Hydropower Development in Nepal: Achievements and Opportunities

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Abstract

This article has assessed the progress and opportunities within hydropower sector of Nepal. It has emphasized its pivotal role in shaping the economic future the country. Hydropower has been integral to development of Nepal, with its journey beginning over a century ago. Despite challenges such as political instability, limited infrastructure, and financing difficulties, significant achievements have been made. The study highlights opportunities for further growth, particularly in large-scale and multi-purpose hydropower projects. The article has explored the roles of government, the private sector, and international cooperation in driving sustainable hydropower development. It has given some recommendations to overcome challenges and maximize future opportunities. Emphasizing environmental and social considerations, the study suggests that hydropower will continue to be central to the economic ambitions and its transition to a greener, more resilient energy future of Nepal.

Keywords: *hydropower development, Nepal energy sector, economic growth, sustainable energy, infrastructure challenges, renewable energy opportunities*

Introduction

Nepal is known for its diverse topography and mountainous terrain. It one of the richest countries in terms of hydropower potential. Its steep slopes and abundant water resources create ideal conditions for generating hydroelectric power. With an estimated potential of 83,000 megawatts (MW), Nepal has the capacity to become a major hydropower producer not only for domestic consumption but also for export to neighboring countries (Ghimire et al., 2019). Hydropower development is critical for economic growth and energy security of Nepal. As the country seeks to reduce its dependence on imported fossil fuels and address frequent power shortages. The expansion of the hydropower sector is essential for industrialization, rural electrification, and poverty alleviation (Lohani et al., 2023). The export of surplus electricity to energy-deficient countries like India and Bangladesh could turn Nepal into a regional energy hub, contributing significantly to national revenue.

The purpose of this article is to assess the achievements made in Nepali hydropower sector and to explore the opportunities that lie ahead. Examining both the progress and challenges in this vital industry, the study to highlight its role in shaping future economic landscape of Nepal.

Hydropower Development in Nepal

Achievements and Opportunities

Hydropower is one of the most critical sectors for development and prosperity. With abundant potential, this sector has been a key contributor to the economic growth. The aspect hydropower development is the practice of present shares in projects to those directly affected by construction. This inclusive approach ensures that local communities benefit from the development process, both economically and socially.

The journey of Nepalinto harnessing its hydropower potential began in the early 20th century with the

completion of the Pharping Hydropower Project in 1911, a modest 500-kilowatt (kW) project. It marked the beginning of electricity generation in the country. Although small, this project was a significant achievement for the country with minimal infrastructure. The early hydropower projects helped provide power to urban centers like Kathmandu, supporting basic industrial and residential needs (Shrestha,2022).

It has been almost 112 years since Nepal's relationship with hydropower projects was established. Pharping hydropower project is the first hydropower project in Nepal and this project has secured the golden history and glory of the second project in Asia (K. C. et al., 2011). From Taplejung in East Mechi to Darchula in West, 6000 MW electricity purchase and sale agreement has been signed and so far, about 2700 MW has been connected to the electricity grid. The other projects of 3300 MW are under construction. Nearly 240 different projects in Nepal are waiting for the Power Purchase Agreement (PPA) to start the process of generating 11716 megawatts of electricity after studying the feasibility (Shrestha,2022).

Despite the challenges, Nepal has achieved significant progress in expanding its hydropower capacity. Major projects such as the Kali Gandaki A Hydroelectric Plant (144 MW), Upper Tamakoshi Hydropower Project (456 MW), and Middle Marsyangdi Hydropower Station (70 MW) have been successfully completed. These projects have contributed substantially to the country's total installed hydropower capacity, which now exceeds 2,000 MW (Ghimire et al., 2019).

The Upper Tamakoshi Project, completed in 2021, stands as a milestone in Nepali hydropower journey, being one of the largest projects funded almost entirely through domestic investment. The project significantly increased Nepal capacity to meet its growing energy demands and reduce its reliance on imported electricity (Singh et al., 2020).

About 50 MW of multi-fuel, diesel plants are closed, cutting the various projects that are in breakdown, about 2400 MW of electricity is the daily production today. The maximum daily peak load of Nepal Grid is 2000 MW while the off-peak consumption is 1600 MW. For some time, nearly 400 MW of electricity is being exported to India every day. The Kulekhani first hydropower project built by damming the Indrasarovar lake is 60 MW and its cascade is the second 32 MW and the third 14 MW, which produces a total of 106 MW of electricity storage projects. Apart from this, the pre-storage projects have not come into operation. There are many ambitious projects in Nepal, including the 1200 MW Tamor, the 756 MW Tamor, the 6,480 MW Pancheswar hydroelectric project, which are waiting for the right time, management and politicians in Nepal(Lohani et al., 2023).

For the Budhigandaki hydropower project, which has been shown readiness to be implemented for 30 years ago. The plan has not been implemented even though the funds have been collected in the name of collecting money from the public through fuel sales. After studying the subject of hydropower to build the Pancheswar hydropower project of 6 thousand 480 megawatts(Ghimire et al., 2019). Nepal has entered a new era of energy self-sufficiency, as electricity is now regarded as a basic necessity for all. Hydroelectric power, which is clean, renewable, and relatively easy to transport and distribute, has become a cornerstone of Nepal's energy strategy. Globally, electrical power has emerged as an environmentally friendly alternative, driving industrial, commercial, and domestic growth.

Expansion and Challenges

In recent years, Nepal has been ramping up its hydropower projects with the goal of boosting its economy through increased electricity production and trade. Despite the immense potential, the hydropower sector has faced significant challenges, particularly during the COVID-19 pandemic. The

global outbreak brought many sectors to a standstill, and hydropower was no exception (Ghimire & Gautam, 2022).

During the pandemic, electricity consumption in Nepal plummeted due to the shutdown of industries, hotels, and factories, leaving many power projects operating below capacity. The demand for electricity dropped to just 600–800 megawatts, far below the country's potential. The oversupply, coupled with limited consumption, led to financial losses in the sector, and ongoing construction projects were also delayed (Butchers et al., 2020).

To mitigate the impact, the government introduced subsidies for small and medium industries to encourage greater electricity consumption. It also promoted the use of electric vehicles and appliances, aiming to reduce dependence on imported fossil fuels and increase domestic energy consumption. However, these plans were largely derailed by the pandemic, as lockdowns and restrictions brought the industrial sector to a halt, and demand for electricity remained stagnant.

The Electricity Regulatory Commission (ERC) was established to streamline and ensure transparency in electricity generation, transmission, and distribution. In recent years, the ERC has worked to make the sector more efficient and consumer-friendly. Last year, the commission attempted to provide electricity at reduced rates, but progress was stalled due to delays in receiving necessary data from the Nepal Electricity Authority (NEA). The commission has also been addressing disputes over the use of trunk lines and dedicated transmission lines, aiming to resolve lingering issues from previous years. Despite efforts to improve transmission infrastructure, many areas in Nepal, such as the Koshi, Marsyangdi, and Solu corridors, still suffer from insufficient transmission lines, preventing generated electricity from reaching key regions. (Shrestha,2022)

Government Policies and Initiatives

In the decades that followed, Nepal government recognized the strategic importance of hydropower and introduced several policies to facilitate its development. Key milestones include the Hydropower Development Policy of 1992, which encouraged private sector participation and foreign investment in the sector. This policy shift opened the doors to independent power producers (IPPs) and saw the rise of numerous public-private partnerships in hydropower development. The establishment of the Nepal Electricity Authority (NEA) in 1985 further consolidated efforts to enhance power generation, transmission, and distribution across the country (Rana, 2020).

Despite the government's commitment to hydropower development, the sector continues to face regulatory and policy challenges. Delays in the approval of projects, unclear guidelines, and frequent policy shifts have caused uncertainty among investors and developers. The Electricity Regulatory Commission (ERC), while working to streamline operations and ensure transparency, has faced difficulties in enforcing consistent tariff structures and resolving disputes (Rana, 2020).

Further complicating matters, land acquisition and issues related to the displacement of local communities often lead to delays. Regulatory reforms are needed to simplify the approval process, promote transparency, and ensure that developers adhere to environmental and social safeguards.

Contribution of Hydropower to Energy Mix of Nepal

Hydropower plays a pivotal role in Nepali energy mix, contributing nearly 90% of the country is total electricity generation. As a clean and renewable energy source, hydropower has allowed Nepal to reduce its dependence on fossil fuels, moving toward sustainable energy development (Asia (Zou et al., 2022). With ongoing projects and future plans,

hydropower is expected to remain the backbone of energy sector of Nepal, contributing to both domestic consumption and export to neighboring countries.

Impact on Rural Electrification and Economic Growth

One of the most profound impacts of hydropower development has been its contribution to rural electrification. The extension of electricity to rural areas, previously reliant on traditional energy sources, has brought numerous benefits. Improved access to electricity has enhanced living standards, supported education, and boosted local economies through the establishment of small industries and businesses. Hydropower has also created employment opportunities during construction and operational phases, thus contributing to the national economy (Shrestha, 2022).Moreover, with the increase in power generation capacity, Nepal has been able to transition from being an energy-deficient country to one that is exploring opportunities to export electricity. This transition has had a direct impact on economic growth, as industries, factories, and businesses now have more reliable and affordable access to energy.

Current Status and Future Scope of Hydropower Development in Nepal

The mountainous terrain and fast-flowing rivers offer immense untapped hydropower potential in Nepal. Out of an estimated 83,000 MW of theoretical potential, only around 2,000 MW has been developed to date. This leaves substantial room for growth, particularly in large-scale and multi-purpose projects that could generate electricity, support irrigation, and control flooding. With advancements in hydropower technology, even smaller rivers and streams can be harnessed more efficiently, creating opportunities for decentralized power generation in remote areas (Pakhtigian, et al., 2021).

Additionally, the geographic position between two large energy markets India and China presents a significant advantage. The country could play a key role as an energy corridor, exporting surplus electricity to these neighboring countries, both of which have rapidly growing energy demands.

Potential for Cross-Border Hydropower Cooperation

Cross-border cooperation in hydropower is a promising avenue for future growth of Nepal. Agreements with India, such as the Power Trade Agreement (PTA) signed in 2014, allow Nepal to export electricity to India, providing a steady source of revenue. Similarly, discussions with Bangladesh and China have opened up opportunities for long-term energy trade. Hydropower development in Nepal could thus transform the country into a regional energy hub, with the potential to supply power to energy-deficient regions in South Asia (Bishwakarma,2020). It focuses on joint projects and creating a seamless energy grid, Nepal could collaborate with its neighbors to develop large hydropower plants with shared benefits. Such cooperation would require harmonized policies, infrastructure investment, and enhanced diplomatic relations.

Role of Hydropower in Promoting Sustainable Development and Climate Resilience

Hydropower is a renewable, low-carbon energy source, making it central to the sustainable development agenda. As the world shifts toward greener energy sources to combat climate change, Nepal is in a unique position to leverage its natural resources for climate resilience. Expanding hydropower will help Nepal reduce greenhouse gas emissions, lessen dependence on imported fossil fuels, and build a more sustainable and self-reliant energy future Asia (Zou et al., 2022).

Moreover, hydropower projects can contribute to climate adaptation by regulating river flows, which

can reduce the risk of floods during the monsoon season and mitigate droughts during dry periods. Multi-purpose hydropower projects that integrate flood control, irrigation, and water supply functions could significantly enhance climate resilience of Nepal (Pakhtigian, et al., 2021).

Challenges and Constraints of Hydropower Development in Nepal

Environmental and Social Impacts

While hydropower is a clean energy source, its development is not without environmental and social consequences. Large hydropower projects can disrupt local ecosystems, affect river biodiversity, and lead to deforestation. They can also have significant impacts on local communities, particularly in terms of displacement, loss of livelihoods, and changes in water access (Pakhtigian, et al., 2021). Environmental assessments and resettlement plans are critical to ensuring that these projects are sustainable and socially responsible. Adopting best practices in environmental management and integrating community benefits into project planning are essential for minimizing negative impacts.

Financial Constraints and Lack of Investment

One of the most significant challenges facing Nepali hydropower sector is the lack of financing. Hydropower projects are capital-intensive, often requiring substantial upfront investments with long payback periods. Securing financing from both domestic and international sources can be difficult due to political instability, currency risks, and an underdeveloped financial market (Bishwakarma, 2020).

Despite efforts to attract foreign direct investment (FDI), the sector continues to struggle with inconsistent policy frameworks, bureaucratic delays, and regulatory hurdles that deter investors. To unlock the sector's full potential, Nepal needs to create a more investor-friendly environment, including clearer regulations, risk mitigation strategies, and incentives for private and foreign investors.

Technical Challenges and Infrastructure Limitations

The rugged geography of Nepal advantageous for hydropower, also presents technical and infrastructural challenges. Constructing large hydropower plants in remote, mountainous areas requires significant engineering expertise and advanced technologies. Poor accessibility to many project sites increases both the cost and complexity of construction. The existing transmission and distribution infrastructure are underdeveloped. (Singh et al., 2020) The lack of adequate transmission lines has resulted in electricity generated in one part of the country being stranded and unable to reach areas where it is needed. Addressing these bottlenecks requires investment in transmission corridors, particularly in regions like the Koshi, Marsyangdi, and Solu corridors, where major projects are located.

Despite these initiatives, the hydropower sector faced significant hurdles in its early stages. Political instability, bureaucratic inefficiencies, lack of investment, and difficulties in constructing infrastructure in Nepal's rugged terrain were among the key challenges. Furthermore, issues related to land acquisition, displacement of local communities, and inadequate transmission infrastructure slowed the pace of development. Hydropower projects, often capital-intensive, also struggled to secure the necessary financing.

Opportunities for Hydropower Development in Nepal for the Future

As Nepal looks beyond the challenges posed by the pandemic, the hydropower sector remains central to its economic ambitions. With significant untapped potential, hydropower can not only meet domestic demand but also position Nepal as a key

energy exporter in South Asia (Singh et al., 2020). Investments in transmission infrastructure, along with policies that promote sustainable energy consumption, will be crucial to realizing this vision. The future of hydropower in Nepal is bright, with opportunities for growth, innovation, and regional cooperation. By addressing current infrastructure gaps and fostering an inclusive development approach, Nepal can transform its hydropower resources into a lasting engine for prosperity (Pakhtigian, et al., 2021).This version is more structured and offers clearer insights into Nepal's hydropower sector, touching on its achievements, challenges, and future opportunities.

Role of the Government, Private Sector, and International Cooperation

The government have a key role in setting strategic goals, creating a stable regulatory environment, and attracting investment. It must act as a facilitator in infrastructure development and policy reform, while ensuring that social and environmental standards are sustained (Rana, 2020).Private investment is vital for hydropower development. The private sector should take the lead in innovation, project development, and capacity building. Companies can also explore new financing models, like public-private partnerships, to advance large projects. International collaboration will be critical for financing, technology transfer, and expertise. Development partners such as the World Bank, Asian Development Bank (ADB), and bilateral agencies can provide technical and financial assistance. As per Singh et al. (2020), international investors and stakeholders can help Nepal build a robust hydropower infrastructure and explore cross-border energy trade (Lohani et al., 2023).

Key Considerations for Sustainable Hydropower Development in Nepal

To ensure the sustainable development and long-term success of hydropower projects, especially in Nepal, the following considerations are critical:

Nepal, being an agricultural country, must prioritize rivers that are or will be vital for agricultural use. Hydropower projects should be prohibited in rivers where a significant portion of the water is expected to be used for future agricultural needs.

With global warming leading to the depletion of rivers, many rivers are likely to become essential sources of drinking water. Hydropower projects should not be permitted in rivers that are projected to supply drinking water in the next five decades, ensuring that future water needs are prioritized over energy production.

The foundation of any hydropower project lies in a thorough study of the geographical stability, soil structure, and water flow, particularly during the dry season. Detailed assessments of these factors should be mandatory before the project is approved.

In Nepal, private energy companies currently bear the burden of managing every stage of a hydropower project, from feasibility studies to construction and operation. In contrast, in most countries, government agencies manage key preparatory activities like detailed project reports, road and transmission line construction, land acquisition, and environmental assessments. By adopting a similar model, Nepal can reduce inefficiencies, prevent redundant infrastructure (such as multiple transmission lines along the same river), and avoid unnecessary damage to village economies and natural beauty. This approach would also eliminate the practice of "locking up" river resources without development, and promote the expansion of road and transmission networks(Butchers et al., 2020).

Many companies or individuals with hydropower licenses lack the financial capacity to implement the projects, posing a significant barrier to hydropower development. Adequate financial assessment and

support mechanisms must be in place to ensure that only capable entities are granted licenses. Feasibility studies and detailed project proposals are critical to the project's success. These sensitive tasks should be conducted only by qualified firms, and these firms should be held accountable for the long-term outcomes of their work, not just their remuneration. A higher standard of responsibility will ensure more accurate and reliable project assessments (Lohani et al., 2023).

The design and structure of the hydropower project should align with the geographical requirements of the site. If meeting these needs would make the project financially nonviable, it would be more prudent to avoid such developments, preventing economic loss to investors and harm to the environment. Hydropower projects can be a major boon for Nepal, but only if they are executed with proper management, modern construction methods, reputable companies, and a complementary plan that minimizes erosion and protects the environment. Timely and efficient implementation is essential for the success of these projects.

Recommendations for Overcoming Challenges and Maximizing Opportunities

To fully capitalize on Nepal's immense hydropower potential and address existing challenges, several key actions are recommended:

The government must create a more conducive environment for investment by simplifying regulations, offering tax incentives, and ensuring policy consistency. Establishing risk-sharing mechanisms, such as insurance for political and financial risks, would help attract both domestic and international investors. Expanding public-private partnerships (PPP) and exploring green bonds could provide innovative financing solutions for large projects.

Investment in transmission lines and grid infrastructure is crucial. The government and NEA should prioritize the construction of transmission corridors, especially in regions where projects are hindered by inadequate infrastructure. Modernizing the national grid to handle intermittent power and ensuring power is distributed efficiently will be essential.

It is critical to integrate comprehensive environmental assessments and social safeguards into all hydropower projects. Community involvement and fair compensation for displaced populations must be central to project planning. Promoting run-of-the-river hydropower projects, which have lower environmental impacts than large storage-based projects, can help balance development with ecological preservation.

The government should streamline the regulatory approval process to reduce bureaucratic delays and ensure a stable policy framework that instills investor confidence. Reforms should also focus on creating a transparent and competitive electricity market, improving tariff-setting processes, and simplifying land acquisition procedures.

Nepal should continue strengthening cross-border energy trade agreements with India, Bangladesh, and China. Developing long-term, mutually beneficial partnerships through regional grids and joint hydropower ventures can significantly boost exports, revenue, and regional energy security.

Conclusion

The future of hydropower development in Nepal is filled with immense opportunities, but also considerable challenges. By addressing financial, technical, and regulatory barriers, Nepal can unlock its hydropower potential to not only meet domestic energy needs but also emerge as a key energy exporter in the region. Sustainable and inclusive development of this sector will be crucial to ensuring that hydropower becomes a pillar for economy and

contributes to global efforts in combating climate change. This sector has vast untapped potential, holds the key to the national economic and energy future. Over the years, significant progress has been made, with several major projects contributing to both domestic electrification and economic growth. However, numerous challenges remain, including financial constraints, infrastructure bottlenecks, and regulatory hurdles.

The future of hydropower development in Nepal looks promising, with the potential to significantly enhance the country's economic prosperity, energy security, and role as a regional energy hub. If Nepal can effectively implement reforms, build infrastructure, and attract investment, the country could harness its vast hydropower resources to meet growing domestic demand and export surplus electricity to neighboring countries. Hydropower will also continue to play a key role in Nepal's efforts toward sustainable development and climate change mitigation, helping to transition the country to a greener and more resilient energy future.

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