Hit by heatwave: Unforeseen transboundary economic consequences of hydropower shortage

Topic: Energy Input-Output Modelling
Author: Ruoqi Li
Co-Authors: Jun Bi, Miaomiao Liu, Yuli Shan

Extreme heatwaves decrease precipitation and water runoff, sharply diminishing hydropower generation. This hydropower shortage triggers immediate disruptions, as regions facing power rationing struggle to maintain production. However, the consequences extend far beyond these direct impacts. Indirectly, energy shortages disrupt downstream sectors reliant on raw materials from the affected regions, creating an unforeseen ripple effect along the supply chain. Previous research focuses on quantifying the direct impacts of heatwaves on energy shortages, yet less is known about the broader, cascading economic losses. The lack of awareness of indirect effects may further reduce the efficiency of actions to mitigate their consequences due to delayed responses.

In 2022, China experienced its most intense heatwave on record, which also became the hottest globally recorded. The Yangtze River, Chinaâ€™s largest, reached its lowest levels since 1865. In this context, we use Chinaâ€™s case as an example to demonstrate the estimation of the reduction in hydropower generation triggered by the heatwave, along with the associated direct and indirect economic consequences. The key research questions guiding this study are: What is the extent of the hydropower generation gap caused by the extreme heatwave in China in 2022? How much cascading economic loss will hydropower shortfall cause? Where did these losses occur and how are they transmitted spatially?

To answer these questions, this study develops a counterfactual scenario based on historical hydropower generation and estimates the reduction in hydropower generation caused by the heatwave using the seasonal auto-regressive integrated moving average (ARIMA) model. Then, we quantify the direct economic losses within the interprovincial electricity grid network. We further assess the indirect economic losses using a supply-side input-output model, uncovering the overall cascading impacts across different provinces.

The results show national hydropower generation decreases by 24% (1.5 trillion kWh), which is equivalent to 12% of the total generation for the entire year of 2022. Notably, 78% of the decline in hydropower generation is concentrated in 5 provinces in southwest China.

The reduction in hydropower generation propagates the energy crisis to all provinces in mainland China via the electricity grid network, accounting for approximately 30% of the electricity shortage. Many of these flows are from less developed regions to more developed regions. For example, power generation facilities in Guangdong and Shanghai are unaffected by the extreme heatwave. However, the power rationing they faced ranks among the top 10 due to the hydropower shortage in the southwest provinces.

The economic consequences of the hydropower shortage are further exacerbated by the interregional trade network. One the one hand, trade expands the spatial spillover of the crisis to more regions and over a wider distance. Up to 62% of the cascading losses are transmitted from other regions via the electricity grid network (30%) and interregional trade (32%). On the other hand, the economic consequences became more severe as trade magnified the total financial losses. These cascading economic losses, resulting from the reduced hydropower generation during the 4-month extreme heatwave in China in 2022, reach 581 billion USD, equivalent to 3.9% of Chinaâ€™s GDP for the entire year. This nearly triples the direct economic losses (206 billion USD).

Our results also reveal significant differences between the provinces with the largest cascading economic losses, those with the most substantial reductions in hydropower generation, and those most impacted by electricity restrictions, after considering the impact of the supply chain. For example, the top three provinces with the greatest cascading economic lossesâ€”Guangdong, Fujian, and Hunanâ€”account for 35% of the total cascading economic losses, while they only contribute to 6.5% of the hydropower generation decrease in 2022. Provinces such as Henan and Shandong are also especially vulnerable to unforeseen lagging effects along the supply chain, though experiencing fewer direct impacts from the electricity restrictions and production cuts during the heatwave. We conclude the study by depicting the major pathways from the provinces most affected by the hydropower generation shortfall to those facing an energy crisis and, ultimately, to the production provinces along the supply chain and highlighting key sectors.

In summary, the study enhances our understanding of the unforeseen transboundary impact of hydropower shortage caused by extreme heatwave, based on an unprecedently severe case in China. The results here can assist policymakers in proactively assessing the climate change-related economic losses, thereby strengthening regional resilience to potential disruptions and improving preparedness for the economic consequences of extreme