Challenges and opportunities for the governance of hydropower

Preface

Over 3,700 hydropower dams over 1 MW are planned or under construction across the Global South, repeating many past environmental and social problems. The World Commission on Dams issued guidelines in 2000, but major dam-building nations dismissed them as impractical. A quarter century later, the net benefits of large dams remain contested, yet the context has shifted. Climate change narratives, China's involvement, private investment, environmental justice movements, and multilevel governance now shape hydropower development. This landscape creates opportunities for better governance, strategic planning and community involvement, as well as for new research on hybrid systems, transboundary contexts, and China's political-economic dynamics.

Introduction

An estimated 3,700 dams that produce more than 1 MW are either planned or under construction primarily in the Global South. [1] From 2005 to 2015, global hydropower capacity grew by 39%, followed by a period of steady growth (1.8% per year) from 2016-2020, reaching a total installed capacity of 1,360 GW in 2021 [2]. This represents around 15 % of global installed electricity generation capacity across all sources [3]. Of the total, about half are run-of-the-river dams with little or no storage capacity, and about 19% are dedicated solely to hydropower generation [3] Going forward, Asia is projected to account more than half of global capacity growth, while Africa is expected to experience the highest relative increase, nearly tripling its hydropower capacity by 2050. [4.] In the Lower Mekong basin, 30 GW of capacity will be added by 2040 [5] and India expects more than 25GW of additional capacity by 2030. [6] In Latin America, hundreds of dams are under construction or proposed. [7] Brazil has announced the construction of three new large dams by 2029 in the Amazon region, with many smaller dams also in the pipeline. [8]

In advanced economies, however, the share of hydropower in electricity generation has been declining, and many plants are aging and being decommissioned. [9] Most developing and emerging economies have a surplus of hydropower potential, while European and other Western countries are now considered hydropower-deficit regions. [3] The US Green New Deal Movement and the European Green Deal plan, could reverse this situation given their ambitious carbon neutrality targets [10]. However, reaching those targets does not necessarily require the development of new hydropower dams. [11]

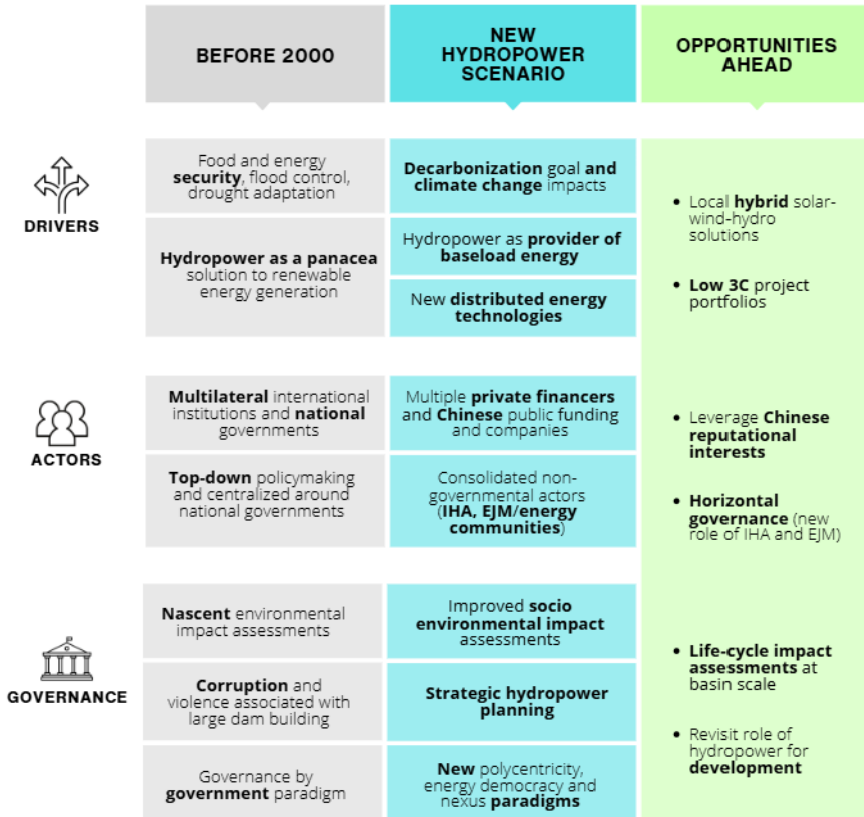
The latest wave of dam construction in the Global South continues to bring familiar harms: ecological disruption, deforestation, biodiversity loss, and negative impacts on local livelihoods, health, and culture—often without proper consultation, fair compensation, or safeguards for water and fisheries access. [12,13] Yet dams do also generate benefits. Of the approximately 10,000 hydropower dams in the database of the International Commission on Large Dams, approximately 40% are multipurpose, including mostly irrigation and flood control services. [4]

In 2000, the World Commission on Dams (WCD) introduced comprehensive guidelines for progressive water and energy project planning, aiming to protect dam-affected communities through improved consultation, fair compensation, and more equitable benefit sharing. [14] However, a quarter century later, the sustainability and net benefits of large dams are still in question [15] and conflicts with local communities or environmental groups persist in far too many cases. [16] At the same time, the debate around dams appears to be increasingly polarized once again between pro and anti-dam groups.

This paper is driven by two research questions: First, what characterizes the current wave of large hydropower dam-building in the Global South? Second, within the current scenario, what opportunities exist to realize the benefits of hydropower without undermining livelihoods and the environment?

In the remainder of this article, we review the emerging scenario of hydropower development from a socio-environmental perspective. We organize our diagnostic around drivers, actors and governance (Figure 1), and discuss it in light of future research and governance opportunities.

Figure 1. Distinctive characteristics of the new hydropower scenario as compared with the scenario before 2000, and governance opportunities emerging from the new scenario



Drivers

Decarbonization

Since the 1970s, developing economies have driven global hydropower growth. Hydropower currently supplies electricity to 800 million people across 28 emerging and developing economies. [17] More recently, large hydropower dams in these countries have been promoted as a strategy for achieving decarbonization goals. The International Energy Agency's flagship Net Zero report claims the world will need 2,600 GW of hydropower capacity by mid-century to have a chance of keeping global temperature increases below 1.5 degrees Celsius by 2050. According to the International Hydropower Association, meeting this target would require building the same amount of capacity in the next 30 years (30GW per year) as in the previous 100 years. [2] Also, hydropower is valued for its ability to support climate change adaptation, i.e., regulation of floods in the wet season and droughts in the dry season, [18] and to avoid new methane emissions due to flooding. [19]

Energy and food security continue to be offered as a justification for large dam projects, especially in African countries and basins with untapped hydropower potential and persistent development challenges. Economic growth and modernization are frequently invoked too, as large dams are often seen as symbols of national progress and prestige. These projects can generate local employment, stimulate real estate and service economies, and support broader industrial development. However, research has shown that promised benefits are often overestimated and may be lower than anticipated [20].

Hydropower for baseload supply

The claim that large-scale hydropower is essential is increasingly challenged by the rapid expansion of other non-carbon energy sources like solar and wind. While these alternatives pose land-use and biodiversity concerns and typically have lower energy density and storage capacity compared to hydropower, [21] they are more spatially distributed and often more socially and environmentally cost-effective. Yet, the increasing cost competitiveness of intermittent energy sources does little to slow the deployment of hydropower under conditions of high economic growth and untapped hydropower potential found in many developing economies. [22] Moreover, as solar and wind drive down electricity prices, they can reduce appeal of hydropower investments, perversely incentivizing back-up fossil fuel options and stymying decarbonization efforts. [23]

Hydropower can play a crucial load-balancing role for solar and wind energy, helping to manage their intermittent generation and future variability due to climate change. Both conventional hydropower dams and pumped-storage hydropower (PSH) plants can contribute to grid stability and reduce the need for backup fossil fuel power plants. [24] Where all sites for conventional dams have been exhausted or new dams would have significant negative environmental or social impacts, PSH can be a lower-impact alternative to store energy at large scales. [25] However, PSH involves higher upfront costs and is generally less economically viable than conventional dams. [26] Also, price fluctuations have been declining, making it challenging to attract private capital for the construction of PSH plants. [27]

Battery storage systems can also increase reliability, with the development of hydro-battery hybrids representing a current research frontier. [28] Battery systems are most effective for short-term storage (minutes to hours), while PSH is more cost-efficient for longer-term storage (overnight, days, or seasonal). PSH systems, with lifespans of 50-100 years, currently dominate global storage capacity, accounting for 96% of power capacity and 99% of energy volume. [29] Compressed air energy storage is also becoming increasingly competitive with PSH, [27] and combining small PSH and solar power is realistic and very promising. [30]

Floating photovoltaic (FPV) systems are a recent renewable energy innovation. Installing FPV on existing dam reservoirs offers benefits such as reduced transmission costs, lower evaporation rates, and improved efficiency due to the water's cooling effect. [31] They may also offset methane emissions from decaying vegetation for greenhouse gas-intensive dam reservoirs [32] and reduce susceptibility to climatic variability that may affect conventional hydropower, [33] though variations in water levels may also present a technical challenge for FPV. [31] Also, FPV could generate as much energy as all proposed new hydropower dams in Africa. [33] While covering as little as 10% of the world's hydropower reservoirs, FPV would add nearly 4,000 GW of new solar capacity, equivalent to the capacity of all currently operating fossil fuel plants. [31] FPV could pose potential risks too, including algal blooms, reduced oxygen production in reservoirs, and socio-ecological conflicts with fisheries and tourism. Additionally, FPV systems may be vulnerable to damage from extreme weather, microbial biofilms, and bird droppings, leading to frequent maintenance requirements.[31]

Climate change impacts and emissions

Hydropower expansion in developing countries often overlooks the impact of climate change projections from the IPCC and other international organizations. [34] Forecasts of increasing rainfall variability and more frequent extreme weather events are expected to affect hydropower generation performance. Projections for the Amazon Basin, for example, point towards a broad drying trend [35] while in the Volta and Zambezi rivers in Africa rainfall variability is expected to undermine electricity generation. [36] The impact of floods on dam safety should not be ignored either. In the central Amazon, the maximum inundation extent of all reservoirs has increased by 26% since 1980. [37]

Additionally, recent studies show that large hydropower, particularly in tropical regions, significantly contributes to greenhouse gas emissions (GHGs). [38] In 2020, methane emissions from reservoirs surpassed those from various anthropogenic sources, including grassland, peat, and forest burning, and the industrial and transportation sector. [39] A recent historical assessment of carbon-based greenhouse gas (C-GHG) emissions from reservoirs found that carbon dioxide emissions dropped from 3.5 teramoles per year in 1970 to 1.9 teramoles by 2010 as reservoirs aged. [39] However, overall radiative forcing from reservoirs continues to increase due to rising methane emissions. [39] The hundreds of hydropower projects planned in Africa by 2050 could increase total energy system emissions by 7%. [40]

Carbon dioxide and methane emissions from artificial reservoirs primarily stem from the decomposition of submerged organic matter. [39] While vegetation removal before flooding can reduce GHG emissions, tropical reservoirs, such as those in Brazil's Belo Monte dam complex, continue to produce substantial emissions even after vegetation is cleared. [41]

Moreover, vegetation removal contributes to deforestation, which is another well-known cause of carbon emissions and stands in contrast with new commitments to halt and reverse forest loss and land degradation by 2030. [42]

Distributed hydropower technologies

In several Global North countries, anti-nuclear and associated environmental movements, as well as the increasing accessibility of distributed energy technologies like solar panels, have inspired a significant wave of community-energy projects. Through these projects, local groups become producers of their own energy and contribute to the energy transition. [43,44]

The movement in the Global North has been followed by a similar trend of distributed energy systems/microgrids in the Global South. [45] Here micro-hydropower and in-stream turbines play a notable role. In the Dominican Republic, for instance, 45 community-managed micro-hydropower systems established over 16 years now provide electricity to remote areas while avoiding over 28,000 tons of CO_2 emissions annually. [46] In Brazil, several research groups have been working to develop in-stream hydropower technologies, and some have deployed them in communities utilizing local support and local manufacturing. [47] In-stream turbines could generate up to 67% of the total planned energy produced from dams in the Amazon region. [48]

Micro-hydropower and in-stream turbines also represent an alternative to small-hydropower plants. Small hydropower plants have been questioned for their vulnerability to climate change and their cumulative impacts at the basin level. [49] Also, researchers across scientific fields are calling for modular solutions that combine solar with in-stream turbines to bring energy to off-grid communities. [47]

Multi-level actors

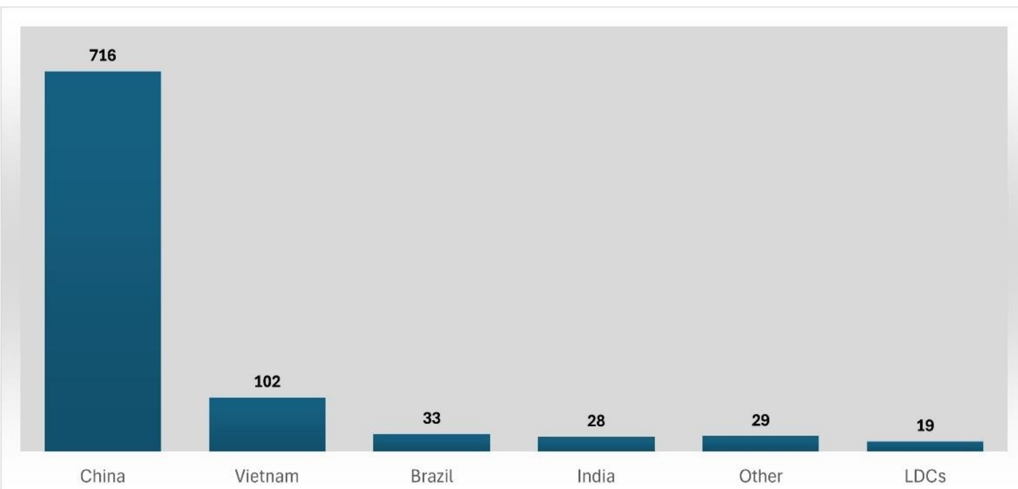
Private and public financing

Until the early 2000s, the World Bank was the primary financier of large-scale hydropower projects in low- and middle-income countries. Today, that role has largely shifted to multilateral organizations and donors such as the International Monetary Fund (IMF), the Asian Infrastructure Investment Bank (AIIB) and carbon offset schemes like the Clean Development Mechanism and the Green Climate Fund.

Between 2005 and 2020, over 300 hydropower projects were registered under the Clean Development Mechanism (CDM), which enables developed countries to earn emissions reduction credits by investing in renewable energy in developing nations. However, most

CDM hydropower projects concentrate in emerging economies—primarily China, Vietnam, Brazil, and India—rather than in the poorest countries. Critics argue that many of these projects would have proceeded without CDM support and raise concerns about the adequacy of their environmental and social assessments. [50]

Figure 2. Distribution of large hydropower projects registered under the Clean Development Mechanism between 2005 and 2020 (source UNFCCC 2021). Only countries with more than one registered project of an output capacity over 15 MW are displayed. The “Other” category includes: Peru (5 projects), Indonesia (3), Mexico, Pakistan and Philippines (2 each), and Albania, Bosnia-Herzegovina, Bhutan, Chile, Cote d’Ivoire, Dominican Republic, Ecuador, Fiji, Georgia, Iran, Malaysia, Nigeria, Panama, Sri Lanka, and Republic of Korea (1 each). The “LDCs” category includes Laos, Cambodia, Madagascar, Uganda, Mali/Senegal/Mauritania, Myanmar, and Zambia.
Source: frequency analysis based on UNFCCC 2021 (https://cdm.unfccc.int/Projects/projsearch.html) data.



In 2020, global Foreign Direct Investments (FDI) in renewable energy, including hydropower, surpassed investments in coal, oil, and gas for the first time. [51] These investments are expected to grow, driven by climate agreements such as COP26’s commitment to phase out fossil fuel subsidies and reduce coal use, alongside COP27’s renewed emphasis on strengthening mitigation efforts. Publicly funded projects are increasingly complemented by private financing through public-private partnerships (PPPs) and bilateral funding. [52] This new, fragmented scenario, in which private investors are mainly focused on profits, weakens the implementation of corporate social responsibility guidelines, public accountability and sovereignty, [7] and results in an unequal division of labor. Governments are responsible for providing guarantees and mitigating impacts, releasing private entities from long-term responsibility. [53]

Chinese public funding and builders

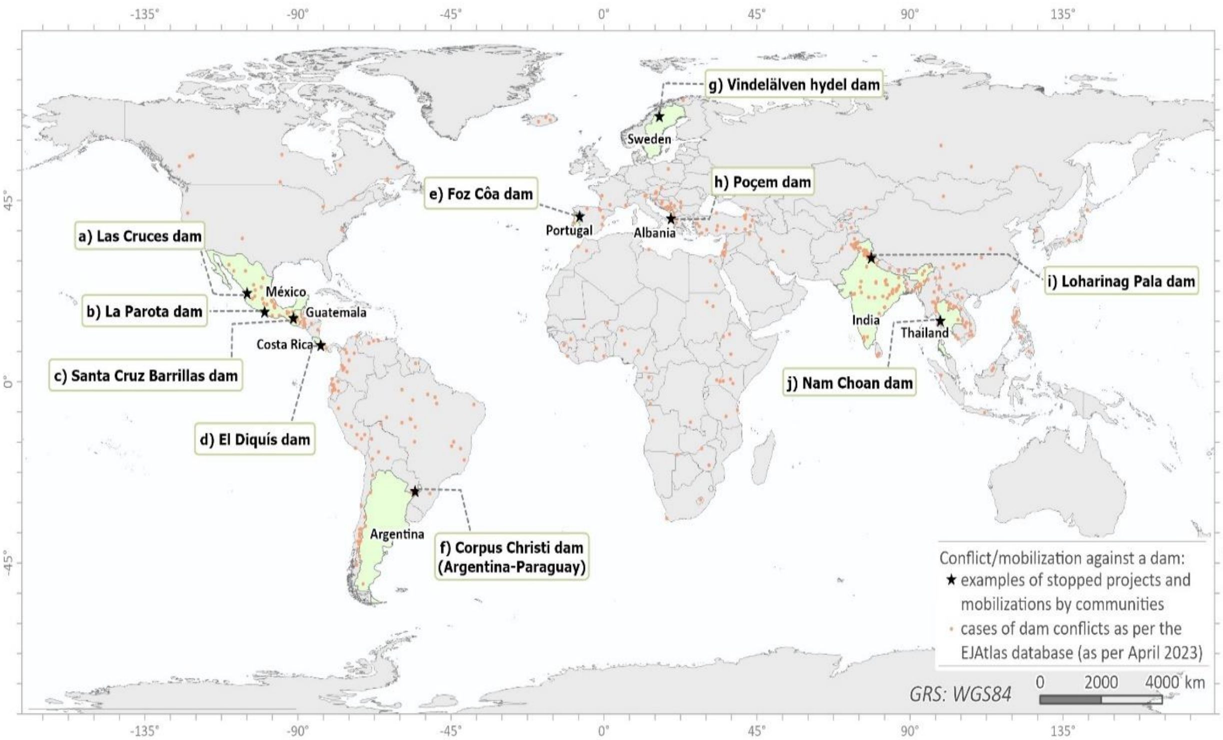
Despite regional power demand exceeding local technical potential in South and North China, the country maintains a significant hydropower surplus due to the vast capacity in the Yangtze Basin.[3] Between 2000 and 2020, the China Development Bank and the Export-Import Bank of China invested $41.2 billion in hydropower development in other countries, accounting for the largest share of China's renewable energy investments abroad. [54] Most of the Chinese funds have been used for the construction of large dams in Africa ($23.5 B), Asia ($12.1 B), and Latin America ($4.8 B). [55] Also, with the support of the Chinese government, shareholder and state-owned Chinese companies have also become global leaders in the construction of approximately 380 large dam projects in more than 70 countries, mostly in the Global South. [56] Chinese companies often offer integrated solutions for power generation, transmission, and distribution, financed through a mix of development loans, government projects, and commercial investment. However, their responsibilities for Environmental Impact Assessments (EIA), resettlement, and mitigation plans can differ depending on the contract type. For example, Build-Operate-Transfer (BOT) contracts, commonly used for large projects, place the responsibility for managing social and environmental impacts on Chinese companies, leading to challenges in implementation. [57] Mitigation, compensation, and resettlement policies are often viewed by these companies as philanthropic efforts rather than as guaranteed rights for local communities. [58]

A global environmental justice movement

Over the past 20 years, dam-affected communities have organized globally to defend their rights and territories, engaging extensively with authorities at all government levels and with environmental justice groups both nationally and internationally. [16] Dam-affected people are indeed part of a growing global environmental justice movement (EJM), evidenced in more than 4,000 registered socio-environmental cases worldwide in the Environmental Justice Atlas (EJA, https://ejatlas.org). Conflicts are varied, reflecting grievances over displacement, livelihood loss, health impacts, and biodiversity loss, among other issues. The actors involved are equally diverse, ranging from local and indigenous communities, to institutionalized groups such as local resource use associations, governments, and scientists.

Around 12% (462) of the conflicts recorded in the EJA are related to large-scale dams, often representing one of the most violent types of conflicts. [16] Despite the repression by governments and multinational corporations [16]dam-affected people mobilizations have been largely non-violent, including street protests, blockades and public campaigns, lawsuits, official complaints to national and international governments, and commissioning independent EIAs, among others. [16] Many of the movements have also acquired notoriety and recognition internationally. Such is the case of the “Narmada Bachao Andolan movement” in India or the “Movimento dos Atingidos por Barragens” in Brazil.

Figure 3. Worldwide distribution of dam-related conflicts (red dots) and selection of illustrative cases of environmental justice movements that succeeded in stopping projects and/or building alternative proposals (stars and boxes). Key mobilization actions, governance features and outcomes: a) Coalition of organizations, legal actions at international level, public denunciation campaign, declaration of protected area as alternative. b) Foundation of local organization, legal actions, defense of indigenous people’s rights. c) Legal actions at different levels, community self-convened consultations. d) Consolidation of environmental justice organizations, artistic actions and events, international solidarity actions, demands for conservation efforts and policies. e) Youth activist camps, involvement of international organizations, designation of UNESCO World Heritage Site. f) Official binding referendum, self-organized consultations, promotion of the “Ley de Ríos Libres”, community-run debate on energy sovereignty. g) Refusal of compensation, local self-organized consultations, creation of nature conservation areas. h) Legal actions, ecotourism initiatives, defense of local farming activities, declaration of Europe's first Wild River National Park. i) Street marches, rallies, and artistic activities, mobilization of the scientific and international community, formal petition to the Prime Minister. l) Hunger strikes, public information campaign, claim of sacredness of rivers, declaration of an eco-sensitive zone and a ban on “development projects”. Source: own elaboration based on data available in the EJ Atlas as per April 2023 (https://ejatlas.org). Administrative boundaries, GADM database of Global Administrative Areas (http://www.gadm.org), 2022. Software: ArcGIS Pro® by Esri, version 3.4.2, www.esri.com.



Opposition to dams has led to various outcomes, including new Environmental Impact Assessments (EIAs) (17% of cases), fairer compensation programs (25%), the application of existing regulations (16%), court rulings protecting movement interests (13%), and the postponement, halting, or modification of projects (37%), among others. Notably, movements have also contributed to contributed to staying within the global carbon budget [59] and the development of alternatives to large dams (65%). These alternatives include new technologies and planning paradigms that emphasize evidence-based knowledge co-production and empower dam-affected communities (Figure 3 and Table S1 in Supplementary Information provide ten illustrative cases).

A part of broader grassroots movements in the water sector, dam environmental justice movements have disseminated their claims through platforms such as the World Social Forum and the Alternative World Water Forum, contributing to key milestones, including the UN General Assembly's 2010 recognition of the Human Right to Water and the 2018 UN World Water Development Report's acknowledgment of local community knowledge. [45]

The hydropower industry

The hydropower industry has also made significant strides in addressing sustainability concerns. Founded in 1995, the International Hydropower Association (IHA) is now the industry's main representative. Since the World Commission on Dams concluded its work in 2000, the IHA has actively contributed to the UNEP Dams and Development project (2000–2007) and supported global efforts to share best practices. Key initiatives include the 2001 launch of the Blue Planet Prize to recognize sustainable development projects, the 2004 publication of its first Sustainability Guidelines (inspired by WCD priorities), and the biennial World Hydropower Congresses, which have been held since 2007.

A significant step made by the IHA has been issuing the Hydropower Sustainability Tools, which include the Hydropower Sustainability Assessment Protocol (HSAP), a Hydropower Sustainability Environmental, Social and Governance Analysis of performance gaps (HESG), and the Hydropower Sustainability Guidelines on Good International Industry Practice (HGIIP). [60] That said, the HSAP has only been applied to 40 cases to date. Also, 65% of assessments were conducted after projects had already entered construction or operation, while 70-80% of those completed before construction focused on dams with less than 200 MW of installed capacity. [60] Other significant innovations include Free and Prior Informed Consent of indigenous peoples, and a Hydropower Sustainability Standard and certification program. [60]

The hydropower sector has also taken steps toward greater recognition of local rights and voices. The 2021 San Jose Declaration on Sustainable Hydropower highlights key principles, including the identification and engagement of all project-affected communities—especially Indigenous Peoples and vulnerable groups—and stresses that post-project livelihoods and living standards should improve compared to pre-project conditions. [61] Despite these advancements, local communities still face significant exclusion from decision-making processes in dam projects. [62]

Many of the above tools have been developed in a multi-stakeholder process with inputs from WWF, Transparency International, several national governments (e.g., Iceland, China, Zambia) and other international organizations. However, critical actors such as International Rivers have been excluded and the various guidelines fail to define a bottom line of acceptability for hydropower projects, reducing their effectiveness at bringing about meaningful change.

Governance

Social and environmental impact assessment

The field of impact assessments has also notably evolved. Today there are a variety of new tools to evaluate trade-offs between hydropower capacity and environmental impacts. [63] It is now well understood that changes in hydrological regimes and sediment flow caused by large dams may trigger land use changes and alter the livelihoods of local communities far away from the reservoirs. [15,64]

Studies on the social impacts of dams, once driven primarily by economic concerns, have also documented a wider range of new challenges for displaced communities, including changes in income sources and employment structures, increased labor migration, [65] disruption in social networks that provide economic support, [66] loss of indigenous sovereignty and cultural heritage, [67] loss of access to non-monetary subsistence resources, and poor implementation of land-based compensation schemes. [68] More broadly, a new agenda for impact assessments is emerging, including increased attention to indirect and long-term impacts, cumulative effects of dams at the basin scale and the costs of environmental mitigation, [69] as well as interactions between environmental and social impacts. [70]

However, there is still a mismatch between the scale at which assessments are carried out and that of hydropower planning; [71] entities with ties to hydropower construction companies are often hired to conduct EIAs and SIAs, creating potential conflicts of interest; [15] public access to assessments results is inadequate; [72] climatic risks are rarely included in EIAs; [73] technical guidelines are poor and stakeholder participation inadequate; [7] and the enforcement of environmental and social protection standards depends largely on the host country's political and legal systems. [74]

A major problem is that "decision-makers may be inclined to favor large infrastructure as they provide opportunities for personal enrichment not afforded by smaller or more diffuse alternatives." [14] (pp.187). This has proven to be the case in countries such as Malaysia, China, Nepal, Ethiopia, India, Argentina, Paraguay or Laos. [75] The case of Odebrecht, a Brazil-based multinational construction company involved in corruption scandals with presidents, former presidents, and government officials from 12 countries over 30 years, suggests that bribery in dam construction and other public works contracts has been more widespread than previously recognized. To be sure, corruption is also present in solar and wind developments and in European and other Western countries. [76]

Governance paradigms

Over the past two decades, policy research and practice have evolved, challenging the "siloed," top-down approach to hydropower planning. The Water-Energy-Food (WEF) Nexus paradigm highlights the importance of considering cross-sectoral resource dynamics in hydropower development planning. [77] The paradigm has been applied to dam building and operations in developing countries to highlight trade-offs between energy and food production [78] and to identify opportunities to jointly address threats to water and energy security supply. [79]

The polycentricity paradigm [80] suggests that natural resources and other public goods can be efficiently governed by different "decision-making authorities" (e.g., regulators and governments at different levels of governance, as well as agencies, firms, cooperatives and civil society groups) if there is sufficient coordination among them. In the energy sector, polycentric systems have proven effective in balancing legitimacy and supply predictability when decision-making authorities count on sufficient autonomy, coordination, conflict-resolution capacity, and a relatively competitive environment. [44]

The energy democracy paradigm also emphasizes the role of households, energy cooperatives, and municipalities as energy producers along with energy firms. [81] In the solar generation context, new distributed energy systems are already challenging the status quo by enabling a new “prosumer” model. Prosumers can generate energy at a scale and form that suits their needs. By bringing demand and supply closer together, the prosumer model has the potential to lay the groundwork for democratizing the power system and empowering civil society. [82]

Strategic hydropower planning

Strategic hydropower planning, also called “hydropower system design”, is an improved approach to hydropower development compared to project-by-project planning, assessment, and operation. [83] It considers the cumulative social and environmental effects of a portfolio of dams, usually at the basin level, using multi-objective optimization methods. In the Lower Mekong River Basin, strategic dam planning could increase hydropower potential by 26% while reducing sediment trapping by 77% compared to the current dam portfolio. [84] In the Amazon, basin-level planning of 351 proposed dams could generate 80% of the projected electricity capacity with a carbon intensity of 80 kg CO2eq/MWh, similar to or lower than solar power, and considerably lower than the current portfolio's 200 kg CO2eq/MWh. [83] An evaluation of African hydropower dams found that strategic planning could reduce emissions and river fragmentation by at least 50%, with minimal cost increases. [40]

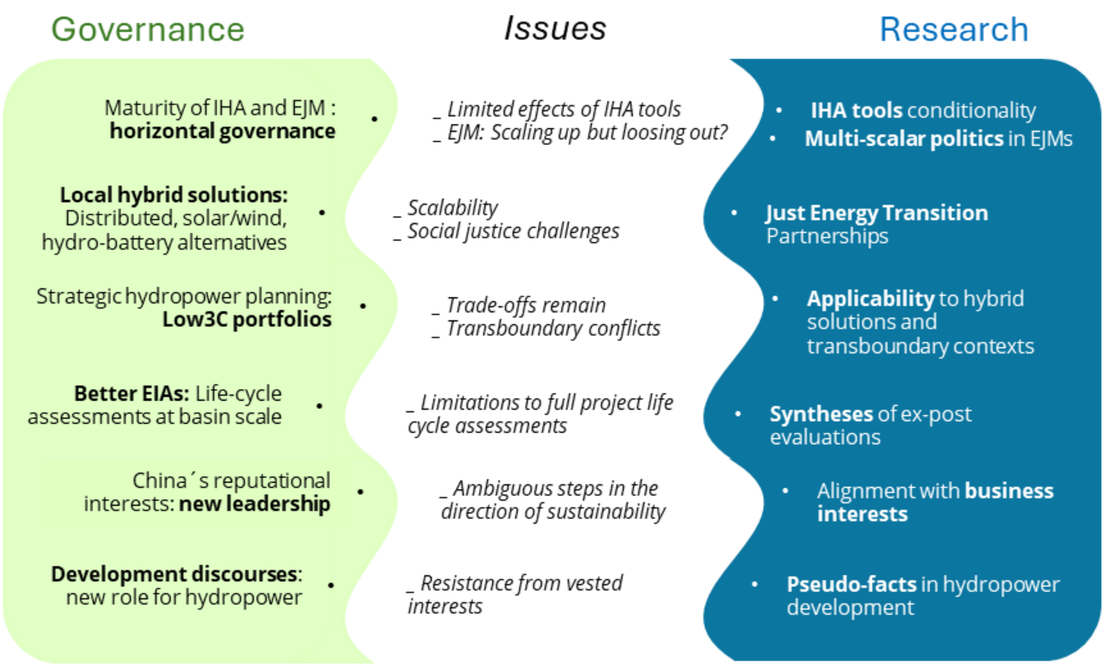
Strategic dam planning and coordinated dam operation may also identify overlooked opportunities to achieve multiple benefits, provide opportunities for better adaptation to climate change effects and be expanded beyond hydropower to include a suite of renewable energy projects. [4,83] Additionally, it can mitigate the social and environmental impacts of existing dams. For example, hydropower’s effects on fish biodiversity might be reduced by removing high-impact dams, retrofitting others with fish passage infrastructure, and developing new dams in areas with lower biodiversity. [85]

Governance and research opportunities ahead

The contemporary hydropower development scenario presents governance and research opportunities (Figure 4). The WCD brought together the pro- and anti-dam communities, and proposed recommendations that would address the negative outcomes of dams. [14]

Its recommendations highlighted all that was amiss with the way decisions about dams were reached and how dams were constructed, proposing a planning approach that would involve negotiated agreements between governments and dam-affected communities, along with extensive use of research and evidence. [86] These recommendations were a radical challenge to the traditional, business-as-usual approach to dam construction and the powerful political and economic interests surrounding it. [86] Likely because of its ambition, and with some notable exceptions, e.g., [87], the WCD was not successful in gaining widespread support in major dam-building countries, suggesting that achieving social justice in dam decision-making continues to be a policy and research challenge. [88]

Figure 4. Governance opportunities, associated issues and resulting research opportunities in the new hydropower development scenario.



Empowering the EJMs and the IHA tools

The new hydropower landscape presents an opportunity to enact the WCD's vision of a horizontal approach to hydropower planning, where non-governmental actors play an equal role alongside governments. The IHA and the EJM have both sought to lead such process. Together, they could form the basis for an international reputation system that recognizes and connects best practices from both builders and financiers, governed collaboratively with governments. In this regard, researchers could investigate how conditionality could be introduced to HSAP tools, to enhance their effectiveness, and to ensure that only projects meeting a certain standard will go ahead. The HSAP is currently governed by a Council, an international multi-stakeholder body aimed at achieving a broader consensus on defining sustainable hydropower projects. However, the Council and the IHA standards may not be enough. The sustainability practices adopted in China's Three Gorges Project, for example, generally followed the HSAP, but this did not prevent ecological impacts and resettlement issues. [89] Also, further research is needed to better understand the cross-scalar politics of community participation in EJMs at local, national and international levels. Previous research on this topic highlights the trade-offs between the ability of movements to act cohesively and the need to represent the diverse interests of local communities. [45] Game theoretical simulations have shown, for example, that the promotion of standard rules about how to share the benefits of energy generation can prevent energy communities to form; [90] and concerns have been raised about the difficulties of securing citizen participation in decision-making when scaling up community-energy projects. [91]

Hybrid solutions and just energy transition

Intermittent energy sources like wind or solar cannot meet the entire demand in contexts of high economic growth and urgent transitions to low-carbon economies. [22] However, this does not imply that hydropower should be the primary energy source. Local hybrid solutions present a critical governance opportunity to bridge the gap. Calls to explore such solutions have become particularly frequent in Africa in recent years, e.g., [40] However, these hybrid solutions are largely untested and not adopted at scale, providing research opportunities to evaluate their tradeoffs and social and environmental impacts. Furthermore, researchers need to evaluate the potential of community-controlled and locally managed water storage and energy generation to deliver energy security and decarbonization in comparison to state-controlled hydropower. This also requires attention to the social justice challenges linked to community energy initiatives, including resource limitations [47] and their potential for conflict. The Mapuche indigenous community in Chile, for example, struggled to participate in a consultation process about small hydropower development due to flaws in the participatory process as well as internal conflicts within the community. [92] Here, multilateral platforms, like the Just Energy Transition Partnerships (JETPs) established at COP26, offer some promise. Through various cooperation models between developed and developing countries, JETPs aim to mobilize financial and technical support from developed countries for sustainable energy solutions and accelerate a just energy transition in Africa and other developing economies. Further research should explore their potential to also promote community ownership and governance capacities. [93]

LowCx3 portfolios and transboundary capacity

Strategic dam planning for LowCx3 (Low on carbon, conflict and cost) renewable energy project portfolios represents another governance opportunity. Studies in Malaysia, Uganda, Chile, and the Mekong Basin have shown that avoiding high cost-conflict-and-carbon hydropower projects is possible by shifting toward more wind and solar along with investments in battery storage and using existing hydropower to provide storage (i.e., LowCx3 portfolios). [4] Almeida et al. [83] propose a multi-criteria approach to strategic hydropower planning, involving the definition of performance metrics, generation and evaluation of dam portfolios, and identification of trade-offs. Further research is needed to explore the potential of this approach for hybrid energy solutions, as well as its limitations. As highlighted in valuation studies, trade-offs are often perceived differently across population groups—and in some contexts, they may be incommensurable. [94]

Another major governance opportunity of strategic dam planning is tackling longstanding but seldom addressed transboundary conflicts associated with dam development. About 70% of dams currently in the planning or construction stages are located on transboundary rivers, with the potential to cause or exacerbate conflict between riparian states. [1] Recent, well-known conflicts include that around the Grand Ethiopian Renaissance Dam on the Blue Nile, which has raised fears downstream in Sudan and Egypt about irrigation deliveries and the operation of existing hydropower projects; [95] and the dams built in Afghanistan on the Harirud and Helmand rivers, with downstream opposition from Iran [96], among others. New research shall assess the institutional capacity (e.g., legal and policy instruments, river basin organizations, treaties) needed to implement hydropower strategic planning across international borders and its impact on conflicts. [96]

Better impact assessments and syntheses

The increased sophistication of environmental impact assessments, data availability and socio-ecological modelling capacities also represents a governance opportunity. Today, assessments can consider the full project life cycle evaluating climate mitigation benefits and safety risks, integrating strategic dam planning, and applying participatory multi-criteria analysis methods. Despite this potential, EIAs are rarely followed up with ex-post evaluations of dams and their (dis)services, which is crucial to improve their operations and better plan future developments. Although many of those evaluations have been carried out by academics, the information remains fragmented across disciplines and time. [97] This presents a research opportunity for proper syntheses of evidence. Basic transparency and interoperability protocols could be established among existing databases, enabling both context-specific knowledge and comparability.[98] These efforts would lead to better-informed decisions about when, where, and which hydropower designs are most suitable for each territory and ecosystem, while best addressing the needs of local populations.

Revisiting the dam-development connection

Finally, the renewed momentum around new hydropower technologies and hybrids presents a governance opportunity for governments in the Global South to redefine the role of large dams in development. The Chinese government has aimed to gain a reputation as a country that promotes sustainable development in the Global South. [9999] Although less rigorous than international standards (e.g., the international human rights principle of Free, Prior and Informed Consent (FPIC), the World Commission of Dams guidelines), China has recognized the importance of environmental and social policies and practices, improving compensation for agricultural damages, [100] taken on leadership in pumped storage capacity planning, and participated in the Hydropower Sustainability Assessment Council. Further research should focus on China's efforts to enhance its international reputation in the hydropower sector and how these align with the growing involvement of Chinese banks and companies in dam construction.

Redefining the connection between hydropower and development also requires new discourses. In Brazil, news articles covering hydropower dams prioritize narratives of national progress and economic development, while neglecting the significant environmental and socioeconomic impacts associated with these projects. [101] In the Lancang-Mekong basin polarization has hindered productive dialogue. [102] Further research should explore how "pseudo-facts" are generated and how to counteract the polarization of hydropower discourses effectively. All stakeholders, including the hydropower industry, must collectively work to combat these practices. Disinformation and misinformation, whether intentional or not, are recognized as significant global risks, second only to extreme weather events, [103] and are a challenge for energy and environmental policy [104] and democracy. [105]

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