure power production rates close to, or better than, those provided by current dam operation strategies.

Exploring the fluctuations in river flow magnitude between the dry and wet seasons, Galelli et al. demonstrated that optimizing for both power generation and natural hydrological variability could lead to the resulting hydrological fluctuations being closer to the range of natural variability. They also noted that, among the various quantitative measures of the efficacy of the proposed re-operation strategies, the length of the dry season — or the low pulse — could be extended while also maintaining the ratio of monthly maximum to minimum flow close to the natural variability range. Bringing the variations in the amount of river flow and the length of wet and dry episodes closer to the range of natural variations is crucial to maintain downstream ecosystems.

Such potential restoration outcome could largely benefit joint management of water, energy and food systems; however, a complete restoration strategy would require transboundary cooperation in the region, a challenge given that China is not a member of the Mekong River Commission. Thus, real-world implementation of re-operation strategies warrants the consideration of the various legal and policy frameworks set by all countries that share the MRB, as well as a holistic approach[9] that considers the trade-offs between power generation and associated social and ecological impacts.

Overall, Galelli et al. offer useful insights for sustainable hydropower development in transboundary basins such as the MRB, and could be implemented also in other tropical basins including the Amazon, where dam construction is booming[10]. The study could be a basis for future research intending to expand the analysis to other socio-ecological indicators and to account for transboundary legal, institutional and management frameworks.

Yadu Pokhrel ✉ **and Amar Deep Tiwari**
Department of Civil and Environmental Engineering, Michigan State University, East Lansing, MI, USA.
✉e-mail: ypokhrel@msu.edu

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Competing interests

The authors declare no competing interests.