International Research Journal of Research in Environmental Science and Toxicology Vol. 14(1)
pp. 1-10, January, 2025
Available online https://www.interesjournals.org/research-environmental-science-toxicology.html

Research Article

Overview of the Hydropower Perspective of Bangladesh

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Received: 01-April-2024; Manuscript No: JREST-24-131098; **Editor assigned:** 04-April-2024; Pre-QC No: JREST-24-131098 (PQ); **Reviewed:** 18-April-2024; QC No: JREST-24-131098; **Revised:** 08-Jan-2025; Manuscript No: JREST-24-131098 (R); **Published:** 15-Jan-2025, DOI: 10.14303/2315-5698.2025.730

Abstract

In the dance of progress, Bangladesh unearths itself on the intersection of socio-economic advancement and the urgent need for sustainable energy answers. The united states of America grapple with the twin undertaking of excessive energy intake and a shortfall in non-renewable power resources. To maintain its boom trajectory, a shift from insufficient fossil gas reliance to the include of renewable electricity is imperative. Among the renewable power heroes, hydropower emerges as a critical participant, contributing 2.15% to the state's hooked up electricity era potential. While the dreams of expansive hydropower may be confined, the degree is ready for small and micro-hydro developments to take the highlight. Enter the Kaptai Hydroelectric electricity plant, a solitary discerns at the Bangladeshi strength landscape, boasting a set up capacity of 230 MW, gracefully providing the countrywide energy grid. This narrative unveils the ancient tapestry and gift tableau of hydropower in Bangladesh, teasing out its potential future, the choreography of techniques and the rhythm of environmental and socio-financial challenges. Within this performance, a crescendo of hints emerges, advocating for the swish pirouette of small-scale hydropower plants, pirouettes that promise to extend the energy generation symphony. In this narrative ballet, hydropower emerges not actually as a technical solution but as a choreographed dance of improvement, assembly electricity wishes and orchestrating the melodious transition to renewable electricity consumption.

Keywords: Hydropower, Bangladesh, Renewable energy, Hydroelectricity, Electricity plant

INTRODUCTION

Embracing renewable electricity not handiest addresses the escalating power call for however also will become a catalyst for monetary improvement (Fischer C, et al., 2010). By substituting fossil fuels, renewable power complements strength capability, fosters variety and concurrently champions environmental protection (Deng W, et al., 2014). The appeal lies in securing a protracted-time period energy supply from easy, green resources while fostering regional improvement. Particularly in far flung regions missing traditional strength sources, the provision of renewable energy serves each as a monetary stimulant and a price-powerful strategy to climate change (Mondal MA, et al., 2010). In Bangladesh's pursuit of sustainable growth, the ambitious plan to elevate the share of renewable power to 17% by way of 2040 and attain 10% of total strength generation from renewables by way of 2025 is not merely an intention but a strategic imperative (Islam MR et al., 2008).

Given its riverine panorama, Bangladesh stands poised to harness the untapped capability of hydropower, leveraging its water assets for small and large-scale initiatives (Haidar AM, et al., 2012). The intrinsic smooth and green attributes of hydropower make it a pivotal player within the country's quest for sustainable energy (Singh S, 2009). Drawing proposal from global achievement testimonies, along with China's reduction of greenhouse gasoline emissions by way of one hundred million tons *via* hydropower, Bangladesh's attention on hydropower aligns with the World Bank's endorsement of this low carbon emission power source

(Demirbaş A, 2006). With water being an inexhaustible resource, the transformative capability of hydropower extends past its modern-day capacity, as evidenced by using almost 20% of world energy stemming from this supply (Williams AA, et al., 2009).

The versatility of hydropower flowers, starting from micro to large-scale capacities, offers a spectrum of easy power answers (Nasir BA, 2014). From micro-hydropower flora producing as much as 100 kW to small-scale installations producing 1MW-30 MW, this green technology can be seamlessly incorporated into small river streams and water networks, contributing to environmental sustainability and cost-effectiveness (Kaldellis JK, et al., 2005). Hydropower emerges not just as a power source but as a multi-functional green technology capable of meeting the diverse energy needs of both industries and individual homes, making it the most efficient renewable energy source for Bangladesh's evolving energy landscape **(Table 1)** (Forouzbakhsh F, et al., 2007).

Table 1. Various hydropower plants contribute to the grid, diversifying renewable energy distribution.

Types of hydropower plant	Capacity of hydropower plant	Description
Pico hydropower plant	Under 5 KW	Hydropower supplies energy to select residential occupants
Micro hydropower plant	Up to 100 KW	Hydropower empowers remote areas and small communities efficiently
Mini hydropower plant	100 KW-1 MW	Hydropower energizes 1000 suburban households with efficiency
Small hydropower plant	1 MW-15 MW	Hydropower feeding electricity grid
Medium hydropower plant	15 MW-100 MW	Hydropower feeding electricity grid
Large hydropower plant	>100 MW	Hydropower feeds electricity in a large grid

The allure of hydropower lies in its unparalleled cost-effectiveness and longevity, setting it apart from other power sources (Frey GW, et al., 2002). Hydroelectric power plants boast lower construction costs compared to their counterparts, exemplified by China's three Gorges Dam, which recouped its expenses within 3-5 years through electricity sales (Morimoto R, et al., 2004). Hydropower's unique ability for rapid scaling, from zero to maximum power generation, establishes it as a superior and flexible energy source, adept at maintaining a delicate balance between power demand and supply (Graus W, et al., 2009). Its efficiency further shines, with modern hydraulic turbines converting up to 90% of available energy into electricity, surpassing the 50% efficiency of even the best fossil fuel plants (Parveen S, et al., 2002). Laos exemplifies how embracing hydropower can elevate living standards and alleviate poverty, showcasing its transformative impact (Pun SB, 2012). Beyond electricity generation, large dams serve dual purposes, including flood control, adding an extra layer of utility (Cameron A, et al., 2012). Notably, hydropower projects often morph into tourist attractions, showcasing their scenic and engineering marvels (Smith SE, et al., 1988). In a select group, Brazil, Norway, Canada, Venezuela and Switzerland stand as nations predominantly relying on hydropower as their primary energy source (Gupta HK, 2002). The collaborative Itaipu Dam in Paraguay, generating 14000 MW, serves as a beacon of successful joint ventures, while Norway strategically utilizes hydropower to meet the majority of its energy needs, emphasizing the multifaceted advantages of this renewable energy source **(Table 2)** (Simonov EA, et al., 2019).

Table 2. Countries with the most hydroelectricity production (2021).

Country	Hydropower plant generation of annual (TWh)	Capacity (GW)	Capacity factor	Percentage of total electricity generation
China	585.2	196.79	0.37	22.25
Canada	369.5	88.97	0.59	61.12
Brazil	363.8	69.08	0.56	85.56
USA	250.6	79.51	0.42	5.74
Russia	167	45	0.42	17.64
Norway	140.5	27.528	0.49	98.25
India	115.6	33.6	0.43	15.8
Japan	69.2	27.229	0.37	7.21
Sweden	65.5	16.209	0.46	44.34

While heralded for his or her minimum environmental pollutants, hydropower vegetation wield a profound effect on nearby ecosystems and biodiversity. Dams, the epitome of this strength source, unharness the most widespread ecological repercussions amongst man-made structures, changing river ecosystems and water waft dynamics. The vital of accomplishing thorough Environmental Impact Assessments (EIAs) earlier than massive-scale hydropower initiatives cannot be overstated, as these critiques are critical for stopping cultural, spiritual and way of life disruptions to nearby groups. A misjudged EIA, coupled with insufficient Social Impact Assessments (SIAs), can lead to catastrophic dam caused failures, as evidenced *via* ancient occasions just like the Hoover Dam's earthquake-triggering creation inside the United States. The Aswan Dam's alteration of water degrees in Egypt, impacting ancient monuments and the 2008 Sichuan earthquake in all likelihood related to the Zipingpu Dam, underscore the gravity of those environmental issues.

Beyond seismic concerns, hydropower projects alter energy and material flows in rivers, affecting abiotic and biological components of ecosystems. Physiochemical and hydrological changes, from dissolved hydrogen to water pH, influence the distribution of large invertebrates, sparking shifts in ecosystem structures. The realm of hydropower research delves into multifaceted dimensions. Grumbine's scrutiny of China's hydropower development at the Mekong river sets a precedent for sustainable practices. Pokharel illuminate's hydropower's role in reducing forest degradation and curbing fuel wood dependence. Wagner's historical exploration of Austria's hydropower journey considers energy structures and consumption, highlighting political, economic and environmental challenges. The USA's small hydropower impact on carbon emissions is articulated by Kosnik, while Moran brings attention to the socio-economic drawbacks of hydropower dams, offering innovative solutions.

Bangladesh's foray into small and micro-hydropower projects garners research attention. Wazed's meticulous analysis of the micro-hydropower sector in Bangladesh provides comprehensive insights. This study not only unravels the current hydropower landscape in Bangladesh, addressing environmental and socio-economic challenges but also extends to evaluating its future, serving as a beacon for energy policymakers in this dynamic and critical domain.

MATERIALS AND METHODS

Bangladesh's hydroelectricity and energy situation

Electricity availability is a pivotal driver for a nation's economic growth and Bangladesh's power sector has exhibited noteworthy progress in meeting the surging national demand. Over recent years, there has been a substantial uptick in both power availability and consumption, marking a positive trajectory (refer to Table 3). Daily load shedding, a prevalent challenge in the past, has markedly reduced, exemplified by the decrease from 1107 MkWh in 2009 to 32 MkWh in 2018. Despite these advancements, Bangladesh's coverage and access rates still lag behind regional standards. As of June 2022, the total installed capacity stands at 25,700 MW, with urban areas boasting a 99% access rate compared to 81% in rural regions.

The distribution of electricity consumption across divisions provides insights into regional disparities. Dhaka division leads the charge, accounting for 19.18% of the total electricity generated in Bangladesh. Other divisions, namely Barisal, Chittagong, Khulna, Rajshahi, Rangpur and Sylhet, contribute varying percentages, reflecting regional dynamics. Notably, in August 2022, Bangladesh achieved a milestone by generating 8410 GWh of power, surpassing its previous record set in November 1993. These achievements underscore the nation's commitment to enhancing electricity accessibility and ensuring a robust power infrastructure for sustained economic growth **(Table 3)**.

Table 3. Energy situation prospective Bangladesh.

Indicator	2022	2023	Change of percentage
Number of power plant	152	152	0%
Power Generation Capacity (MW)	22348	28562	(+) 27.8%
Maximum Peak Generation (MW)	14782	15648	(+) 5.85%
Per Capita Power Generation (KWh)	560	602	(+) 7.5%
Distribution System Loss (%)	8.48	7.65	(-) 0.83%

Electricity derived from hydropower is termed hydroelectricity and its production holds substantial implications for economic growth, given its comparatively low generation cost. The formula for calculating the power generated from hydroelectricity is as follows:

$$P = — \eta(\dot{m} g \Delta h) = — \eta((\rho Q) g \Delta h) \quad (1)$$

The equation for calculating hydroelectric power (P) involves multiple parameters: η (efficiency coefficient), $\dot{m}$ (mass flow rate in kg/s), g (gravitational acceleration at 9.8 m/s^2), Δh (change in height in meters) and Q (volumetric flow rate in m^3/s). Analyzing the contribution of hydroelectricity to Bangladesh's total power generation, Table 4 reveals that, on average, it accounted for 2.63% between 2000 and 2015. In 2015, this share dropped to 0.96%, but during its peak in 2001, hydroelectricity contributed a significant 5.71%. As of 2022, Bangladesh maintains a consistent hydropower capacity of 230 MW, unchanged from the previous year, highlighting stability over the past decades **(Figure 1)**.

 ISSN: 2315-5698

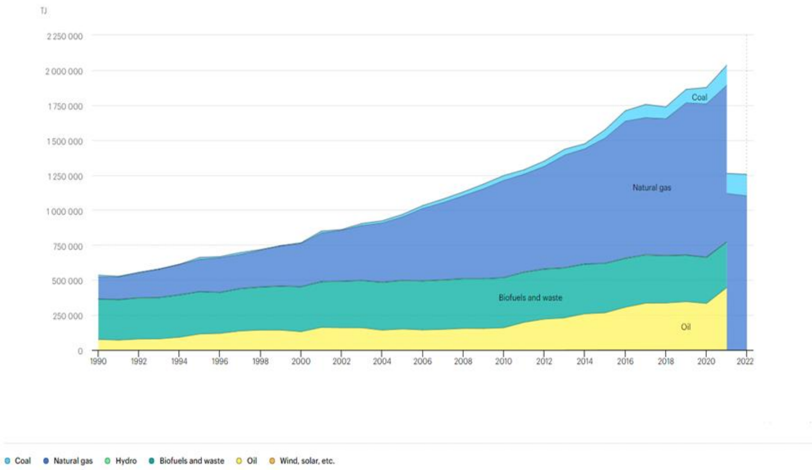

Figure 1. Electricity production from hydroelectric in Bangladesh.

The average installed hydropower capacity in Bangladesh from 2000 to 2011 stood at 228.33 MW. However, a decline of 10 MW was observed in 2011 and 2012, as depicted in Figure 1. Recognizing the potential, the Bangladesh Power Development Board (BPDB) has outlined plans to enhance the output of the Kaptai Hydroelectric plant to 330 MW by 2030. Despite approximately 80% of the population having access to electricity, sustaining economic growth necessitates an estimated power capacity of 34,000 MW by 2030. Bangladesh is eyeing its substantial hydroenergy reserves, estimated at 1,100 TWh/year, to meet these ambitious energy goals.

Hydropower potential of Bangladesh

Hydro energy emerges as an exceptionally clean source, especially when compared to other conventional energy options deployed on a large scale for power generation. With low supply costs and minimal Greenhouse Gas (GHG) emissions, hydropower generation stands out as an excellent and environmentally friendly choice for energy harvesting. Bangladesh, blessed with abundant rivers, holds a unique advantage given the significant role rivers play in the livelihoods of its people. Figure 2 illustrates the extensive river network weaving through the landscape of Bangladesh **(Figure 2)**.

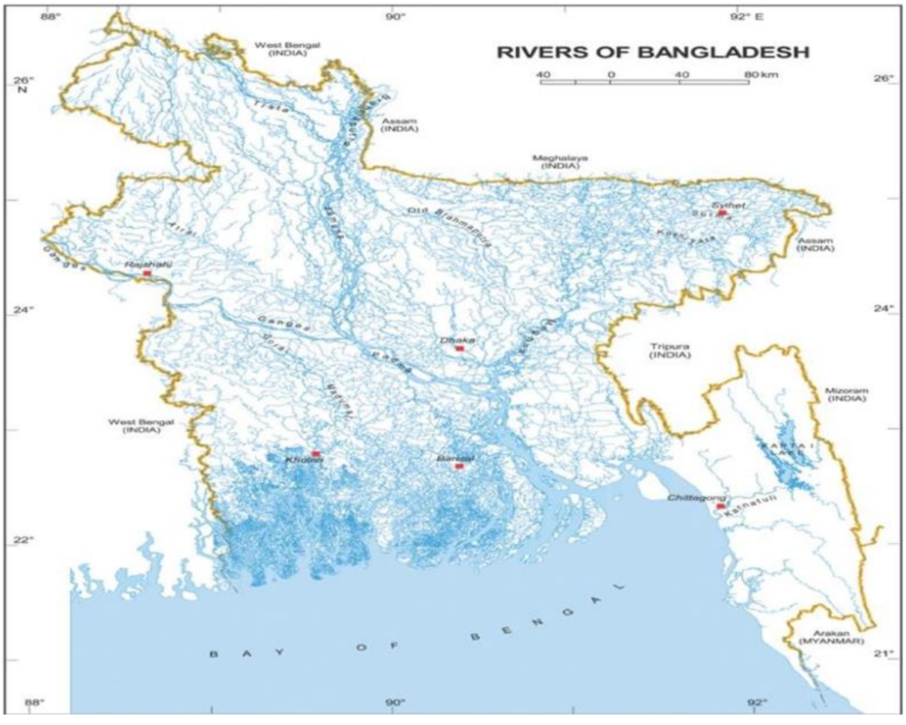

Figure 2. Bangladesh river network.

Despite the abundance of rivers in Bangladesh, hydropower generation faces limitations due to the absence of high head and flow rates. The nation, recognizing the significance of optimizing its limited resources, is striving to enhance hydropower generation to meet the escalating demand sustainably. Globally, hydro energy accounts for approximately 20% of total electricity production. Bangladesh, leveraging its rainy seasons, envisions maximizing hydropower potential. The Kaptai power plant, the pioneer hydropower facility with a 230 MW capacity, exemplifies this effort. Capitalizing on excess rain, the Bangladesh Power Development Board (BPDB) plans to establish an additional 100 MW capacity plant in the region.

In addition to large-scale projects, micro-hydropower plants have garnered attention. The country's first small-scale micro-hydropower plant in Bandarban, with a 10 kW capacity, caters to the energy needs of 140 households and a temple. The government, too, has set up a 50 kW micro-hydropower plant in Barkal Upazila, Rangamati. A survey by the sustainable rural energy project identified potential sites for micro-hydro plants in the Chittagong district, estimating a capacity of 135.5 MW. Notably, the Sangu and Matamuhuri river basins, with hydro potential capacities of 87 MW and 80 MW respectively, are deemed suitable for cost-effective power generation, projecting annual energy productions of 300 GW/year and 200 GW/year. The Brahmaputra river basin presents a colossal potential of 1,400 MW for large-scale power generation.

The northeastern region, recognized for its promising potential, is subject to assessment under the Northeast Regional Water Management Project (FAP-6). This initiative, part of the Flood Action Plan, focuses on identifying feasible sites for low head hydropower plants. Preliminary assessments of ten potential sites estimate an overall potential of 161 MW, yielding an annual energy production of 1,410 GWh. From nine suitable rivers in the region, it is projected that they will produce 307 GWh annually, generating an estimated power output of 35 MW. The seasonal variations in river discharge, notably high in the rainy season and low in winter, influence the expected power generation. This comprehensive exploration underscores Bangladesh's multifaceted approach to harnessing hydropower and underscores the diverse potential across its geographical landscape **(Table 4)**.

Table 4. Prospective sites for micro hydropower development in Chittagong hill tracts.

River	Site	Catchment Area (km²)	Estimated Capacity (MW)	Estimated Annual Output (GWh)
Someswari	Dugapur	2134	5	43
Jadukata	Saktiakhola	2513	13	115
Jhalukhali	Dalura	448	5	45
Sarigoyain	Lalakhal TG	802	3	30
Lubha	Mugulgul	724	3	27
Dhalai	Khalasadaq	342	2	15
Umium	Chalelhnapur	518	2	20
Bhugai	Hati	453	1	6
Darang	Ghosegaon	381	1	6
Total			35	307

In 1984, a Chinese expert team identified 12 potential hydropower sites in the hill tract areas of Bangladesh. Mahamaya Chara, situated in Mirsharai, Chittagong, emerged as the most promising location for developing a small-scale hydropower plant.

The feasibility study revealed that hydroelectricity production could be sustained throughout the year, with exceptions in April and May. A proposed dam in Mahamaya Chara, covering an area of 10.5 km², aims to store water for irrigation purposes. A mini-hydro plant, positioned at the dam's base, will harness the reservoir water for power generation.

The hill tracts of Bangladesh, rich in small rivers and canals, present substantial potential for hydroenergy. The Local Government Engineering Department (LGED) actively endeavors to leverage hydro energy resources to address energy needs in these remote hill tract areas. LGED has identified several prospective sites in these regions, emphasizing the significant power generation potential. The details of these prospective sites, along with their power generation potential, are outlined in Table 5. This concerted effort highlights the commitment to harnessing hydro energy to meet the energy demands of the hill tract areas in Bangladesh **(Table 5)**.

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Table 5. Potential small hydropower sites identified by BPDB and BWDB.

District	River/stream	Potential of electrical energy (kW)
Chittagong	Faiz Lake	4
Chittagong	Choto Kumira	15
Chittagong	Hinguli Chara	12
Chittagong hill tracts	Sealock	81
Chittagong	Lungichara	10
Chittagong	Budichara	10
Sylhet	Nikhan Chara	26
Sylhet	Madhab Chara	78
Sylhet	Banga Pani Gung	616
Jamalpur	Bhugai Kangsa	60 (10 months)
Jamalpur	Marisi	35 (10 months)
Dinajpur	Badul	24
Dinajpur	Chawai	32
Dinajpur	Talma	24
Dinajpur	Pathraj	32
Dinajpur	Tangon	48
Dinajpur	Punar Haba	11
Rangpur	Bari Khora	32
Rangpur	Ful Kumar	48

RESULTS AND DISCUSSION

Status of hydropower in Bangladesh

Established in 1962, the Kaptai hydroelectric power plant in Chittagong stands as Bangladesh's inaugural and solitary hydroelectric facility, boasting an installed capacity of 230 MW. In the wake of this milestone, Bangladesh has diversified its hydroelectric portfolio, incorporating small, micro and pico-hydropower plants. Recognizing the pivotal role of hydropower in the renewable energy sector, the Government of Bangladesh has reinvigorated its focus on this clean energy source. Hydropower, ranking as the second-largest commercial energy source after natural gas and oil, plays a significant role in Bangladesh's energy landscape. This renewed emphasis underscores the commitment to harnessing hydropower's potential for sustainable and renewable energy in the country.

Small hydropower

The aggregate installed capacity of small hydropower plants in Bangladesh ranges from 1 to 15 MW. In the northeastern region, an estimated exploitable energy of 161 MW and 1410 GW/year has been identified. A cluster of 19 potential small-hydro sites, situated near the Teesta Barrage, holds promise for further development. The prospect of enhancing hydropower production in Bangladesh is underscored by the proposition to incorporate turbines into the barrage, potentially tripling the current capacity.

Aligned with national energy development objectives, the plan aims to fully harness the hydropower potential of the country by 2025. Nine rivers, characterized by small discharges in the dry season and significant discharges during the monsoon season, have been pinpointed for potential hydropower generation. The projected annual power generation stands at 35 MW, contributing to an annual energy generation of 307 GW, as detailed in Table 6.

This strategic approach seeks to optimize the diverse hydropower potential in Bangladesh and aligns with broader sustainability and energy development goals **(Table 6)**.

Table 6. Small-hydro potential at the Meghalaya river in the northeast of Bangladesh.

Small hydro plant	Rivers	Estimate Annual Production (GWh)
Hatipagar	Bhugai	6
Lalakhal	Sarigoyain	30
Khalasadaq	Dhalai	15
Ghosegaon	Lubha	6
Mugulgul	Lubha	27
Durgapur	Someswari	43
Dalura	Jhalukhali	45
Saktiakhola	Jadukata	115

Micro hydropower plant

Harnessing the natural flow of water, micro-scale hydro plants in Bangladesh exhibit a capacity ranging from 5 kW to 100 kW, offering a vital electricity source for remote areas lacking a grid system. As of now, the installed micro-hydropower capacity is approximately 50 kW, constituting 0.25% of the total renewable energy portfolio. Post-2016, a surge in micro-hydropower projects has occurred, driven by collaboration between the private and public sectors.

The pioneering micro-hydropower plant, a 10 kW demonstration project, was introduced in the Chittagong Hill Tracts (CHT) region. Subsequent endeavors include a 50 kW installation in Barkal Upazilla, Rangamati and an ongoing project in Mirersorai, Chittagong district, anticipating a capacity of 50–70 kW. Notably, research indicates a remarkable 400% increase in installed capacity for micro-scale hydropower projects between 2013 and 2016.

Acknowledging the transformative potential, the Bangladesh Council of Scientific and Industrial Research (BCSIR) and the Institute of Fuel Resource Development (IFRD) conducted a pre-feasibility study titled "feasibility study on R and D of Renewable Energy: Solar, wind, micro-mini hydro". With a strategic vision, BCSIR and IFRD aim to install micro-hydropower plants across hilly regions in Bangladesh, contributing to sustainable energy development. To gauge water flow and head, essential equipment has been installed at two separate locations, as detailed in Table 6. This progressive approach underscores Bangladesh's commitment to expanding micro-hydropower initiatives and fostering innovation in renewable strength **(Table 7)**.

Table 7. Potential micro hydropower plant sites of Bangladesh.

Waterfalls	Location	Annual Energy Production (KWh)	Electric Power (KW)
Modhobkundu	Moulvibazar	131400	15
Shailopropat	Bandarban	43800	5

Kaptai hydropower plant

Following the installation of the Kaptai Hydroelectric strength plant in 1962, Bangladesh witnessed large improvement, marking a crucial milestone in its electricity landscape. Typically located on big rivers with constant water waft, hydropower plant life plays a vital position in sustainable strength generation. The Kaptai Hydroelectric electricity plant, integral to the Karnafuli multipurpose project, is strategically positioned on the Karnafuli river, about 70 km upstream of the Chittagong estuary. Serving as a cornerstone in the u.S.'s electricity infrastructure, this plant has contributed appreciably to Bangladesh's financial and strength advancements for the reason that its inception in 1962. Upon the setup of the fourth and 5th generator devices, the total technology potential of the Kaptai hydroelectric power plant surged to 230 MW.

This hydroelectric facility harnesses the water waft of the Karnafuli river as its primary supply of energy. The strength generated by using the Kaptai hydroelectric power plant serves as a sizeable contribution to Bangladesh's electricity portfolio, presenting big strength to aid the state's developing needs and economic development.

The power generated (in kilowatts, KW) by a hydroelectric system can be calculated using the formula: Power (KW)=5.9 × flow × head (1)

Where:

where flow is measured in m^3/s and the head is measured in m. 216 the two factors that affect the amount of energy generated are: The two crucial factors influencing the amount of energy produced by the system are the vertical distance of the water flow and the rate of flow through the hydroelectric system. These parameters play a pivotal role in determining the overall efficiency and output of the hydroelectric power generation process.

Role of hydropower in socio-economic and energy development

For a country like Bangladesh, the construction of a large hydropower plant represents a significant milestone. Its first and only hydropower plant was established on the Karnafuli river in 1962. Driven by the escalating energy demand and limited public and private sector investments, the project was integrated into the Karnafuli multipurpose project to meet the surging electricity requirements. Currently contributing 2.15% to the total electricity generation, hydropower has consistently supplied electricity for many decades. The construction of the Kaptai Hydroelectric Power Plant resulted in the creation of the Kaptai reservoir, now one of the largest man-made freshwater lakes in South-East Asia.

Bangladesh has set an ambitious goal of generating 24,000 MW of power by 2025, with 5% originating from renewable energy sources. To achieve this, two additional units will soon be installed at the Kaptai Hydroelectric Power Plant. Hydropower, being a clean and renewable energy source, is deemed environmentally friendly, as no water is polluted or consumed during the power generation process. Hydroelectric power plants emit significantly fewer greenhouse gases than fossil fuel-based counterparts, potentially reducing emissions by 20%. Moreover, they contribute to the reduction of sulphur dioxide and nitrogen oxide emissions.

Globally, with an installed capacity of 230 MW, the Kaptai Hydroelectric power plant is a part of the substantial share of approximately 1000 GW in the hydroelectric sector, representing the largest portion of

 ISSN: 2315-5698

electricity generated from renewable sources. Bangladesh, with a 36% capacity utilization rate in the hydro/marine sector in 2021, is actively harnessing its potential renewable energy resources to promote sustainable living and recognize the critical role of energy production capacity in economic growth **(Figure 3)**.

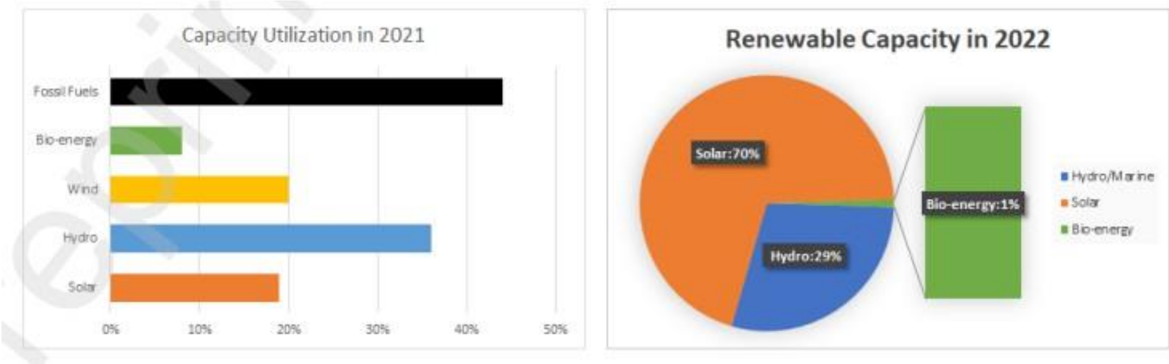

Figure 3. Hydropower capacity utilization in 2021.

In contrast to large-scale hydropower projects requiring reservoirs and extensive maintenance, micro and small-scale hydropower projects offer a more straightforward solution, particularly in remote, non-grid- connected hilly areas of Bangladesh. A notable example is Aung Thuwai Pru Para, situated approximately 400 km from Dhaka, where a private firm installed a 10 kW pico-hydropower plant across the Sangu river in 2018. Serving 30 households, this plant primarily supports irrigation needs. The installation cost amounted to 0.18 million USD. Micro and small-scale hydropower projects emerge as a vital energy source, especially in areas where grid connectivity is absent.

In Bangladesh, hydropower stands out as the most prevalent renewable energy source, distinguished by its cost-effectiveness. Hydroelectricity boasts production costs ranging from 8 BDT/unit to 18 BDT/unit, surpassing other renewable energy alternatives and even proving more economical than fossil fuels. Furthermore, hydropower exhibits superior energy efficiency, ranging from 60% to 90%, compared to the 43–60% efficiency of fossil fuels. Reflecting on the past, the construction of the Kaptai Hydroelectric Plant initially disrupted local agriculture, fisheries and socio-economic structures through waterlogging. However, over time, the Kaptai reservoir has become a significant contributor to small-scale fisheries, yielding approximately 8,989 metric tons of fish annually and becoming a cornerstone of the local economy **(Figure 4)**.

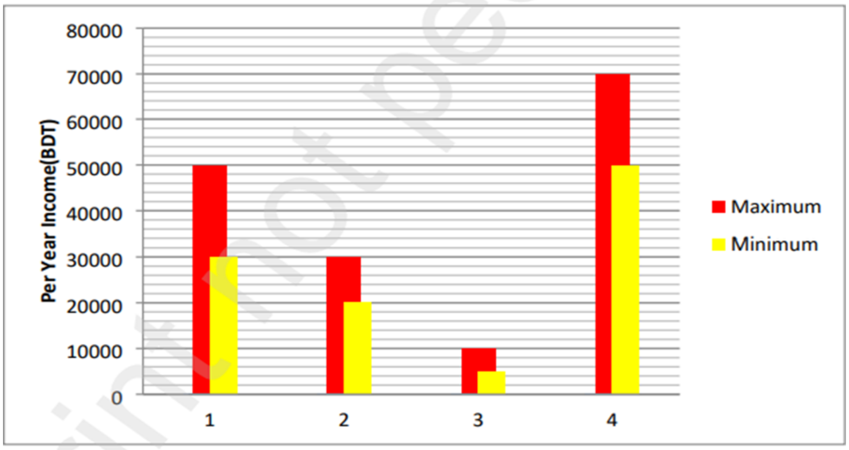

Figure 4. Income from Kaptai reservoir.

The socio-economic landscape around the Kaptai reservoir has experienced positive transformations over time. The maximum income from the reservoir starts at 10,000 BDT, with a minimum income of 5,000 BDT (**Figure 4**). These economic shifts have prompted local communities to engage in creek and pen culture practices. The overall well-being of the Kaptai Upazilla has seen improvements in education and health facilities, directly attributed to the hydropower plant's presence. The project has implemented specific policies targeting local schools and hospitals, contributing to enhanced community services. While economic opportunities such as employment and resource demand have flourished, remote areas face challenges in accessing these benefits. Nevertheless, the construction phase of the Kaptai Hydroelectric Power Plant generated numerous job opportunities, adding to the economic vibrancy of the region. Beyond these social and economic advantages, the Kaptai Hydroelectric power plant continues to offer benefits such as no fuel charges, low maintenance and operation costs and sustained long-term plant efficiency.

Prospects of hydropower in Bangladesh

The Bangladesh Power Development Board (BPDB) envisions expanding the nation's hydropower capacity with the installation of two additional units-one at Sangu with a power generation capacity of 140 MW and the other at Matamuhuri with a capacity of 75 MW. Concurrently, collaborative efforts with India through the "Ganges Barrage Project" are underway, wherein two hydropower plants with capacities of 76 MW and 36 MW are planned. This joint venture aims to harness water resources from the Ganges. The Water Development Board, completing the pre-feasibility study in 2002, supports the installation of these hydropower plants, contributing an additional 100 MW to the national grid. Anticipating the completion of the Ganges Barrage Project and the integration of the new units, the total power generated from renewable energy sources is poised for a substantial boost.

Solar Power, $S\alpha$= Area per sq. feet × Watts per sq. feet (3) Wind Power, $W\alpha = 0.5 \times p \times A \times v3$ (4)

Hydro Power, $H\alpha = H \times Q \times g \times 1000$ (5)

The total Power, $T\alpha = S\alpha + W\alpha + H\alpha$ (6)

These equations are an estimation of the power contributed by each source and the total power equation.

Hydropower at present =230 MW

If two new hydropower plants and two additional units are installed, Available hydropower will be=(230+140+75+100) MW=545 MW

If 50 Siemens wind power turbines of 2.3 MW capacity each are installed,

Available $W\alpha$=115 MW

If 4000 modules with a rating of 250 WP and an efficiency of 15.50% cover 6451 m2 generating 1 MW of electricity are installed,

Available $S\alpha$=55 MW

Thus, the total power will be $T\alpha = S\alpha + W\alpha + H\alpha$=(55+115+545) MW=715 MW.

Adding 545 MW of hydroelectricity to the national power grid can help contribute towards satisfying the huge domestic and industrial demand, while also solving the energy crisis.

CONCLUSION

While Bangladesh faces limited potential for large-scale hydropower, emphasis on developing its small and micro hydropower sector is crucial for sustainable growth and socio-economic advancement. As renewable green energy becomes a catalyst for sustainable development, the interdependence of electrical energy and the economy necessitates a focus on power generation. With industrial growth on the rise, electricity has emerged as a top government priority, aiming to generate over 10% from renewable sources by 2030. Hydropower, in addition to meeting this goal, can address environmental concerns and provide electricity to rural communities. This research, serving as a potential reference, outlines hydropower projects for assessment and urges the government to leverage modern technology throughout planning, design, construction and operation. Geological technology, mathematical models and ecological studies are recommended for a comprehensive understanding of dam structures, downstream impacts and environmental conditions. Efforts to settle environmental refugees, enhance maintenance systems for existing plants like Kaptai and integrate modern engineering solutions are pivotal for success. With water as a life source and electricity as a driver of social development, hydropower emerges as a key player in Bangladesh's energy industry, fostering sustainable development. The paper discusses the history, challenges and strategies of hydropower development, emphasizing scientific development to guide Bangladesh's future endeavors. Favorable economic policies and microfinance support systems underscore the government's commitment to renewable energy. Innovations in hydropower models must balance ecological protection, human resettlement and promote holistic economic and social development.

REFERENCES

1. Fischer C, Preonas L (2010). Combining policies for renewable energy: Is the whole less than the sum of its parts?. Resource for the future discussion paper. 10-19. [Crossref] [Google Scholar]
2. Deng W, Liu F, Jin H, Li B, Li D (2014). Harnessing renewable energy in cloud datacenters: Opportunities and challenges. IEEE Network. 28(1):48-55. [Crossref] [Google Scholar]
3. Mondal MA, Denich M (2010). Assessment of renewable energy resources potential for electricity generation in Bangladesh. Renew Sust Energy Rev. 14(8):2401-2413. [Crossref] [Google Scholar]
4. Islam MR, Islam MR, Beg MR (2008). Renewable energy resources and technologies practice in Bangladesh. Renew Sust Energy Rev. 12(2):299-343. [Crossref] [Google Scholar]

5. Haidar AM, Senan MF, Noman A, Radman T (2012). Utilization of pico hydro generation in domestic and commercial loads. Renew Sust Energy Rev. 16(1):518-524. [Crossref] [Google Scholar]

6. Singh S (2009). World Bank-directed development? Negotiating participation in the nam theun 2 hydropower project in Laos. Dev. Change. 40(3):487-507. [Crossref] [Google Scholar]

7. Demirbaş A (2006). Global renewable energy resources. Energy sources. 28(8):779-792. [Crossref] [Google Scholar]

8. Williams AA, Simpson R (2009). Pico hydro–Reducing technical risks for rural electrification. Renew Energy. 34(8):1986-1991. [Crossref] [Google Scholar]

9. Nasir BA (2014). Design considerations of micro-hydro-electric power plant. Energy procedia. 50:19-29. [Crossref] [Google Scholar]

10. Kaldellis JK, Vlachou DS, Korbakis G (2005). Techno-economic evaluation of small hydro power plants in Greece: A complete sensitivity analysis. Energy Policy. 33(15):1969-1985. [Crossref] [Google Scholar]

11. Forouzbakhsh F, Hosseini SM, Vakilian M (2007). An approach to the investment analysis of small and medium hydro-power plants. Energy Policy. 35(2):1013-1024. [Crossref] [Google Scholar]

12. Frey GW, Linke DM (2002). Hydropower as a renewable and sustainable energy resource meeting global energy challenges in a reasonable way. Energy policy. 30(14):1261-1265. [Crossref] [Google Scholar]

13. Morimoto R, Hope C (2004). Applying a cost-benefit analysis model to the Three Gorges project in China. Impact Assessment and Project Appraisal. 22(3):205-220. [Crossref] [Google Scholar]

14. Graus W, Worrell E (2009). Trend in efficiency and capacity of fossil power generation in the EU. Energy Policy. 37(6):2147-2160. [Crossref] [Google Scholar]

15. Parveen S, Faisal IM (2002). People versus power: The geopolitics of Kaptai Dam in Bangladesh. Int J Water Resources Dev. 18(1):197-208. [Crossref] [Google Scholar]

16. Pun SB (2012). Lessons from paraguay's 14,000 MW itaipu project vis-a-vis Nepal's 6,720 MW pancheshwar project. J Int Assoc Electr Gen Transm Distrib. 25(1):3-7. [Google Scholar]

17. Cameron A, Wei L (2012). An environmental impact assessment for hydropower development in China. Vt J Envtl L. 14:275. [Crossref] [Google Scholar]

18. Smith SE, Abdel-Kader A (1988). Coastal erosion along the Egyptian delta. J Coast Res. 245-255. [Google Scholar]

19. Gupta HK (2002). A review of recent studies of triggered earthquakes by artificial water reservoirs with special emphasis on earthquakes in Koyna, India. Earth Sci Rev. 58(3-4):279-310. [Crossref] [Google Scholar]

20. Simonov EA, Nikitina OI, Egidarev EG (2019). Freshwater ecosystems versus hydropower development: Environmental assessments and conservation measures in the transboundary Amur River Basin. Water. 11(8):1570. [Crossref] [Google Scholar]