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EVALUATING POTENTIALITY OF RUN-OF-RIVER (ROR) HYDROELECTRICITY IN BANGLADESH; A CASE STUDY OF MATAMUHURI RIVER

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ABSTRACT

To support sustainable energy development and reduce reliance on fossil fuels, it is essential to evaluate the feasibility of renewable energy resources in Bangladesh. This study investigates the potential for electrical power generation from the kinetic energy of the Matamuhuri River, a significant river flowing through the Chittagong Hill Tracts, using the publicly available Reference Model 2 (RM2) turbine developed by Sandia National Laboratories. Historical discharge and velocity data from the Lama station (1981–2024) were analyzed to estimate electrical power output, using Python-based calculations, power coefficient curves, and Monte Carlo simulations with a fitted Weibull distribution. The results indicate that the river's flow characteristics—particularly the low average velocity and the high proportion of flow below the turbine's cut-in speed—limit power generation, resulting in a high levelized cost of energy, and making installation of RM2 devices at this site economically unfeasible.In addition to technical assessment, the study considers environmental and operational factors. The Matamuhuri River exhibits relatively stable flow regimes with minimal habitat disruption, sediment transport issues, or displacement of local communities, suggesting that low-impact installations could be environmentally sustainable. However, the analysis is limited to a single station, a specific turbine design, and data with low temporal resolution. Future work could extend feasibility assessments to other river locations in Bangladesh and explore alternative turbine designs or other forms of marine energy, such as tidal and wave power, including devices customized for local hydrological conditions. Overall, this study provides a comprehensive site-specific evaluation of marine-hydrokinetic energy potential, combining technical, economic, and environmental considerations, and contributes to the knowledge base supporting localized renewable energy development in Bangladesh.

Keywords: *Marine energy, renewable energy, Matamuhuri, Monte-Carlo Simulation*

1. INTRODUCTION

The economic development of Bangladesh has brought upon the increased demand of power and to maintain the economic growth this increased demand must be met by our power grid. However, meeting this increased demand through traditional fossil fuel sources have several downsides. It causes our national fuel reserve to deplete, or may cause to incur high cost due to import, both of which is detrimental towards our national energy security. Additionally, this also results in increased green house gas (GHG) emissions, which consequently escalates our ever-existing environment pollution problem and risk of land submerging due to sea level rise as a effect of global warming. Renewable energy presents the most feasible alternative of these traditional fossil fuel sources. The addition of renewable energy into the grid also aligns with the Sustainable Development Goals (SGD) declared by the United Nations (UN), in particular SDG targets 7 and 13. Bangladesh has integrated a fair amount of renewable into the grid over the last decade, particularly in form of solar photovoltaics (PV). Assessing onshore wind potential revealed it to be unfeasible due to geographical and meteorological reasons. While offshore wind offers significant potential, its integration becomes challenging due to high investment and maintenance costs.

Although Bangladesh is a riverine country, the relatively flat surface has limited its opportunity in hydropower, the Kaptai hydropower plant being the only one operating. The hydropower also disrupts the natural flow of the river, causing flooding of nearby local communities and agriculture lands.

Marine energy is an untapped resource of renewable energy with tremendous potential for Bangladesh. It is a form of renewable power source that can be harnessed from the natural movement of water, including waves, tides, and river and ocean currents. The United States Department of Energy (DOE) estimates that the energy contained in their oceans and rivers has the potential to satisfy about sixty percent of their annual electricity demand. Bangladesh with plentiful of river bodies, can benefit highly from utilizing marine energy opportunities. Since it does not restrict the natural flow of the water and the power generating devices are submerged under the water surface, it does not disrupt marine life such as fisheries or river-based transport and does not create flooding. Also, marine energy production can be estimated with high accuracy due to cyclical nature of waves, tides, and currents.

This has led researchers to explore alternative ways of generating energy from water bodies without obstructing their natural flow, broadly referred to as marine energy. One source of marine energy is river current energy, which is converted from kinetic to electrical energy through electromechanical devices called river current turbines (Khan et al., 2007). The earliest developments of this technology occurred in the late 1970s, led by the UK-based development organization Practical Action (known then as the Intermediate Technology Development Group). They built a total of nine prototypes of river current turbines within four years and field-tested them in the Nile. This effort later helped shape the modern designs seen today (Garman 1986, 1998; Dunn 1986).

Recent research in marine and river hydrokinetic energy has focused on full-scale prototype testing, control strategies, and validation of numerical and data-driven models under real flow conditions. Field-based studies have demonstrated that experimental measurements are essential for verifying turbine performance and improving operational reliability (Hauck et al., 2018). In parallel, numerical and experimental investigations of wake interactions have been conducted to understand turbulence characteristics and recovery behavior, which are critical for array deployment and environmental impact assessment (Gotelli et al., 2019). Emerging approaches using machine learning have further contributed to improved reconstruction and prediction of wake flow fields in large rivers (Zhang et al., 2024).

At the global scale, riverine hydrokinetic energy has been assessed using long-term discharge datasets combined with high-resolution river network representations. These studies indicate substantial untapped theoretical potential, particularly in Asia, South America, and Africa (Ridgill et al., 2022a). Countries such as China, Brazil, and Russia have been identified as having the highest riverine hydrokinetic potential, followed by regions in South and Central Asia (Ridgill et al., 2022b). However, technology readiness assessments suggest that riverine hydrokinetic converters are generally less mature than tidal systems, highlighting the need for further experimental validation and site-specific studies (Malali et al., 2025).

The Tanana River Test Site (TRTS) in Alaska is recognized as the most prominent experimental site for river hydrokinetic energy research. Multiple field deployments at TRTS have enabled detailed measurements of velocity, turbulence, and wake recovery downstream of operating turbines. Field observations showed that flow velocities recover to near-ambient conditions within approximately 20 turbine diameters downstream, providing important guidance for turbine spacing and array design (Edgerly & Ravens, 2019). The site has also supported hydrodynamic modeling studies and machine-learning-based prediction of electrical output, reinforcing its role as a benchmark location for validating river energy technologies (Alvarado et al., 2024; Browning, 2024).

Beyond North America, hydrokinetic energy research has been conducted at several international sites. Experimental and numerical studies of marine hydrokinetic turbines have been reported in Europe, including wake interaction experiments in France (Gotelli et al., 2019). Techno-economic and feasibility studies have examined river and tidal energy deployment in regions such as Nigeria, Colombia, and Southeast Asia, with emphasis on cost reduction and off-grid electrification (Eme et al., 2019; Ibrahim et al., 2019; Salazar et al., 2024; Tan et al., 2021). In Asia, site-specific assessments and environmental studies, particularly in the Yamuna Canal and the Mekong River basin, have highlighted both the hydrokinetic potential and ecological considerations associated with turbine deployment (Martinez et al., 2019; Saini et al., 2021).

Despite being an riverine country, the potential of river current energy has not been studied in Bangladesh, leading to a research gap that needs to addressed. This paper evaluates the feasibility of hydrokinetic power generation in the Matamuhuri River using the RM2 turbine by combining long-term hydrological data analysis, Weibull-based Monte Carlo simulation, and turbine performance modeling. It provides realistic estimates of power output and levelized cost of energy for the site, highlights the limitations imposed by low river velocities, and identifies key environmental and operational considerations. The study also outlines methodological and data-related gaps, offering guidance for future assessments of river current energy potential in Bangladesh.

2. METHODOLOGY

This section describes the working principle and structural description of the energy generation device, the data is from the river is utilized to estimate the yearly energy generated by the RM2 device at a specific site location in the Matamuhuri river and assess the feasibility of installing such device for electricity generation. The following subsections provide the details on the collected data and the analysis method.

2.1 Energy generation principle

The energy generation from the river current can be explained with the stream tube model. Figure 1 illustrates this process in a simplified way. A simple channel is shown in the figure, where the plane at the centre represents the rotor disc, which receives kinetic energy from the flow of the river and converts it to the electric energy through a generator. The water enters the stream tube with upstream velocity U_∞ and pressure p_∞. When the water crosses the rotor disc area, the pressure increases to p_1 and the velocity decreases to U, after utilizing some of the kinetic energy to move the rotor. After crossing the rotor disc plane, pressure drops to p_2 while the stream tube cross section expands to keep the mass flow rate constant at both sides of the rotor disc with a reduced velocity U_w at wake or downstream. The pressure at far downstream again reaches the upstream pressure.

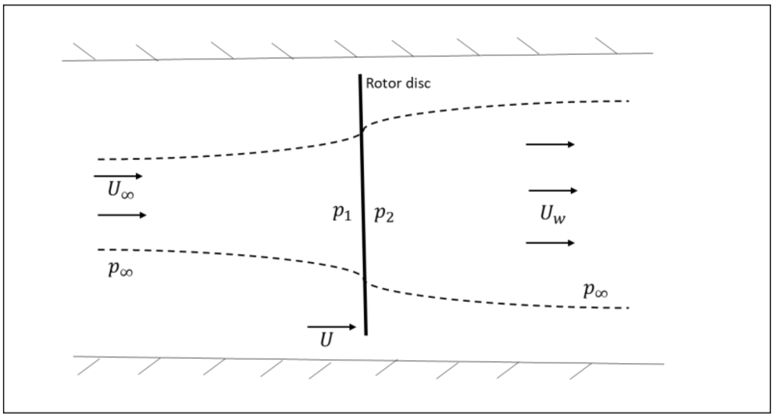

Figure 1: Energy generation process.

By applying Bernoulli equation at upstream, rotor disc and the wake region it can be shown that, the turbine or rotor disc power:

$$P_T = \frac{1}{2}C_P(\lambda)\rho A_t U^3 \tag{1}$$

Where A_t is the cross sectional area of the rotor disc. The formula for rotor disc area depends on the turbine type. For a horizontal axis turibine it is given by $A_t = \pi(\frac{d_t^2}{4})$, while for a cross flow vertical axis device it becomes $A_t = d_t h_t$, where d_t and h_t are the diameter and height of the rotor, respectively. Here, ρ is the density of water and C_P is the power coefficient, defined as the ratio of turbine power and available power. It is a function of the tip speed ratio λ defined as the ratio of the rotor tip speed to the speed of the approaching flow:

$$\lambda = \frac{\omega d_t}{2U} \tag{2}$$

Where, ω is the rotational speed of the rotor. For a device with fixed dimensions, it may be represented as function of the velocity of the current. The electrical power generated is then found by the following equation:

$$P_{elec} = \min\,(\eta_{gear}\eta_{gen}\eta_{xfr}\eta_{inv}P_T, P_{rated}) \tag{3}$$

Where, $\eta_{gear,}\eta_{gen}, \eta_{xfr,}\eta_{inv}$ are the gearbox, generator, transformer, and the inverter efficiency, respectively. P_{rated} is the rated electrical power capacity of the turbine.

2.2 Energy Generation Device

For energy generation, this study employs the Reference Model 2 (RM2) device developed by Sandia National Laboratories under the U.S. Department of Energy (Neary et al., 2014). The RM2 was originally designed for deployment at a reference site in the Mississippi River. As shown in Figure 2, the device consists of rotors mounted on a two-pontoon vessel platform, with three cross-bridges providing structural support between the rotors and pontoons.

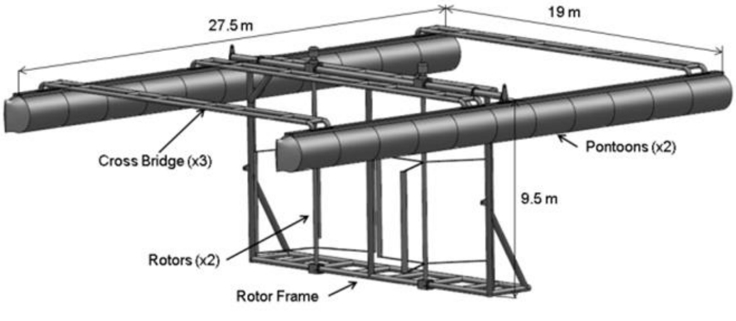

Figure 2: Design of the RM2 device.

The dimensions of the RM2 device from the side and the top view are shown in Figure 3. The rotor centerlines are positioned one blade length below the free surface to minimize the risk of cavitation.

Even under shallow flow conditions, when river discharge is reduced, the rotors maintain a clearance of at least 5 m above the riverbed that helps mitigate effects of velocity gradients, turbulent shear, and asymmetric loading across the rotor.

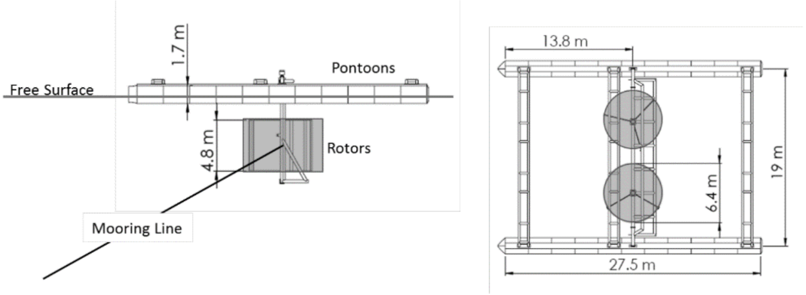

Figure 3: RM2 side and top views with dimensions.

The structure is submerged and held in position using two mooring legs attached to each side of the turbine frame. This configuration ensures the device stationed at the energy generation site.

Table 1 lists the turbine parameters of the RM2 device.

Table 1: RM2 Turbine Parameters

Parameter	**Value**
Rotor Diameter (m)	6.45
Rotor Height (m)	4.84
Rotors per Turbine	2
Mid Rotor Depth (m)	4.84
Rotor Area (m^2)	62.4
Generator Rated Capacity (kW)	89.5
Gearbox Efficiency	94.0%
Generator Efficiency	88.9%
Transformer Efficiency	96.0%
Power Inverter Efficiency	97.0%
Lifetime (years)	20
Investment cost ($)	3,188,000
Operation and Maintenance cost ($)	200,000

The experimental results from the test site on the Mississippi River provide the power coefficient curve of the rotor turbines as a function of flow velocity, as shown in Figure 4. From the curve, it can be observed that the power coefficient remains zero until the velocity reaches 0.7 m/s, after which it stays relatively constant up to about 1.6 m/s. Beyond this point, the coefficient gradually decreases and drops to zero again at around 2.8 m/s. The velocity of 0.7 m/s is defined as the cut-in speed of the rotor turbine, while 2.8 m/s represents the cut-out speed. Between 2.1 m/s and 2.7 m/s, the rotor operates at its rated power output.

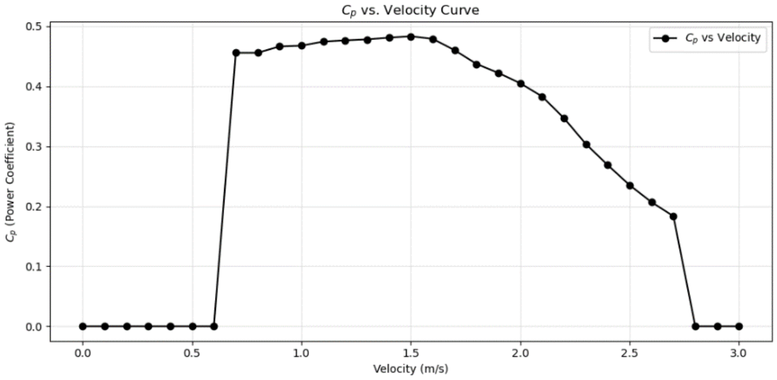

Figure 4: Power Coefficient Curve of RM2.

2.3 Data Description

Discharge data of the Matamuhuri River from the Lama station (Latitude: 21.78°, Longitude: 92.19°), located in Lama Upazila of the Bandarban district, were collected for this study. The dataset spans the period from 1981 to 2024. Measurements were generally taken every two weeks; however, the earliest records are sporadic and do not follow this regular collection cycle. In total, the dataset contains 922 data points and includes water level (mMSL), discharge (m^3/s), cross-sectional area (m^2), and maximum depth (m). Figure 5 presents a GIS map of the study area, indicating the location of the Lama station.

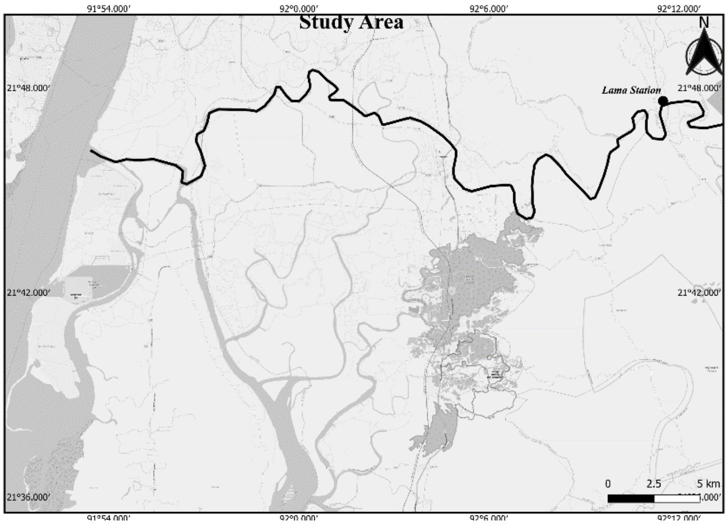

Figure 5: GIS map of the study area.

2.4 Method of Analysis

The obtained discharge and cross-sectional area data are used to calculate the velocity of the river current using following formula:

$$U = \frac{Q}{A_R} \qquad (4)$$

where, Q is the discharge and A_R is the cross-sectional area of the measurement. However, it was observed that there are some inconsistent outlier values of very high magnitude, which may have arisen from incorrect measurements. Table 2 presents the distribution metrics of the velocity data from the Lama station in the Matamuhuri River.

Table 2: Data Distribution Metrics of Original Velocity data

Metric	**Count**	**Mean**	**Std. Deviation**	**Min.**	**Q1**	**Median**	**Q2**	**Max.**
Value (m/s)	922	1.366	10.18	0.107	0.343	0.518	0.721	179.28

As the table indicates, there are some unrealistic values on the higher end of the distribution. These outlier values were eliminated from our analysis by limiting our velocity data to 99th percentile. Table 3 provides the distribution metrics for the filtered velocity data after outliers are removed.

Table 3: Data Distribution Metrics of Filtered Velocity data

Metric	**Count**	**Mean**	**Std. Deviation**	**Min.**	**Q1**	**Median**	**Q2**	**Max.**
Value (m/s)	912	0.543	0.252	0.107	0.342	0.516	0.715	1.979

This data is then used to plot the normalized histogram and fit the distribution using a Weibull distribution. The rationale behind using the Weibull distribution is that it is commonly used to describe wind velocity in wind energy studies, which is analogous to river current velocity in the context of this work. The probability density function of a Weibull distribution is defined as:

$$f(x) = \begin{cases} \frac{k}{c}\left(\frac{x}{c}\right)^{k-1} e^{-\left(\frac{x}{c}\right)^{k}}, x \geq 0 \\ 0\ , x < 0 \end{cases} \qquad (5)$$

where k > 0 is the shape parameter and c > 0 is the scale parameter of the distribution. The mean and variance, μ and σ^2, of the distribution are related to the scale and shape parameters of the distribution with the following equations:

$$\mu = c\Gamma(1 + \frac{1}{k}) \qquad (6)$$

$$\sigma^2 = c^2[\Gamma\left(1 + \frac{2}{k}\right) - \left(\Gamma\left(1 + \frac{1}{k}\right)\right)^2] \qquad (7)$$

The fitted Weibull distribution yields shape and scale parameters of 3.19 and 0.52, respectively. To confirm how well this Weibull model represents the sample data, we perform a Kolmogorov–Smirnov (K–S) test and examine the resulting p-value. The p-value is calculated as 5.931×10^{-5}. This low p-value indicates that the fitted Weibull distribution closely matches the sample distribution. Figure 6 presents the normalized histogram of the velocity data along with the fitted Weibull curve.

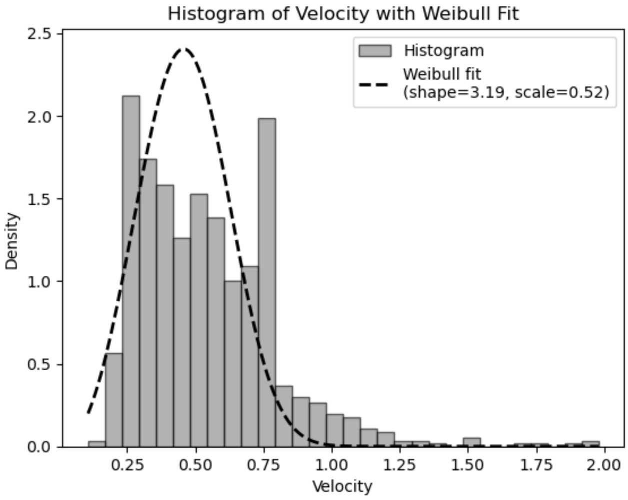

Figure 6: Histogram and fitted Weibull distribution of the Velocity Data.

The historical velocity data are then used to calculate the corresponding electrical power using Equations 1 and 3, along with the parameter values from Table 1 and the power coefficient values shown in Figure 4. Linear interpolation is applied to determine the power coefficient for velocities that fall between the defined points on the power coefficient curve. The average power is first calculated from the historical velocity data. Next, a Monte Carlo simulation is performed: 10,000 velocity samples are generated from the fitted Weibull distribution, and the power for each sample is calculated using the same procedure. Finally, the average power is computed across all generated samples.

3. RESULTS AND DISCUSSIONS

We compare the results obtained from the historical velocity data with those from the Monte Carlo simulation. Figure 7 illustrates the electrical power generated from both the historical data and the Monte Carlo samples based on the fitted Weibull distribution. As seen in the figure, the generated samples do not exceed a velocity of approximately 1.1 m/s, whereas some historical values exceed this and reach nearly 2 m/s. This results in a significant difference in the generated power, as power is proportional to the cube of the velocity. The difference in velocities between the generated and historical samples can be explained by examining the distributions in Figure 6. A substantial number of historical samples are around 0.75 m/s, while the fitted Weibull distribution peaks near 0.5 m/s and then gradually declines.

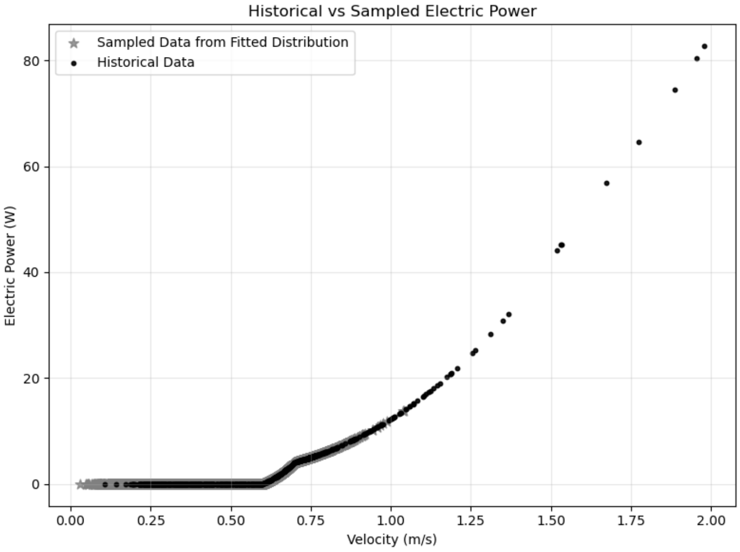

Figure 7: Electrical power generated from historical and sample velocity distribution data.

The average electrical power generated from the historical data and the Monte Carlo simulation is shown in Figure 8. This figure reinforces the insights from Figure 7. The average power from the historical data is 2.664 kW, while the Monte Carlo simulation converges near 0.611 kW. This significant difference can be attributed to the discrepancy in the distributions around 0.75 m/s. Recall that the cut-in speed of the turbine is 0.7 m/s, meaning the turbine generates no power at velocities below this threshold, which accounts for most of the fitted distribution. Additionally, the cubic relationship between power and velocity further amplifies this difference.

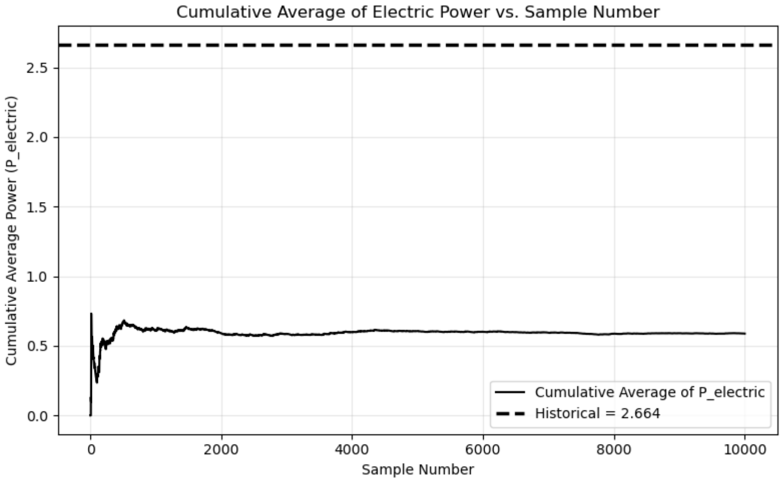

Figure 8: Average power from historical data and Monte-Carlo Simulation.

The levelized cost of energy (LCOE) is a metric that represents the lifetime cost of a power plant divided by its total energy production, expressed as the present value of all construction and operating costs, enabling comparison across technologies with different lifetimes, sizes, costs, and performance characteristics. The LCOE is calculated using the following formula:

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \quad (8)$$

Where, I_t, M_t, F_t are the investment, maintenance and fuel expenditure in year t, r is the discount rate, and n is the estimated lifetime of the project. E_t is the annual energy production (AEP) in year t. The AEP is calculated in kWh using following formula:

$$E_t = 365 \times 24 \times P_T \quad (9)$$

Table 4 compares the LCOE of the RM2 device based on historical data and Monte Carlo simulation results for the Matamuhuri River, along with experimental results reported by Sandia National Laboratories for the Mississippi River.

Table 4: LCOE Comparison

Scenario	**LCOE ($/kWh)**
Historical data (Matamuhuri)	7.25
Monte Carlo simulation (Matamuhuri)	29.25
Sandia Experiments (Missisipi)	0.83

These results from table 4 indicate that installing and generating power from the selected site on the Matamuhuri River using the RM2 device is economically infeasible. The large difference between the Matamuhuri site and the Sandia experiments on the Mississippi River can be explained by the distributions of their respective river velocities, as shown in Figure 9. In the Mississippi River, only about 6% of velocities fall below the turbine's cut-in speed, whereas in the Matamuhuri River, 75% of velocities are below the cut-in speed. This means the turbine is unable to generate electricity most of the time. Consequently, the economics are unfavorable: not only is power generation intermittent, but the power produced when the turbine operates is significantly lower than the rated value, because generated power is proportional to the cube of velocity. The average river velocity in Matamuhuri is 0.543 m/s, compared to 1.25 m/s in the Mississippi River, further explaining the large difference in performance and cost.

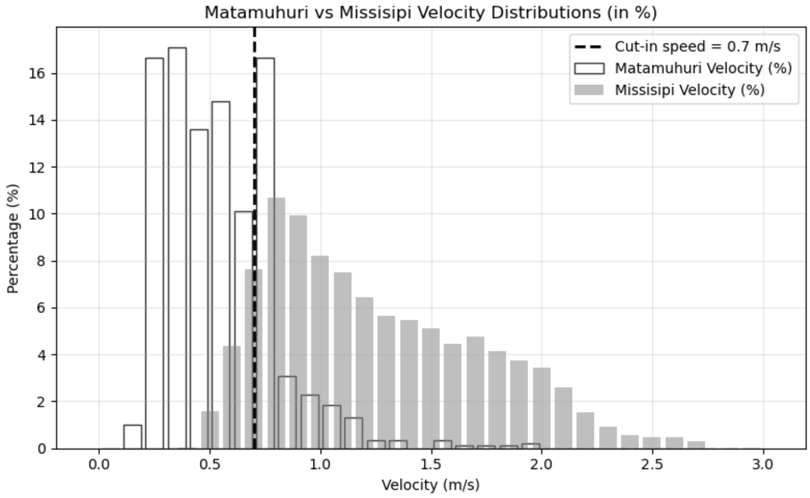

Figure 8: Velocity distributions of the Matamuhuri and Missisipi rivers.

Although the results do not support marine power generation at this site, this should not be taken as a general conclusion for Bangladesh. There are several limitations to this study. The analysis is based on data from a single station; other rivers or even other stations along the Matamuhuri River could prove feasible if studied in detail. Additionally, the data were not collected daily, so short-term peak velocities may be missed in this dataset. Our investigation focuses on the RM2 device, which was tested on the Mississippi River and designed based on its flow characteristics to optimize power generation. Other turbine designs could potentially be more suitable for local conditions. There is also the possibility of developing a custom turbine specifically adapted to the characteristics of rivers in Bangladesh.

4. CONCLUSIONS

In this study, we assess the feasibility of generating electrical power using the kinetic energy of the Matamuhuri River's current. We utilize the publicly available design specifications of the Reference Model 2 (RM2) device, developed by Sandia National Laboratories, along with data from the Lama station of the Matamuhuri River. The results indicate that installing RM2 devices at this site is not economically feasible. This infeasibility can be primarily attributed to the low average current velocity and that the major proportion of time during which velocities remain below the turbine cut-in speed, resulting in negligible power generation and a substantially higher LCOE compared to experimental results in the Mississippi River. While the findings do not support RM2-based deployment at the studied site, they do not necessarily rule out the potential of river current energy across entire Bangladesh. There were several limitations, including reliance on data from a single station, evaluation of only one specific device design, and low temporal resolution of the dataset. Future work could extend this assessment to other river locations in Bangladesh and explore additional forms of marine energy, such as wave and tidal power, using different device designs, including custom solutions tailored to local conditions.

DECLARATION OF USE OF AI

Artificial intelligence (AI) tools were used in this study to assist with language editing, clarity, and coherence of the manuscript. In addition, AI-assisted coding ("vibe coding") was employed to generate and refine scripts used for data analysis and visualization. All analytical methods, interpretations, results, and conclusions were independently verified by the authors, who take full responsibility for the content of this work.

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