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Research Article

Hydropower Development in Nepal: Status, Opportunities and Challenges

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ABSTRACT

Nepal is endowed with huge water resources. The available water resources and altitudinal topography provide the ideal situation for the generation of hydropower. Nepal, since about the century ago had started to generate hydro energy but its development over the time is not satisfactory and importing fossil-based fuel significantly. Based on secondary materials, this paper tries to analyses the status of self-reliant energy generation reviewing its development trend within the country. It outlines the current status of hydropower generation, opportunity associated with it and major challenges therein. Paper argues that though Nepal has developed only 3 % of hydro energy so far, it has been approaching toward saturation of its national demand very soon. Replacement of imported fossil fuel by its self-reliant hydro energy is very urgent action to be adopted but it's quite challenging. The socio-economic transformation of country by utilizing its own generated energy is the most effective way to gear toward the path of prosperity. Acknowledging its major development challenges, formulation of investment friendly policy, power connectivity with reginal economy could drive the nation toward the sustainable development through utilization of naturally endowed water resources.

Keywords: hydropower potential, Policy interventions, Energy demand, Opportunities Add hydrogen fuel as new opportunities

Introduction

Nepal is a landlocked developing country situated between two major Asian nations, China and India. The country boasts significant water resources, characterized by steep altitudinal variations from the towering Himalayas to the low-lying Terai plains, making it highly suitable for hydropower generation. Despite possessing immense potential for hydropower, Nepal experienced severe energy shortages, with load shedding lasting up to 18 hours a day until 2017 (Shrestha et al., 2018). Currently, the nation meets its energy demands through imports from India and limited domestic generation, raising questions about the paradox of power in Nepal.

Hydropower Potential and Development

Nepal's hydropower potential is estimated at 83,000 MW, with approximately 43,000 MW deemed economically feasible (Shrestha, 1966). The country initiated hydroelectricity generation in 1911, with its first plant, the Pharping Hydropower Plant, followed by its neighbors, China and India, starting in 1912 and 1897, respectively (Adhikari, 2006). However, over the past century, Nepal has harnessed only about 5% of its economically viable hydropower potential, indicating a sluggish pace of development (Panta, 2022).

Energy Consumption Trends

Despite the vast opportunities for renewable energy generation, Nepal's energy consumption is dominated by traditional fuels (68%), followed by commercial fossil fuels (23%), and renewable energy sources, which account for merely 9% (MoF, 2021). This reliance on traditional and fossil fuels reflects a significant lag in the development of self-reliant clean energy solutions. To achieve energy independence, the Government of Nepal must ensure electricity access for all sectors, including households, industries, and agriculture, while transitioning from fossil fuels to hydroelectric power (Shrestha et al., 2018).

Challenges in Hydropower Development

The path to generating hydropower in Nepal is fraught with challenges, including high initial investments, the need for multi-sectoral technical expertise, coordination among various sectors, fragile geology, and inadequate infrastructure. Energy generation is crucial for socio-economic transformation, especially for a country like Nepal, which has a complex geopolitical landscape. Dependence on fossil fuels imported from India poses risks of potential energy crises due to political changes or other factors (Shrestha et al., 2018). The 2015 border blockade by India exemplifies the vulnerabilities associated with such dependencies.

Harnessing sustainable and environmentally friendly energy sources is imperative for Nepal to balance economic development and budget gap (Mishra and Aithal, 2022 a&b). , with hydropower being the most viable option to meet the country's energy needs. The government must prioritize the development of this sector to ensure energy security and self-reliance, thereby facilitating economic growth and stability in the region.

Objective

This paper aims to analyze the historical background and current status of the hydro energy sector in Nepal, including hydropower generation technology, policy provisions, and trends in demand and supply, while identifying the opportunities and major challenges associated with hydro energy. Additionally, the study will provide recommendations to support working agencies in enhancing the effectiveness and sustainability of the hydro energy sector.

Methodology

The main methodology of this study is review of secondary materials. This includes some published articles, report of government authorities related to hydropower development, website of stakeholders, energy news articles, hydro related government policies etc. In addition to this, knowledge gained during working in the sector is also incorporated. Overall hydro energy intervention in Nepal is analyzed, from its beginning to the present status using those resources. Also, aspect of technical capacity building, institutional arrangements, demand and supply and its growth

are outlined with some recommendation for robust energy development.

Results and Discussion

Background, Interventions and Current Status

Only 29 years later, when first hydropower built in Wisconsin, USA in 1882, Nepal established first hydro power Pharping plant (500-KW) in 1911 during Prime Minister Chandra Shamsher Rana's time to meet the energy requirements of ruling family (Adhikari, 2006). Even at the present, Nepal is facing the energy crisis, it is fascinating to note that Nepal had such an early history of hydropower generation. In 1936,

Table 1

Summary of Major Interventions in Hydropower Sector in Nepal

Decade	Electricity Generation (MW)		Remarks (Major Interventions)
	Decade gen.	Commutative	
1911-1920	0.5	0.5	Pharping Hydro
1921- 1930	0	0.5	
1931-1940	0.6	1.1	Sundarijal Hydro
1941- 1950	0	1.1	
1951-1960	0	1.1	Incorporated in development planning process
1961-1870	27.5	28.6	Grant projects from India,China, USSR (Trishuli, Panauti projects)
1971-1980	26.7	55.3	
1981-1990	180.3	235.6	Establishment of NEA
1991-2000	125.9	361.5	Involvement of private sector
2001-2010	282.86	644.36	Development of Kalagadi A-144 MW, largest project
2011-2021	484.365	1396	Construction of Upper Tamakoshi -456 MW, is not considered as its generation not officially documented

Note. Adhikari (2006) & NEA (2019)

The second hydropower plant (640 KW) was established at Sundrijal (Shrestha et al., 2018). No significance contribution had been made in the subsequent decades and hydropower development was institutionalized after the initiation of development planning process in 1956. In the meantime, His Majesty Government formed the electricity department to carry out generation, transmission and distribution of electricity, later in 1962, a separate institution named Nepal Electricity Corporation was formed and had given responsibility of transmission and distribution. Small hydropower's were developed at that time with technical and financial support of India, China, USSR, Norway. Also, the technical capacity of Nepalese manpower was significantly enhanced during the time. In addition to this, former technical institutions in hydro industry of Nepal namely, Butwal Technical Institute, Nepal Hydroelectricity were established. In 1985, there was reform in government institution forming Nepal Electricity Authority which was given full responsibility of generation, transmission and distribution of electricity. Water and Energy Commission was formed in 1975 with objective of developing water and energy in integrated manner. Consequently, a permanent secretariat of WEC was formed in 1981 and given the name Water and Energy Commission Secretariats (WECS) .After the formulation of different policies and acts by government such as Hydropower Development Policy (1992) , Electricity Act(1992) and Water

Resource Act(1992); hydro sector became more liberal to ensure hydropower development by attracting private sector investment in the 'Build, Own, Operate and Transfer' (BOOT) mechanism. In 1993, Electricity Development Center was establishment pursuant to Electricity Act and later in 2000, it was renamed as Department of Electricity Development (DoED). Then after, Independ Power Producer (IPP) become more active player in hydropower generation. Making Power Purchase Agreement (PPA) with NEA, private sector has been developing hydropower and selling it to NEA. At present, total hydropower generation has reached 2081 MW, of which 1020 MW is contributed by IPP (NEA ,21/22). Decade wise development of hydropower with major intervention can be summarized in the table 1. Table1 Summary of major interventions in hydropower sector in Nepal

Hydropower Classifications and Status in Nepal

Classification of hydropower differ from county to country and authorities. Based on Nepal's standard, adopted classification may be outlined as below.

Based on Capacity

Based on installed capacity, projects in Nepal are classified in five categories: Micro, Mini, Small, Medium and Large (Baral, 2016). Capacity wise classification is presented in table 2

Table 2

Hydropower Classification based on Installed Capacity

S. No	Classification	Plant Capacity
i	Micro Hydropower project	Up to 100 KW
ii	Mini hydropower Project	100- 1000KW
iii	Small Hydropower Project	1- 25 MW
iv	Medium hydropower project	25-100 MW
v	Large hydropower project	Greater than 100 MW

Source: Baral (2016)

Most of developed projects are of small and mini type. Some medium size and very few large e project is in operation. Kaligandaki -A (144MW) and Upper Tamakoshi (456MW) are the notable large project in Nepal.

Based on functional basis and Operation

i) **Isolated Plant:** In isolated project, it has its own steady demand and power is connected to this local grid. In Nepal, micro and mini projects are in isolated system. AEPC is responsible for managing isolated projects in Nepal.

ii) **Grid connected Plant:** In this system, several projects are connected in one grid and connected from single point In Nepal, all projects are connected to INPS (Integrated National Power system), own by NEA, which is operated through load center at switcher Kathmandu.

Based on storage capacity

i) **ROR/ PROR project:** ROR projects are constructed without considering the seasonal variation of water and power is generated simply diversion of required water without having storage. PROR type, are designed with daily poundage provision thereby meeting peak demand. In Nepal, total installed capacity of those project is 1975 MW (NEA, 21/22).

ii) **Storage project:** In those projects, the seasonal water is stored and can use to generate power in dry season. Those projects are accompanied with dam and reservoir behind it. In Nepal, there are only three storage projects, Kulekhai -I, II and III having capacity of 106 MW in operation (NEA, 21/22).

iii) **Pumped storage projects:** Those projects are designed for balancing. It consists of two

reservoir named lower reservoir and upper reservoir. Off peak electric current is used to lift water from lower to higher elevation and during the time of high demand stored water is used to the turbine and generate electricity. In Nepal, not such plant is developed however few projects are in planning phase such as Begnas Rupa pump storage project.

Capacity Building, Institutional Arrangements and Policy Intervention

Since mid of 1960, Nepal embarked in the journey of hydropower development and parallelly capacity building of Nepal is ongoing. For engineering and design, Nepalese consultant are in joint venture with international consulting companies and even alone doing many projects now. Likewise, for the civil construction, Nepalese companies are leading hydro construction including tunneling projects as well. In the history, Nepal first time use Tunnel Boring Machine (TBM) in Bheri Babai Diversion Multipurpose project in 2017. Further, in the hydromechanical work, Nepal is fully capacitated now and many good firms working in this sector. Nepal do not have any electromechanical supplier company yet and need to depend in Indian and Chinese supplier. Nepalese experts in hydro sector are even delivering their services beyond the country in hydro sector.

Beside the technical capacity building, Nepal now has many institutions who collectively delivering their effort with allocated responsibilities for the hydropower development. The major institutions are: Nepal electricity Authority, Department of electricity Development, Nepal water and Energy Commission Secretariats, Alternative Energy Promotion Centre, Electricity Terrific Fixation Commission, Hydropower Investment and Development Company Limited, Independent Power producer Association Nepal (IPPAN), investment Board of Nepal etc.

To make the hydropower development more liberal and encourage the private sector participation, Nepal government promulgated hydropower power policy in 1992. It was later revised as hydropower policy 2001. Some major provisions in policy can be outlined below.

- Hydropower project to be implemented through BOOT model.
- Government of Nepal to issue simple, clear, transparent and environment friendly producer to encourage private sector participation.
- Provision of Power purchase Agreement with Individual Power Producer.
- Provision of licensing with time bond (survey license, generation license and transmission license)
- Provision of domestic and foreign investment- sole or joint venture.

To implement the hydropower policy, GoN had issued the electricity act (1992) and electricity regulations (1993).

Demand and Supply Trend and their Predictions

Energy Demand

Table 3

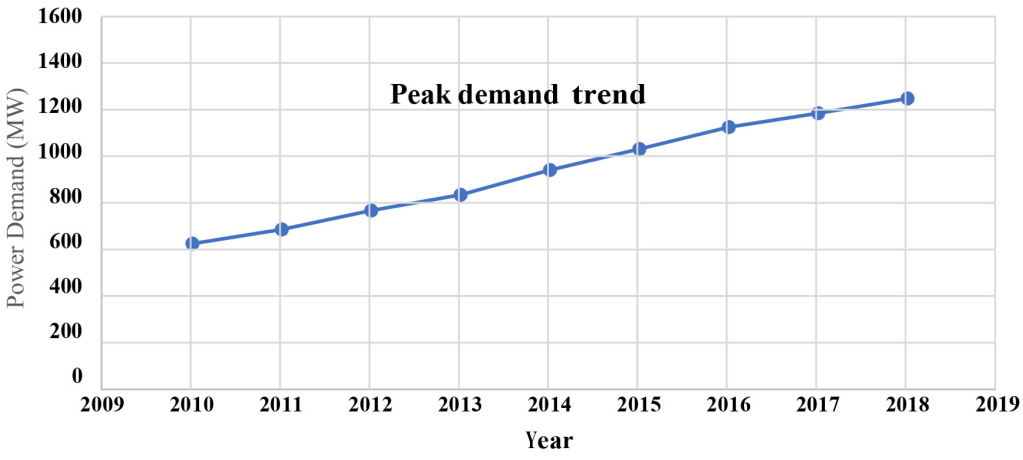
Per Capita Demand Forecast Based on Different Growth Scenario

Year	Total Installed Capacity (MW)		
	Business As Usual 4.5%	**Reference scenario 7.25 %**	**High Scenario 9.2%**
2015	1721	19151	1721
2020	3384	3611	3794
2025	5787	6617	3794
2030	8937	11111	3794
2035	13242	18124	3794
2040	19151	29427	42228

Note. WECS Report (2017)

Figure 1

Energy Demand

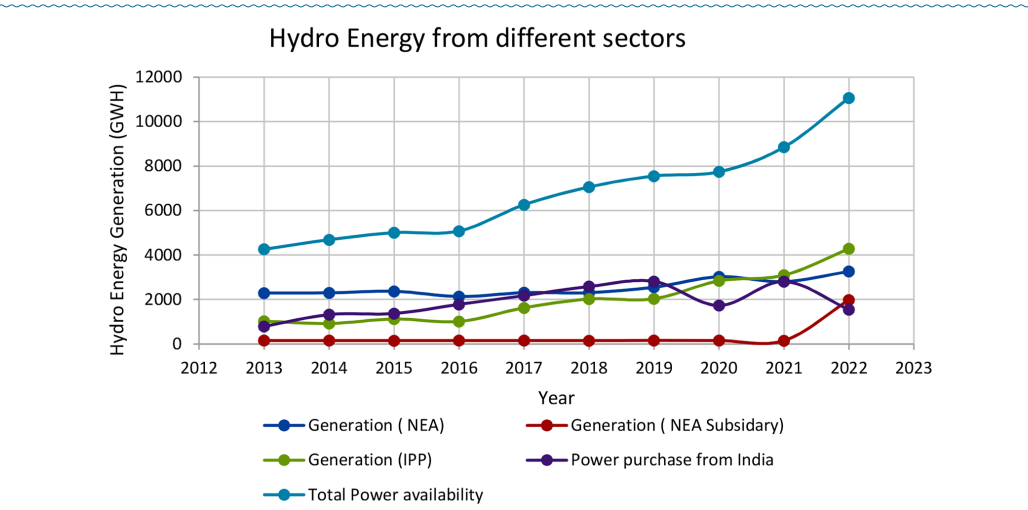


The result depicts that there is huge energy demand within a country if move in rapid development. The current demand trend is shown in figure 1.

As per the target of 15 th National plan, Nepal will have per capita consumption of 700 KWHr by end of FY 80/81. Likewise, at the end of 2100 AD, the per capita demand will reach 3500 KWHr and there will be 100 % access to electricity.

Figure 2

Energy Demand



Hydropower is the major source of electricity supply in Nepal, though some contribution also been made from solar and thermal power. Out of total installed capacity (2189 MW); 2081 MW is supplied from hydropower which is about 95 % of total supply (NEA,2021). 4.5MW of power is generated in isolated system specially for rural community.

Hydropower development trend is going increasing now. NEA has 487 MW project under

construction and 3219 MW project are in planning phase. Similarly, from private sector cumulative 3281 MW project are under construction and 357 project having cumulative capacity of 6366 MW already signed PPA with NEA (NEA 21/22) . The 15 th national plan also set ambitious target in the sector of hydropower generation. It plans to generate 5820 MW hydropower till FY 2080/ 81 BS and by 2100 BS Nepal target to generate 40000.00 MW hydropower. Supply of hydro energy from different sources is presented in figure 2.

Opportunities Linked with Hydro Energy

As the issue of alternative energy promotion raising over the globe, Nepal has huge potential on hydro energy development and many opportunities linked with it. Some of them can be outlined below.

a) As seen from the data, only around 5 % of tech-economical potential harnessed so far. In the situation of energy crisis, it reflects that Nepal can generate significant hydro energy from untapped potential which support rapid development activities of Nepal. Further, it helps to attain self-reliant energy, which is very essential for Nepal, having a complex geopolitical location.

b) The peak demand of energy in Nepal is about 1717 MW in year 2022 and it is in raising trend. It seems from the power forecast data that Nepal power demand will reach 42,000 MW up to year 2040 at optimistic Growth rate of 9 %. (WECS report 2015). This shows that Nepal's own domestic demand is the potential market for energy consumption. Also, export of energy to power deficit countries India and Bangladesh is great opportunity for Nepalese hydro sector.

c) Nepal facing extreme unemployment problems within a country and huge human resource is going abroad for employment. Development of hydro project is accompanied with generation of large employment during construction, operation and maintenance.

d) Hydropower project brings environmental and health benefits from the reduction of emission that may otherwise results from fossil fuels based thermal plants. It includes reduction of primary pollutants in the local environment and reduction of green gases that polluted the global environment.

e) Beside the power generation, the implementation of hydropower project is accompanied with social responsibilities of community development. The project is usually implemented in remote undeveloped area and its implementation brings many public benefit activities for economic stabilization.

f) The multipurpose project can bring many opportunities beside power generation.

Irrigation, water supply, recreational activities, flood control can further be integrated in project for maximum benefits.

Abundant Hydropower Resources

Nepal is endowed with substantial hydropower potential, estimated at approximately 83,000 MW, with about 43,000 MW considered economically feasible even stated in 2021 (Kaini et al., 2021; Mishra & Aithal, 2021). The country has around 6,000 rivers and an average annual water runoff of about 220 billion cubic meters, providing a robust foundation for hydropower generation (Kaini et al., 2021).Situated between two major economies, China and India, Nepal can leverage its hydropower resources to foster regional energy cooperation. This geopolitical positioning allows Nepal to attract foreign investments and partnerships in hydropower projects, enhancing its energy production capabilities and market reach (Mishra & Aithal, 2022).With a target to produce over 28,000 MW and export 15,000 MW by 2035, Nepal aims to utilize its hydropower resources not only for domestic consumption but also for export to neighboring countries (Kaini et al., 2021). The recent establishment of agreements for electricity exports to countries like Bangladesh signifies a strategic move towards enhancing Nepal's role in

regional energy markets (Mishra & Aithal, 2022). The prioritization of storage hydropower projects is crucial for managing seasonal variations in water flow and ensuring a stable energy supply. By focusing on these projects, Nepal can enhance its energy security and reduce wastage of surplus electricity generated during the monsoon season (Kaini et al., 2021).Despite the vast potential, Nepal's hydropower development has been slow, with only about 2,800 MW of installed capacity to date. The country must address challenges such as high initial investment costs, infrastructure deficits, and the need for effective policy frameworks to facilitate private sector participation (Mishra & Aithal, 2021).

Major Challenges

1. **Huge Initial Investment:** Hydropower projects require huge initial investment for its implementations. Per MW cost of the hydropower project is around NRS 0.20 billion. For the country like Nepal having small economy (GDP 2019- 37 billion) it is not possible to implement large projects from its own resources. Attracting huge foreign investment for hydropower development is a challenging job.
2. **Complex Guidelines:** There is no a dedicated institution from government having full responsibilities for hydropower sector. It makes the development more time consuming in multisectoral coordination and delay in project activities. Further, ambiguous guidelines and policies retard the motivation of developers.
3. **Technical Expertise:** Even the technical capacity of Nepalese manpower and companies increasing gradually, foreign funded large project still requires international expertise. Also, the procurement of electro mechanical equipment still fully depends on international suppliers.
4. **Market Capitalization:** As per the energy consumption pattern of Nepal, household's consumption is dominant (42.6%) and this contribute in peak demand (AEPC, 2019). Also, from the data's, it seems that current demand will saturate very soon. To have the adequate continuous domestic demand, it is very essential to go for rapid industrialization and very efficient development- oriented government is needed for this. Also, hydro sector has huge potential for the export of energy, our geopolitical location provides both challenge and opportunities for energy market. Special negotiation and diplomatic ties are very essential to grab Indian and Bangladesh market.
5. **Fragile Topography:** Nepal has a complex geography that always challenge development activities. Further, location of hydro project remains mostly in rural hilly and mountain area make it more tedious. Lagging in road access and inadequate transmission is the hindering aspect of hydro energy development.
6. **Natural Disasters:** Floods and Landslide are the frequent events that damage the hydropower project. Being their location on the river, some unpredicted floods damage the project infrastructures and the human life's. The recent event in Nepal are, Jure landslide in Middle Bhotekoshi project, flooding in Dordi projects.

Resettlement and land acquisition: Specially storage hydropower projects require huge resettlements and acquisition of land which is one of key challenges.

Though Nepal has large hydropower potential, it is seen that only around 5 % of economic potential is developed so far. Only after the promulgation of hydropower policy in 1992, Nepal expedited to generate hydropower with involvement of private sectors. As the country located in a complex geopolitical location, it very essential to become self-reliant in energy sector. Nature has endowed Nepal with immense opportunity to generate green energy, Nepal couldn't able to exploit it and relay in

India. Further, instead of generating huge revenue by selling hyo energy, Nepal has been importing from India.

Comparing status of hydro generation with Bhutan, a country having almost similar geography, geopolitical location and hydropower potential, it is quite ahead in hydropower generation. Hydropower sector is the backbone of Bhutanese economy. Though Bhutan embarked journey of hydropower development since 1967, 56 years later than Nepal, it has developed hydropower 1615

MW as of 2015(IHA). Whereas, Nepal has developed only 1396 MW till the year 2018 and importing hydro energy from India to meet the energy demand.

Further, Bhutan is attracting most of investment from India and exporting more than 75% of generated energy to India contributing 27% of government revenue (IHA website). The strong diplomatic tie of Bhutan and India in development of hydropower is one of the key factors of Bhutan's socioeconomic transformation through hydropower promotion (Tshering & Tamang, 2004).

Hydro industry Nepal growing now and many large sized projects has been envisioned to develop. As per the planning commission of Nepal, it has ambitious plan of generating 40000.00 MW in next 25 years. Development of Bhutan could be one of aspiring development model for Nepal. Strong implementation of transparent, clear and investment friendly policy to attract investors, development strategic power plan, strong diplomatic tie with India, a dedicated GoN could lead Nepal in the path of robust hydro industry development. As in case of Bhutan, hydro energy of Nepal has huge opportunity to contribute significantly in the economy of Nepal.

Conclusion

Hydropower, a dominant alternative energy resource in Nepal remains stage of untapped. Though 43000 MW techno-economically potential is available, only 1396 MW is generated so far which is about 3 % of this potential. At the initial phase, its development is quite sluggish, but after 1990, its development shows some encouraging pace. In its century long history more than 75 % of electricity is generated in last 30 years. In the course of development, hydro industry is going robust with new technologies and expert manpower's. Though many institutions are engaged in hydropower development sector, NEA is playing a major role in generation, transmission and distribution of energy. After 1990, private sector is one of the major actors in hydropower development and contributing about 50% of total generation till 18/19. A reliable hydro industry

needs mixed types projects whereas in Nepal, hydro projects are dominated by RoR schemes. PRoR and Storage projects are only in handful quantity. The result from demand forecast shows that, Nepal itself a probable market to consume the hydro energy but replacement of fossil-based fuel is very necessary for this, which cannot be achieved with comfortable steps. Exporting energy to neighboring county for the revenue collection is very good opportunity linked in hydro energy sector. Hydro development itself a challenging activity but the strategic action and dedication of government can bring the nation to the next level of socioeconomic transformation through development of hydro energy sector. Based on the discussion on the paper, we can recommend the following for the robust hydro industry.

Recommendation

1. Investment friendly environment should be made to attract national and foreign investors.
2. A mixed technology projects should be promoted for the balanced energy.
3. Nation should move toward rapid development and industrialization for internal consumption of energy.
5. Steps toward fully electricity-based household consumption should be carried to promote internal consumptions.
6. Multipurpose and cascade projects should be promoted.

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