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Hydropower in South Asia: Challenges, Resilience, and Sustainable Development in the Face of Climate Change and Socio-Political Dynamics

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Abstract

South Asia, characterized by rapid economic growth and increasing energy demands, is turning to hydropower as a cornerstone of its renewable energy strategy. Hydropower offers low-carbon electricity, grid stability, water regulation, and rural electrification, with countries like Bhutan, Nepal, and India relying heavily on it for domestic needs and regional energy trade. However, the hydropower sector faces significant challenges due to climate change, which is altering hydrological regimes and threatening infrastructure reliability. Rising temperatures, glacial retreat, and erratic monsoons have disrupted water flow patterns, complicating predictions of water availability and stressing existing infrastructure. Additionally, hydropower development in the region is shaped by complex socio-political dynamics, including transboundary water governance, geopolitical tensions, and environmental justice concerns. Large-scale dam projects often result in ecological degradation and social displacement, disproportionately affecting vulnerable communities. Despite these challenges, recent technological advancements in turbine design, reservoir modeling, and energy storage offer potential solutions to enhance hydropower resilience and sustainability. Furthermore, integrating hydropower with complementary renewables like solar and wind could address climate vulnerabilities and provide load balancing. This study explores the evolving role of hydropower in South Asia, focusing on climate resilience, energy security, and social equity. It synthesizes technological, environmental, and political perspectives to offer insights into how hydropower can be sustainably developed amid climatic and socio-economic transformations. The study emphasizes the need for adaptive policy frameworks, cross-border cooperation, and inclusive governance to ensure that hydropower development aligns with sustainable development goals and environmental justice principles. Ultimately, the future of hydropower in South Asia hinges on a comprehensive approach that integrates infrastructure, governance, and climate resilience.

Keywords

South Asia, International Conflict, Prevention and Settlement, Electricity Trading

1. Introduction

South Asia, a region encompassing some of the world's most densely populated and environmentally diverse countries, is undergoing rapid economic transformation, urbanization, and demographic shifts. These trends have intensified energy demands, placing unprecedented stress on national power systems and transboundary natural resources (Sun et al., 2020; Yalew et al., 2020). In this context, hydropower has emerged as a central pillar of South Asia's renewable energy strategy, offering not only low-carbon electricity but also vital services such as grid stability, water regulation, and rural electrification (Vaidya et al., 2021; Islam & Mondal, 2013). Countries like Bhutan, Nepal, and India rely heavily on hydropower to meet domestic needs and, increasingly, to foster regional energy trade (Saklani et al., 2020; He, 2022; Haque et al., 2020).

However, the hydropower sector in South Asia is at a critical crossroads. Despite its promise, the sector faces deep structural and environmental vulnerabilities, particularly as climate change alters the fundamental hydrological regimes upon which hydroelectric generation depends (Zhong et al., 2020; Li et al., 2020; Qin et al., 2020). Rising temperatures, glacial retreat in the Himalayas, erratic monsoons, and the intensification of extreme events such as glacial lake outburst floods (GLOFs) and droughts have disrupted seasonal flow patterns and reservoir operations (Aryal et al., 2020; Rasul et al., 2021). These phenomena complicate predictions of water availability and challenge the operational reliability of existing infrastructure, many of which are aging and not designed for such dynamic variability (Yang et al., 2019; Kaunda et al., 2012; Lyu et al., 2023).

Moreover, the socio-political landscape of hydropower in South Asia is fraught with transboundary tensions, governance gaps, and environmental justice concerns (Rampini, 2021; Llamosas & Sovacool, 2021). River systems such as the Ganges, Brahmaputra, and Indus cross multiple national boundaries, entangling hydropower projects in complex geopolitical narratives, power asymmetries, and contested water-sharing frameworks (Saklani et al., 2020; Kharat & Mundra, 2020; Zarfl et al., 2019). Simultaneously, large-scale dam projects often trigger ecological degradation and social displacement, disproportionately impacting Indigenous communities, smallholder farmers, and vulnerable ecosystems (Ogino et al., 2019; Kuriqi et al., 2021; Arias et al., 2014). The lack of gender sensitivity in energy policymaking and decision-making processes further exacerbates these inequities (Govindan et al., 2020).

In the face of these challenges, recent scholarship and policy innovations have explored technological and institutional pathways to enhance hydropower resilience and sustainability. Advances in turbine design, reservoir modeling, and real-time control systems—often supported by machine learning and hybrid optimization algorithms—have improved forecasting accuracy and operational adaptability (Sapitang et al., 2020; Dehghani et al., 2019; Zhou et al., 2020; Ahmadianfar et al., 2021). Pumped-storage hydropower (PSH) systems and complementary integration with solar and wind power also offer promising solutions for load balancing and energy storage, especially as South Asia seeks to diversify its energy mix (Tan et al., 2021; Sanchez et al., 2021).

Nevertheless, significant research gaps remain, particularly in understanding the temporal and spatial dimensions of climate change impacts on hydropower generation, and in integrating the water-energy-food (WEF) nexus into infrastructure planning and governance (Rasul et al., 2021; Sun et al., 2021; Yalew et al., 2020). For instance, studies in regions like China's Pearl River Basin provide transferable insights into the impacts of seasonal climate variability on reservoir operation and power output, yet such analyses are still nascent for major South Asian River basins (Zhong et al., 2020; Li et al., 2020). Furthermore, there is a pressing need for adaptive policy frameworks, cross-border agreements, and participatory governance models that align hydropower development with sustainable development goals and environmental justice (Arango-Aramburo et al., 2019; Saklani et al., 2020; Llamosas & Sovacool, 2021).

This study builds on these perspectives by examining the evolving role of hydropower in South Asia through the lens of climate resilience, energy security, and social equity. By synthesizing technological, environmental, and political dimensions, it aims to contribute to a more nuanced understanding of how hydropower can be harnessed sustainably amidst accelerating climatic and socio-economic transformations. Ultimately, the future of hydropower in the region will depend not just on infrastructure upgrades or technological fixes, but on the integration of inclusive governance, regional cooperation, and science-based adaptation strategies.

2. Conventional Hydropower: Principles of Operation and Climate Change Challenges in South Asia

2.1. Working Principle of a Conventional Hydropower Plant

The working principle of a conventional hydropower plant is founded on the efficient conversion of the natural energy contained in flowing or falling water into usable electrical power. This process involves a sequence of carefully engineered stages, each playing a vital role in harnessing the energy of water in a sustainable and controlled manner. It begins with the construction of a dam across a river to form a reservoir, **Figure 1** which stores a large volume of water

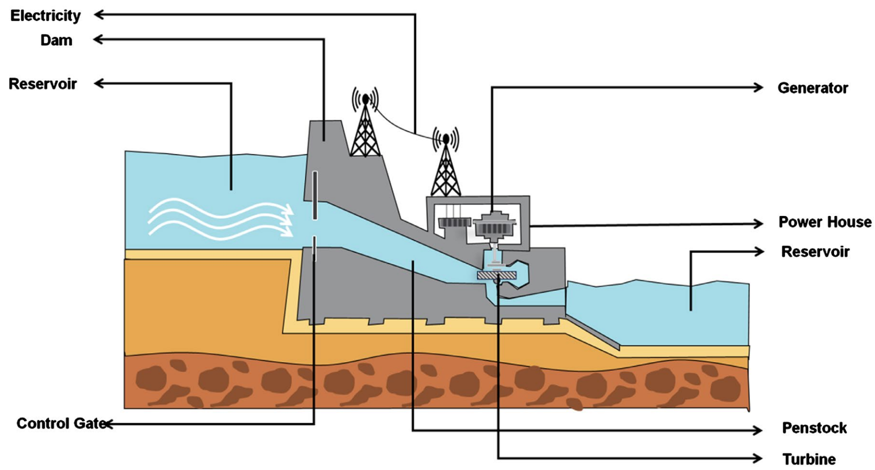

Figure 1. Schematic representation of a hydroelectric power plant.

at an elevated height. This elevation provides the water with substantial potential energy, making it the core energy source for electricity generation. The reservoir acts not only as an energy reserve but also helps regulate the flow of water to ensure a steady and predictable supply for power generation throughout the year, even during dry seasons (Kumar et al., 2011). When electricity demand arises, water is channeled from the reservoir through an intake structure, equipped with control gates and screens to regulate flow and prevent debris from entering the system (U.S. Department of Energy, 2020). From the intake, water flows into a large, pressurized conduit known as the penstock. The penstock is typically inclined downward, enabling gravity to accelerate the water as it descends, thereby increasing its kinetic energy. This high-velocity water stream then strikes the blades of a turbine located at the lower end of the penstock. The force of the water causes the turbine blades to rotate rapidly, converting the kinetic energy of water into mechanical rotational energy (International Renewable Energy Agency [IRENA], 2015).

The spinning turbine is mechanically connected to a generator, usually housed in a powerhouse adjacent to the dam. Inside the generator, the rotational motion is used to spin a rotor within a magnetic field, initiating electromagnetic induction—a process by which mechanical energy is transformed into electrical energy (World Bank, 2009). The resulting electricity is in the form of alternating current (AC) and is then passed through a step-up transformer, which increases its voltage to a level suitable for long-distance transmission. High-voltage transmission minimizes energy losses during transport, ensuring that electricity can be efficiently distributed to homes, industries, and cities located far from the hydropower plant (Paish, 2002).

After its energy has been extracted, the water is discharged through an outflow channel called the tailrace, where it rejoins the natural river downstream. This ensures that the ecological flow of the river is maintained, reducing the environmental disruption that may otherwise occur (Gleick, 1993). The entire cycle—storage, release, energy conversion, and reintegration into the river—demonstrates how hydropower harnesses the natural water cycle for clean energy generation. Conventional hydropower systems such as this offer a wide range of benefits. They produce electricity without burning fossil fuels or emitting greenhouse gases, thus contributing significantly to climate change mitigation (REN21, 2021). Moreover, hydropower plants provide auxiliary services such as water supply for irrigation, flood control, and recreational opportunities (International Energy Agency, 2020). In regions like the Himalayas and other mountainous terrains where rivers possess high flow and elevation gradients, such systems are particularly advantageous and have become critical components of national energy strategies. By utilizing a renewable resource in a closed-loop system, hydropower exemplifies the synergy between engineering innovation and environmental sustainability.

2.2. The Impact of Climate Change on Hydropower Development in South Asia

South Asia, home to some of the most populous and climatically sensitive countries, faces significant challenges due to climate change, particularly in the context of hydropower development. The region's reliance on hydropower as a primary source of energy for its rapidly growing economies is growing, but it also faces vulnerabilities that arise from climate-induced changes in hydrological patterns. These impacts include altered precipitation patterns, glacial retreat, and extreme weather events, all of which contribute to the unpredictability of water resources. This creates both risks and opportunities for hydropower development, with profound implications for energy security, economic stability, and social equity.

Altered Water Availability

One of the most significant impacts of climate change in South Asia is the alteration of precipitation patterns, which directly affects the availability and predictability of water for hydropower generation. In regions like the Himalayas and the Hindu Kush, glacial meltwater is a vital source of water for rivers that feed hydropower plants (Shrestha et al., 2015). However, rising temperatures are causing glaciers to retreat at an alarming rate, threatening the seasonal flow of rivers that depend on glacier-fed runoff (Kang et al., 2019). This has been particularly problematic for countries like Nepal, Bhutan, and India, where hydropower constitutes a large share of the energy mix (Gautam et al., 2020).

Increased frequency of droughts and unpredictable rainfall patterns further complicate hydropower development, reducing the reliability of existing projects and diminishing the potential for future investments (Meldrum et al., 2013). For instance, the Indus River in Pakistan has experienced reduced flow during periods of drought, affecting hydropower production and energy supply to the country (Immerzeel et al., 2010).

Glacial Retreat and Seasonal Shifts

Glaciers in the Himalayas are retreating at an accelerated pace, which initially led to an increase in water flow in rivers, but over time this trend is expected to reverse. As glaciers recede, the long-term impact will be a reduction in water availability during the dry season, which is critical for hydropower plants that rely on consistent water flows (Murtaza et al., 2014). This poses significant risks to hydropower infrastructure and energy production in countries like Nepal and Bhutan, where hydropower development has been prioritized as a clean energy source (Rana et al., 2021).

Moreover, as rainfall patterns shift, countries in the region are experiencing an increased frequency of extreme weather events, including floods and cyclones, which can damage hydropower infrastructure, disrupt electricity supply, and lead to costly repairs (Sarker et al., 2016).

Socioeconomic and Environmental Justice Implications

While hydropower can offer a clean and renewable energy source, the development of large-scale projects often leads to displacement of local communities, loss of biodiversity, and disruptions in local economies. These negative impacts disproportionately affect marginalized and vulnerable populations, such as indigenous communities living in river basins and floodplains (Ranjan et al., 2018). In the context of climate change, the vulnerability of these communities to both environmental and social disruptions is heightened, as they may already be facing the consequences of extreme weather and shifting livelihoods due to changing water availability. Furthermore, the management of hydropower resources often lacks proper environmental safeguards, which exacerbates the adverse impacts on both ecosystems and communities (Sharma et al., 2020). As climate change intensifies, addressing environmental justice concerns becomes increasingly important to ensure that hydropower projects contribute to sustainable development while minimizing harm to vulnerable groups.

The impact of climate change on hydropower development in South Asia is multifaceted, with both challenges and opportunities for energy security, economic stability, and environmental sustainability. As hydropower remains a central element of South Asia's renewable energy strategy, it is crucial for policymakers to integrate climate change projections into hydropower planning, prioritize climate-resilient infrastructure, and ensure the equitable distribution of benefits from these energy projects. Future hydropower development must balance the need for clean energy with the risks posed by climate change, while also considering the social and environmental dimensions of these projects. Adaptation strategies, including diversifying energy sources, improving water management, and protecting vulnerable communities, will be essential in navigating the challenges posed by climate change in the hydropower sector in South Asia.

3. Hydropower Generation and Coordination between Countries

3.1. Hydropower Generation in the Eastern Himalayan Region and South Asia

The eastern Himalayan River system, primarily comprising the Brahmaputra and the Ganga rivers, plays a central role in shaping the hydropower potential and regional energy dynamics of South Asia. These river basins traverse and are shared by several countries, including China, India, Bhutan, Nepal, and Bangladesh, with their headwaters located in the glaciated regions of the Himalayas. While the

Ganga originates in the western Himalayas, both rivers feed a complex and interdependent hydrological network that sustains vast populations and ecosystems downstream. This transboundary nature necessitates cooperation among riparian nations, which, to date, has largely taken the form of bilateral agreements—with India acting as the central node in most of these collaborations.

The seasonal nature of river flows and the corresponding patterns in energy demand across these countries create a unique opportunity for regional cooperation in energy sharing. For instance, peak hydropower generation in countries like Bhutan and Nepal, driven by summer monsoon flows, often coincides with increased energy demand in India and Bangladesh. This natural synergy has encouraged power trade and joint infrastructure projects, especially between India and its smaller Himalayan neighbors. Such cooperation not only optimizes the use of renewable energy but also strengthens economic and diplomatic ties in a historically complex region.

A closer look at the current energy production mix across South Asia reveals the significant role hydropower plays in some nations while highlighting the continued dependence on fossil fuels in others. As shown in **Table 1**, Bhutan and Nepal stand out with nearly exclusive reliance on hydropower, generating 100% and 99.8% of their electricity from this renewable source, respectively. This reflects both their abundant natural hydrological resources and limited domestic fossil fuel reserves. In contrast, countries like Bangladesh and India remain heavily reliant on combustible fuels, which account for 98.3% and 81.7% of their electricity production, respectively. Pakistan, though more diversified, still relies on fossil fuels for 66.7% of its power, while generating a notable 26% from hydropower. Afghanistan also emerges as a hydropower-dependent nation, sourcing 84.7% of its electricity from hydro resources.

Table 1. The portion of the total power generated.

	Total production of electricity (GWh)	Hydro (%)	Wind (%)	Solar (%)	Other sources (%)	Combustible fuels (%)	Nuclear (%)
Bangladesh	73,158	1.4	a	0.2	-	98.3	-
India	1,490,293	8.5	2.6	1.7	3.0	81.7	2.6
Pakistan	123,533	26	1.2	0.5	-	66.7	5.6
Afghanistan	1098	84.7	-	-	-	15.3	-
Bhutan	7730	100	a	-	-	0	-
Nepal	4639	99.8	0.1	a	-	-	-

The disparity in energy generation profiles across the region highlights both challenges and opportunities. The heavy reliance on fossil fuels in Bangladesh, India, and Pakistan contributes to greenhouse gas emissions and exposes these nations to fuel price volatility and supply insecurity. In contrast, the hydropowercentric models of Bhutan and Nepal offer a cleaner, more sustainable path—albeit one that is vulnerable to seasonal fluctuations and climate-induced changes in water availability. As climate change and environmental concerns intensify, efforts are underway to diversify energy portfolios and transition towards more sustainable alternatives. The rise of solar and wind energy, although currently minimal in the region—with solar contributing only 1.7% in India and less than 1% elsewhere—suggests a growing recognition of the need to harness a broader range of renewables. Future energy strategies are likely to focus on reducing dependence on fossil fuels, expanding cross-border energy trade, and leveraging the complementary strengths of neighboring countries. In this context, hydropower stands out not only as a key energy source but also as a catalyst for regional integration and cooperative development in South Asia.

3.2. Coordination between Countries for Hydropower Development

3.2.1. Indian and Bhutan Collaboration in Water

The initiative between India and Bhutan to solve problems relating to water was launched at this point. The creation of networks for hydrometeorological and flood forecasting along Bhutan's and India's shared rivers was conducted in 1955 and 1979. The system provides a model for resource and information exchange across nations with constrained resources. Additionally, the Joint Group of Experts on Flood Management (JGE), which was founded in 2004 has been meeting to review proposed corrective measures and examine the flooding as well as erosion issues seen in the southern of Bhutan and the nearby region of India (Table 2).

Table 2. Agreements for hydropower in the area.

Beneficiary countries	Hydro co-operation		Power Co-operation
	Hydro Agreements	Present Situation	
Nepal and India	Kosi Pact	Signed for in 1954 the purposes of preventing erosion, irrigation, and the production of hydroelectricity.	The nation of Nepal aims to advertise abroad electricity to India and Bangladesh through India while a net energy importer. The 900 MW Arun-3 and Upper Karnali projects, supported by the public and private sectors of India are viewed as game-changers for regional energy cooperation.
	Gandak Pact	For the creation of power and land irrigation, signed in 1959	-
	Mahakali pact	According to Nepalese analysts, the pact is significant since it was drafted within Nepal's conditions.	-
India and Bangladesh	Treaty of Ganges	Signed in 1996 and good until 2026 for the Farakka Barrage's share of the Ganges Waters.	Agreements reached between Indian and Bangladeshi public/private organizations for the production, provision, and/or financing of more than 3600 MWh of energy.
India and Bhutan	Networking plan for hydrometeorological data	On the subject of flood predictions and disaster management, there is active communication and data exchange.	India and Bhutan are working together to construct hydropower projects to meet their respective 2020 power-generating goals.

Continued

India and China	Data-sharing agreements for reducing the risk of disaster	Collaboration between the two countries in the distribution of flood information and emergency warnings for the Brahmaputra river.	-
Nepal and Bangladesh	-	-	Collaboration among the governments of Bangladesh and Nepal to transport energy

3.2.2. Power Generation between India and Bhutan

The hydroelectric projects Punatsangchu-I (1200 MW) and Punatsangchu-II (1020 MW) are under the construction, India and Bhutan are waiting for them to be finished. The 720 MW Mangdechu projects, which were funded by a 30% grant and a 70% loan, was their fourth joint venture and it was established in 2019. In addition, a Joint Venture (JV) agreement is used to create four other projects, namely Kholongchhu, Bunakha, Wangchu and Chamkarchu Hydropower is anticipated to generate three-quarters of government income and half of Bhutan's GDP, even though a large percentage of the labor and knowledge for these projects originates from India. Bhutan does confront difficulties such as rising domestic energy needs and the effects of climate change on hydropower production. Growing research points to social and environmental impacts that might restrict future power exports and minimize the significance of hydropower as a source of revenue for the nation. Despite Bhutan's small industrial base, lack of economic diversification and the MSME sector's low value and productivity, hydropower is expected continue to play a vital role in the country's economic growth and in bilateral cooperation between India and Bhutan.

3.3. India and Bangladesh Collaboration in Water

There is a long history of collaboration between India and Bangladesh both colonial possessions of the British Empire until 1971 and which share a network of 54 rivers. It was hailed as a wise diplomatic gesture. This treaty's main goal is to improve the cooperative water allocation between these bordering nations. The deal has made it easier to share water during dry seasons, but key requirements like raising the water flow at Farakka in the Gangaremain unmet. The pact only focuses on water allotment, failing to consider the river's diverse worth and uses. A framework pact for increased collaboration in hydro management was agreed by the major leaders of both nations. There have been disagreements about India's unwillingness to provide information and Bangladesh's environmental concerns related to upstream water withdrawals as shown in Figure 2.

Power Generation between India and Bangladesh

It is a common knowledge that interregional cooperation can be seen in the electrical industry as the cases of Bangladesh and India. To simplify the energy transfer from India to Bangladesh, which lacks adequate power, the first link between the two nations was established in 2013. India supplies 1160 MWh of electricity to Bangladesh. Up to 1540 MW more power might be sent from India to Bangladesh due to the building of additional lines. Public and private businesses in Bangladesh and India have linked agreements for the production, provision and financing of more than 3600 MWh of energy. India and Bangladesh have reached an understanding about the idea of a "power corridor". It would let India to use Bangladeshi land to link its northern provinces to its central region. The use of India's transmission networks for exporting 500 MWh of electricity by Bangladesh and Nepal is also approved in principle.

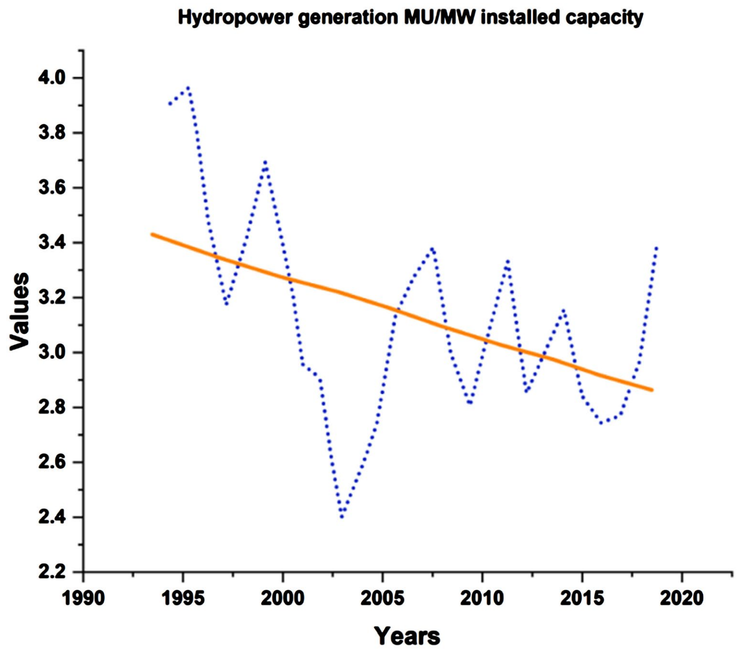

Figure 2. Hydropower performance.

3.4. India-Nepal Collaboration in Water Management

The standard flow of water from the Himalayan ranges to the Ganga has allowed Nepal and India to coexist in a symbiotic connection that keeps physically connected and fosters a strong cultural bond. Sacred Hindu pilgrimages have thrived for millennia are known as tirthas, or auspicious pilgrimage destinations, along the banks of Ganga and its tributaries. However, the actual water cooperation activities that were started in 1874 marked the formalization of this long-standing free movement of people and goods between the two countries. Barrage building in Nepal helps with flood control, energy production and water routing for cultivation. Cooperation among investigators, engineers, as well as managers of water resources is critical for addressing Nepal's complex water-related concerns (Sharma & Sharma, 2025) Three crucial accords controlling that flow through Nepal and into India serve as the foundation for these initiatives. These agreements stipulate the amounts of water allotted to each country, the duties and obligations of each nation in utilizing water-related advantages, and the control over infrastructure development. All the barrages listed in these agreements have been finished, which is significant since fulfillment of the Pancheshwar multipurpose project depends on a mutual understanding of its specifications.

Power Generation between India and Nepal

In Nepal, the hydropower plan is to satisfy domestic energy consumption demands to export any extra energy to its neighbors. Nepal continues to be a net energy importer in 2018-19, with an annual power consumption of 6394.38 GWh. domestic energy production produced 62.75% of this energy, whereas imports comprised the remaining 37.25% from India. Nepal expects to sell power abroad in the future due to the functioning of the new hydropower project. Currently under development are facilities with a total installed capacity of 7952 MW. After providing Nepal with a piece of the free electricity promised (21.9% or 197 MW), the business has started construction on the hydroelectric project to export produced power to India using a particular transmission line. Similarly, the Upper Karnali Hydropower Project, supported by the private Indian business GMR, aims to create energy with Nepal before exporting it to Bangladesh using India. GMR and the Bangladeshi government have agreed upon the particular Power tariffs. Nepal and India inked a crucial deal in 2019 to build a 69 km pipeline between Motihari, Bihar, and Amlekhgunj, Nepal, and cooperate on hydropower projects as shown in Figure 3. This would enable commerce in petroleum products between the two countries.

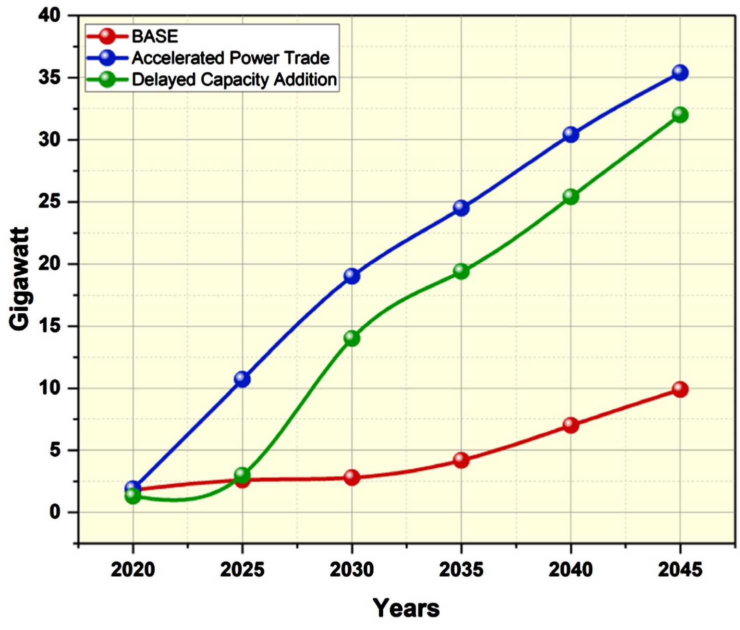

Figure 3. The capacity of Nepal's installed power-generating.

3.5. India-China Collaboration in Water Management

The bilateral memorandum of understanding between China and India, which had expired in 2007 was renewed in 2018 with the aim of fostering strategic trust and communication by exchanging hydrological data during the Yarlung Zangbo flood season. Since information exchange is permitted during the flood season, however, execution of the agreement is difficult. The agreement's scope is limited to specific local parts of the larger problem of integrated water management and excludes any methods for resolving disagreements, not even for data sharing. China declined to provide India access to its data. despite a bilateral agreement, it was claimed that the Assam floods in 2017 caused more damage than required. Even though the two countries have an expert level mechanism on Trans-Border Rivers, there is much space for improvement in terms of their collaboration between countries on water concerns.

Power Generation between Nepal and Bangladesh

Nepal traveled to Bangladesh to work with them, to use Nepal's large hydropower potential to address Bangladesh's energy needs after forging energy cooperation deals with China and India. Bangladesh is a natural gas-dependent country. The Joint Steering Committee (JSC) for Power Sector Cooperation between Nepal and Bangladesh had its first meeting in December 2018 off discussions on different facet of energy cooperation. The potential for power exchange, investments in hydropower development, the creation of transnational links, and the discussions concerned the development of energy production and utilization in the field of solar home systems. Due to Nepal and Bangladesh's intrinsic reliance on Indian transmission infrastructure for electricity trade, these restrictions are vital. In order to support Bangladesh's ambitious plan to import a sizable quantity of electricity from Nepal during the next ten years, a historic agreement has been made. With this arrangement, a sizeable amount of electricity (measured in MWh) would be purchased from Nepal's 900 MW Upper Karnali hydropower plant. A Joint Working Group (JWG) has been looking at possibilities for cooperation between Nepalese and Bangladeshi authorities in the electricity sector. This partnership intends to increase capacity and experience in fields including energy conservation, industrial reforms and energy efficiency. It's important to note that South Asia has a huge untapped hydropower potential resource, which makes this partnership even more viable. Bhutan used 10%, Nepal used 3%, while Afghanistan only used 1% of its hydroelectric capacity in 2019 (**Table 3**).

Table 3. Install and potential hydroelectric capacity.

Country	Installed capacity as a percentage of potential ability (%)	possible capability (MW)	installed power (MW) (various years)
Bangladesh	15	1887	235 (2018)
India	36	148,721	50,413 (2020)
Bhutan	12	23,758	2336 (2019)
Nepal	6	42,915	1129 (2019)
Pakistan	18	59,786	9900 (2019)
Afghanistan	15	23,000	333 (2019)

The extent of the potential's actual development and its viability remain in doubt. It appears that additional hydropower development is possible while considering the supply side. However, this cannot be done without international collaboration. A vision for the region's growth hasn't existed in the past. However, hydropower offers millions of South Asians living there a chance to grow.

4. Discussion

While South Asian nations have made significant progress in ensuring energy access for their populations, the region still faces challenges related to low per capita power consumption and unreliable energy supply. As industrialization progresses, energy demand is expected to rise substantially, making it increasingly difficult to meet this need without increasing atmospheric carbon emissions. Given the global push toward reducing reliance on fossil fuels, hydropower presents a promising alternative. It is considered a safe, reliable form of energy storage and a renewable resource that can significantly contribute to achieving energy security in South Asia. However, the full hydropower potential in the region remains largely untapped, and the development of hydropower continues to be a contentious issue (Kumar & Singh, 2017).

Proponents of hydropower argue for rapid expansion, citing the substantial energy potential it offers, while opponents raise concerns about its negative impacts on social and environmental systems. The large-scale development of hydropower projects can result in significant ecological disruption, displacement of communities, and adverse social outcomes. As such, balancing energy demand with environmental and social sustainability will be crucial in shaping the future energy landscape of South Asia. To address these concerns, this study employs a risk-analysis approach, evaluating hydropower from multiple perspectives, including cost-effectiveness, sustainable social and environmental practices, and the potential of alternative complementary energy sources (Shah & Joshi, 2019).

Hydropower advocates suggest a moderate approach, one that recognizes the need for growth while addressing environmental and social issues. This approach underscores the long-term economic viability of hydropower, which, while inexpensive in the near term, could lose its cost advantage over time. The cost trajectory of alternative renewable energies, such as solar, wind, and biomass, along with advancements in technology, will influence hydropower's position as the primary energy source in South Asia (Bhattarai & Shrestha, 2020). The World Power Outlook 2018 suggests that solar power could surpass hydropower and coal in terms of installed capacity by 2030 and 2040, respectively. While this highlights the growing competitiveness of solar energy, hydropower still holds significant potential as a dependable and efficient energy storage solution.

A key factor in realizing hydropower's potential will be the role of national politics and policies within South Asia. Effective governance and regional cooperation will be necessary to foster the development of hydropower in a way that minimizes its environmental and social impacts. A comprehensive approach to managing risks and incorporating climate change considerations into hydropower projects can enhance their long-term sustainability. All hydropower initiatives should be accompanied by specific Environmental Impact Assessments (EIAs) to identify potential repercussions, with mitigation strategies and sustainability plans in place. Additionally, the design of hydropower projects should incorporate the potential benefits of climate change adaptation and multifunctional project considerations, ensuring that these projects contribute to broader regional development goals (Shah & Joshi, 2019).

In conclusion, while hydropower remains a critical part of South Asia's energy future, its growth must be carefully managed to balance the increasing demand for energy with the need to protect the region's social and environmental systems. By adopting a holistic approach to hydropower development, the region can harness its energy potential while safeguarding long-term sustainability.

5. Conclusion

Hydropower plays a crucial role in South Asia's energy landscape, providing a renewable and scalable solution to meet the region's growing electricity demands while helping to mitigate carbon emissions. However, its development is deeply intertwined with the challenges posed by climate change and the complexities of transboundary water governance. Increasing temperatures, shifting precipitation patterns, and more frequent hydrological extremes threaten the stability and reliability of hydropower infrastructure, necessitating the adoption of adaptive strategies. These strategies should incorporate climate projections into reservoir management and energy planning to ensure the long-term sustainability of hydropower.

The collaborative efforts between India and its neighbors—Bhutan, Nepal, and Bangladesh—illustrate the importance of bilateral agreements in promoting resource sharing, disaster mitigation, and cross-border energy trade. These partnerships demonstrate the potential for regional cooperation but also highlight significant gaps in addressing environmental and social impacts, including displacement, ecological degradation, and inequitable distribution of benefits.

For hydropower to play a key role in a sustainable energy future, South Asian nations must embrace integrated river basin management approaches that prioritize ecological resilience and inclusivity in decision-making. Comprehensive Environmental Impact Assessments (EIAs) and long-term sustainability plans are critical to balancing the need for energy production with the preservation of ecosystems. In addition, diversifying the energy mix with complementary renewable sources—such as solar and wind—can help mitigate the climate-related vulnerabilities of hydropower and reduce dependence on fossil fuels.

Strengthening regional institutions for transboundary water governance and harmonizing policies across borders is vital for preventing conflicts and improving grid stability. As hydropower's future depends on effective governance, a shift toward adaptive, equitable, and collaborative management will be key. By integrating technological advancements, fostering trust through multilateral cooperation, and embedding climate resilience into infrastructure design, South Asia can fully realize its hydropower potential.

To ensure hydropower remains central to the region's sustainable energy transition, it is essential to balance progress with ecological and social well-being. This will require not only engineering expertise but also a long-term commitment to creating a more equitable, climate-resilient future for all.

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Conflicts of Interest

There are no conflicts of interest.

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