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When the River Runs Dry: Climate Change and the Political Economy of Hydropower Disruption

Johnathan Guy, Ishana Ratan, Anthony Calacino

Summary

Climate change is beginning to reshape patterns of hydroelectric generation around the world, with important security ramifications. Preliminary evidence from Brazil, Colombia, and Nepal establishes the multifaceted challenges hydropower-dependent nations face, and divergent responses governments have taken in response.

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In mid-June 2023, a series of floods struck eastern Nepal. Brought on by unusually torrent monsoon rains, the floods inflicted more than $63 million worth of damage to 30 hydropower plants under construction or in operation, equivalent to almost a quarter of the nation's electricity supply. Meanwhile, in Brazil, government officials braced for El Niño, expected to bring water levels even lower than the 91 year old record-shattering drought which shook the country's power system two years ago, sending electricity prices skyrocketing and the country's water minister on national television to plead with consumers to reduce their power consumption. In Cambodia, farmers adjusted to the new reality of coal and oil infrastructure impacting their crops, a consequence of a rapid buildout initiated by the government after a series of power shortages in 2019.

Each of these incidents is inextricably linked to a defining security challenge of our time: climate change. Although hydropower is often heralded as a key source of cheap clean energy, dramatic shifts in precipitation patterns, sedimentation, and other hydrological processes threaten its role in climate change mitigation. The global boom of dam construction that began in the 1950s has left more than 60 countries dependent on hydropower for at least 50 percent of their electricity needs—and thousands more dams are being planned by governments across the world. Dependence on hydropower could make countries vulnerable, both in the short and long term. Policymakers must prioritize power system flexibility and revisit risk management practices to avoid catastrophic disruptions to power supply and the human and fiscal costs of dam failures.

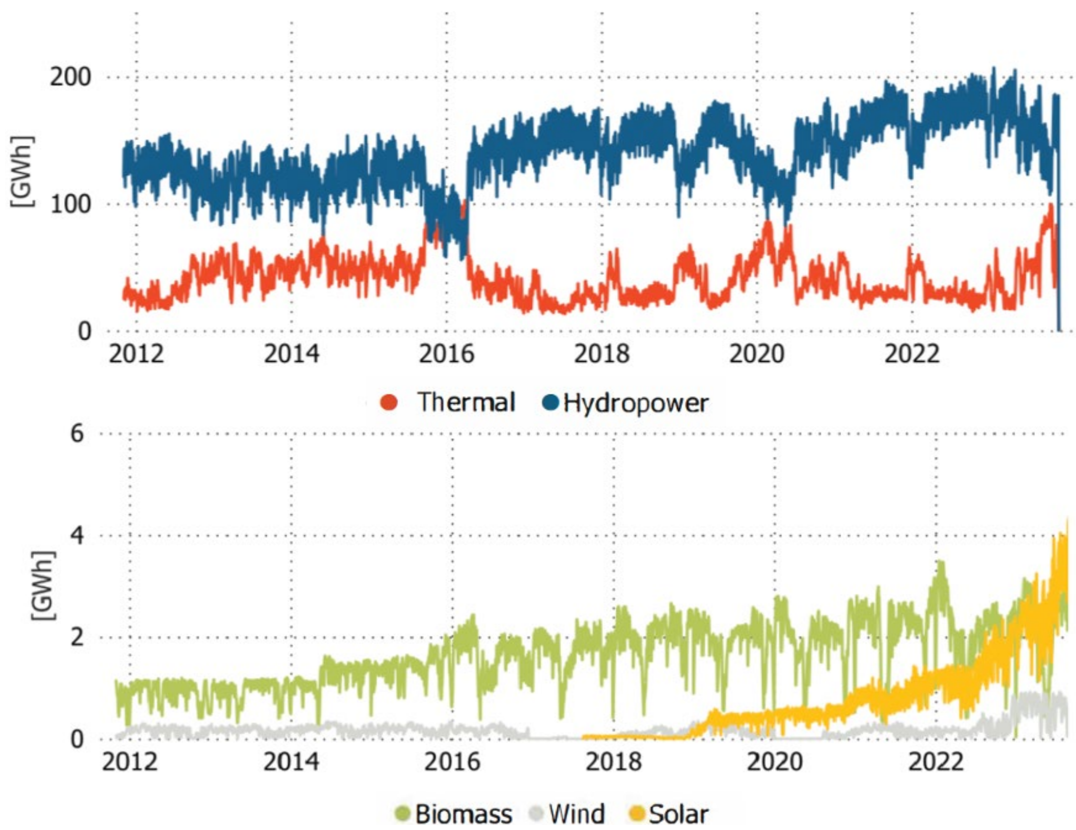
How Climate Change Is Affecting Hydropower

Scientists are still trying to understand and forecast the effects of climate change on hydropower potential. But there are at least two distinct patterns of hydro stress: volatility and long-term structural decline.

First, volatility. In the span of weeks to years, climate change is increasing the volatility of rainfall and snowmelt patterns—and thus hydropower production and potential—both across and within seasons. Most hydropower-dependent countries experience a wet season and a dry season over the course of a year, and energy production is significantly higher in the former. Climate change is making wet seasons wetter and dry seasons drier, and increasing the severity and frequency of intra-seasonal floods and droughts. This increasing variation, coupled with growing demands for power, increases the need for load balancing—that is, distributing electricity equally across the grid—across hours, days, weeks, and seasons.

An example of increasing hydropower volatility is seen in Figure 1, which charts electricity generation by source over time in Colombia. Since the 2010s, the seasonality of hydropower production has increasingly amplified. To offset shortages in the dry season, growing reserves of natural gas capacity have been constructed, and are used to supplement dips in hydropower production, as indicated by the red line. Over time, wind and solar have risen to fill ever increasing energy shortfalls, represented by the yellow and grey lines below for wind and solar respectively.

FIGURE 1. Electricity Generation in Colombia by source (2012-2022)



Source: Sinergox (2023)

In some regions, hydropower potential may actually increase over the next few decades, as increased snow and glacier melt causes greater average flows in snow-fed rivers, in addition to broader shifts in precipitation patterns. In other regions, namely those with relatively flat terrain, aggregate hydropower potential will decrease. Volatility creates uncertainty about the future. It is becoming harder to predict how much energy hydropower plants will provide next week, next season, and next year, both at existing and prospective dam sites. The sudden onset of drought can mean electricity shortages in the span of weeks if backup measures are not in place. In September 2023, for example, a drought in Tanzania produced a 400 megawatt electricity shortage, forcing the government to ration electricity across an already underserved population. In Vietnam, drought-induced shortages have damaged the export-oriented manufacturing sector, shaking investor confidence and raising concerns about capital flight.

Climate change also degrades hydropower infrastructure. Flooding, sedimentation and other turbine-damaging debris, glacial lake outburst flooding, and mudslides damage hydropower assets, which in turn has huge and uneven economic and safety consequences for surrounding communities. Under these conditions, power system flexibility and risk management practices become paramount.

Adaptation in the Short- and Long-Run: Storage, Trade, and Replacement

Hydropower-dependent countries must adapt to near-term supply shocks and develop long-term strategies to address shortfalls and other impacts. Governments facing a short-run crisis have three basic options: 1) they can draw from or feed into existing power storage, whether fuel, batteries, or hydropower reservoirs ("store"), 2) they can choose to increase or decrease imports of electricity and fuel to meet demand ("trade"), or 3) they can ration or curtail power ("ration"), creating a grim allocation problem among consumers (in the case of power rationing) or producers (in the case of curtailment).

In practice, political and economic considerations combined with a country's existing asset base in the power sector place constraints on some of these options. For example, if a country lacks backup generation capacity or grid storage, then electricity imports or rationing are the only feasible options, as peaking plants and storage take time to construct. In Nepal, power shortages during the dry season once meant up to 18 hours in the dark for residential consumers, before the completion of delayed dam projects, a change in grid management, and increased electricity imports from India mostly alleviated these shortages in 2016–17. Similarly, if transmission lines to facilitate significant trade with neighbors have not been built, trade is not an option. While Colombia and Ecuador could theoretically trade power during periods of complementary over and under supply, the transmission line at the border has too little capacity to make a significant difference in Colombia's energy security.

Yet countries are not permanently stuck with the hand they've been dealt. Over the long run, governments can develop strategies and invest in infrastructure and institutions that better prepare them for future supply shocks. These strategies can likewise be grouped into three categories: store, trade, and replace.

Storage strategies, such as the addition of batteries, pumped or reservoir hydro, and hydrogen fuel to the power system, allow for load balancing over days, weeks, and/or seasons. During periods of high production, storage assets store energy potential in the form of water reservoirs, electric batteries, and hydrogen tanks, which then can be drawn upon in periods of unusually low production, such as droughts. Large-scale reservoir projects like El Quimbo in Colombia may be land intensive but can offset declines in rainfall during dry months.

Storage strategies are capital-intensive, involving significant planning, investment, and coordination between public and private actors. Often, these requirements present insurmountable political and technical barriers—reservoir storage, in the case of El Quimbo, typically involves land acquisitions and population resettlement, while grid and hydrogen storage are still emerging technologies with steep learning curves. But storage assets pay off by allowing a short-term response to volatility that avoids both trade dependency and rationing.

Trade strategies include diplomatic agreements facilitating power trade, as well as the construction of assets that allow for transnational energy flows, such as cross-border transmission lines and fuel import infrastructure like pipelines and ports. Compared to building storage capacity, trade strategies are less capital intensive, in the sense that they typically require less new infrastructure, which, when it is necessary is relatively technically simple. In the case of liquid markets, reliance on trade can achieve significant efficiency gains while similarly avoiding rationing. However, trade strategies involve dependence on trading partners or global fuel commodity markets, which threatens energy security. Nepal's emerging strategy to rely on power trade with India to load balance over seasons, for example, has provoked controversy, in part because of longstanding fears over losing national autonomy.

The Trade-Offs Involved in Investing in New Energy Sources

Countries can also invest in new sources of energy to help supplement and eventually replace ailing hydroelectricity generation stock. Countries have choices about what type of energy source they invest in. From coal, oil, and gas, to renewables like solar and wind, to geothermal, nuclear, biomass and new hydro—each comes with a set of advantages and disadvantages. Ideally, countries would transition to clean renewable energy such as solar, wind, and geothermal, but in practice, there are many things that can stand in their way.

The advantage of thermal energy is that it is a reliable baseload power which can "plug the gaps" and "void the gluts" caused by hydropower volatility without the political and technical challenges associated with storage. The disadvantage of thermal—in addition to the obvious downside of increased carbon emissions—is that most hydropower-dependent countries lack significant domestic fossil fuel deposits, meaning that building new coal, oil, and gas plants usually involves increased fuel import dependence as well. In contrast, variable renewable energy plants (VRE) such as wind and solar do not depend on fuel imports after the initial plant construction. The downside is that VRE production patterns often do not match well with patterns of hydropower volatility. For example, in South Asia, wind production is highest during the monsoon, amplifying rather than offsetting the seasonal generation fluctuations of hydropower. The daily cycle of solar, meanwhile, peaks during the middle of the day, but rapidly declines in the evening just as energy consumption rises in consumers' homes.

Baseload renewables are a mixed bag. Reservoir hydropower often requires the politically fraught largescale resettlement of nearby populations and negotiation of compensation schemes. There is a long history of reservoir development projects being accompanied by forced displacement, human rights abuses, and corruption, which makes multilateral lenders—

Photo: Ekendra Lamsal, CC BY-SA 4.0, via Wikimedia Commons often the only party with enough working capital to invest in such projects—reluctant to support them. Reservoir, geothermal, and nuclear plants also require a high level of technical knowledge to construct and operate, meaning hydropower dependent countries often must contract this work out to foreign firms and governments, on terms perceived—often correctly—as unfavorable by some domestic audiences. While run-of-river hydropower is less disruptive to local landscapes and requires less up-front capital and technical know-how to build, it cannot store water to be run through turbines later. This has the potential to amplify the volatility problem, albeit while raising the "floor" of production in particularly dry periods or cases of dam failure. Peaking run-of-river—hydropower plants with small reservoirs—pair well with solar and can offset within-season fluctuations in volatility to a limited extent.

Short-Run Responses Have Long-Run Consequences

What determines whether countries choose to store, trade, or replace in the long run? Countries' decisions have a lot to do with the political and economic ramifications of their short-term responses during early episodes of volatility. When a shortage (or glut) of supply emerges, countries typically have a default response either of drawing from (or depositing into) storage, increasing imports (or exports), or rationing (or curtailing) power. A country's default depends on what resources—energy stocks and storage capacity, grid interconnections and power trade agreements, and grid capacity—are available at the time. Short-run responses can deepen into long-run strategies. For example, in Nepal, large-scale imports of electricity from India during shortages led its leaders to pursue trade agreements to ensure supply over decades. Short-run responses can also cause countries to reverse course, such as in Colombia, where the onset of El Nino in 1992 led to massive rationing in the short run, and the regulation of thermal (and then renewables buildout) in the long run.

Whether short-run responses deepen into long-run strategies depends on who pays the costs and reaps the benefits of early-stage hydropower shocks, which influences policy learning and adaptation in the aftermath. Evidence from Brazil, Colombia and Nepal suggests that the relative political power of consumers and power generation companies and industry is important, as is the composition of domestic resource endowments.

Profit over Principle Sparks a Move to Renewables in Colombia

In Colombia, the 1992–93 blackouts led to massive consumer unrest, which catalyzed power sector reform and the creation of a capacity market. To create a capacity market, the government paid thermal producers to build surplus plants to be used in case of a hydropower shortage, and simultaneously capped the prices that they could charge to avoid price gouging. The cap was too low, and thermal producers, pressured by high fuel and labor costs, abandoned these plants during later periods of drought, such as in 2007. Though the government has attempted to retool the capacity market to address these problems, firm and government reluctance to rely on expensive and unreliable imported fuel has encouraged power generation companies to instead invest in renewable energy as a more profitable substitute for hydropower in case of crisis. As a result, power generation companies have de-emphasized thermal in their lobbying and investment decisions, pivoting instead to solar and wind. The move to renewables is a good outcome for climate change mitigation, but it was achieving—counterintuitively—by a policy status quo (the price cap) which made renewables more profitable course of action over the long term.

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Weak Consumer Power Deepens Entrenched Thermal Interests in Brazil

In Brazil, by contrast, the government responded to increasing hydropower volatility, first by rationing, and then by supporting the buildout of natural gas, starting with the Programa Prioritário de Termoeletricidade (PPT) in 2000. In contrast to Colombia, Brazilian consumers were weak as a political force, and unable to agitate price caps at the wholesale and retail level when thermal producers began to reap record profits during hydropower shortages in the early 2000s. As a result, thermal producers continue to enjoy market rates during crises, entrenching the fossil fuel lobby and creating incentives for investment in natural gas plants over wind and solar. A relatively greater share of renewables generation is bound up in long-term power purchase agreements with private companies which are not responsive to short-term fluctuations. In short, renewables are sold to large firms to reduce their costs of electricity on a separate market, while consumers bear the brunt of price increases from expensive thermal generation during hydroelectric crisis.

Political Competition Delivers Power to Nepalese Consumers

In Nepal, power shortages were historically addressed through load-shedding—often up to 18 hours paper day during dry season. Cuts were concentrated among residential consumers while reserving power for industrial production. In 2016, however, heightened political competition and the entrance of a new Maoist-led government empowered mass consumer interests. The Nepal Electricity Authority consequently redistributed power supply away from industrial to residential consumers and increased power imports from India. The long-run response involved the build-out of run-of-river hydropower, grid interconnections and trade negotiations with India, aimed at facilitating exports during the wet season and self-sufficiency during the dry. Increased trade in the short term leverages the sky-high hydropower endowment of the Himalayas and reflects the favor of hydropower developer and trading interests with the government over industrial consumers.

Conclusion

Hydropower is the predominant renewable energy source globally and will play a key role in transitioning countries away from fossil fuels. Yet hydropower production is threatened by the effects of climate change, with significant implications for both energy security and the energy transition. In the face of increasing uncertainty, hydropower-dependent countries—already vulnerable to the impacts of seasonal disruptions to power supply—must develop robust strategies for load balancing and project risk management.

For hydro-dependent countries to move towards other renewable energy sources, policy bargains between producers and consumers will have to be made that balance producers' profit interests with consumer interests to maintain low prices and reliable supply. Focusing governmental financing on transmission lines and grid storage—and away from fuel import and transport infrastructure—may help reconcile these interests by increasing the technical feasibility and financial attractiveness of using renewables as reserve capacity (and eventually replacement) relative to fossil fuels. Yet, each of these alternatives has their own (geo)political liabilities. Just as relying on thermal reserve capacity leaves hydropower-dependent countries without fossil fuels vulnerable to global price movements, reliance on power trade can be a national security liability. Reservoir projects are disruptive to local communities and, often, to international water flows, and require enormous investment and technical knowledge well beyond the ability of many hydropower-dependent countries to provide on their own. Moreover, embarking on such projects requires strong and responsive institutions to negotiate resettlement and compensation, as a matter of both fairness and expediency.

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Authors

Johnathan Guy is a PhD candidate in Political Science at UC Berkeley. He studies the comparative politics of climate change and energy transitions, with a particular focus on South and Southeast Asia.

Ishana Ratan is a PhD candidate in Political Science at UC Berkeley. Her research focuses on the causes and consequences of patterns in solar power development, with a particular focus on Latin America and Southeast Asia.

Anthony Calacino is a PhD candidate in Political Science at UT Austin, and an incoming postdoctoral researcher at the University of Oxford. His research focuses on environmental politics in the Global South, with a particular focus on Latin America.

About the research

These insights and many more were gleaned from seventy-five interviews with government, industry, and civil society actors conducted across three countries between May – July 2023. Fieldwork in an additional country-case, Laos, is scheduled for early 2024. These initial country case studies will be complemented by an ongoing cross-national study, which aims to track hydro stress events and associated responses for a larger number of hydro-dependent countries.

This ongoing research is funded by a grant through the IGCC's initiative on the Security Implications of Climate Change. More information on the initiative and its work can be found here.

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9500 Gilman Drive #0518, La Jolla, CA 92093-0518