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Feasibility Study and Performance Analysis of Rooftop Solar Panels and Airdolphin Wind Turbines

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***Abstract*—Bangladesh's economy has grown significantly in recent years. The nation's rapid industrialization and population have increased the demand for power. However, to mitigate such issue a vast amount of measures have been taken which is not permanent. The world is moving towards renewable generation as it is also beneficial for the environment. However, renewable generation requires lots of land, that is not so freely available in a capital city like Dhaka. Dhaka has a high energy demand as it consumes 46% of the total generated electricity. In this study, two approaches are shown by utilizing the same space we can generate electrical energy. The first one is to use the empty rooftop space of various Govt. buildings, commercial buildings, and petrol pumps to install solar panels. Another approach can be taken as implementing telecommunication connected to AirDolphine tower which can convert the wind energy into electrical energy and can be mounted in the existing cell tower. A methodology is established to check the renewable generation feasibility from the performance and the economic standpoint. Using the weather data to simulate the final output from rooftop generation and telecommunication-connected wind turbines, a significant amount of energy can be provided from the given model. An annual generation of 1190.986 GWh with a 10.554 km^2 area can be generated from our simulation which is very positive for the fact that renewable generation is not responsible for any carbon dioxide emissions.**

***Index Terms*—Renewable Generation, Rooftop Solar, Airdolphin Wind turbine, Economic Feasibility.**

I. Introduction

The government of Bangladesh is constructing additional power plants in order to close the disparity between the amount of electricity produced and the amount required. Using solar, hydroelectric, and off-grid wind turbines for Dhaka city, this research offers a grid-connected hybrid power generation concept to reduce its energy shortage. The projected rise in consumption of energy between 2010 and 2040 is 56%, and 90% of the population has access to electricity, meaning that approximately 40,000 MW of power is needed to provide electrical power to the majority of the population. However, Dhaka city consumes between 4,000 and 4,500 MW of electrical power [1], [2]. Even though solar PV generation is becoming more and more popular, there is a significant dearth of land in densely populated countries like Bangladesh. Solar PV systems can be installed with plenty of solar energy [3], [4]. As a result, due to its many advantages, the limited amount of land favors rooftop photovoltaic systems (RPS). Application-based RPS feasibility studies, such as those for government properties, private properties, filling stations, etc., were the consequence of this. The fight against chronic pollution has greatly increased due to global warming. As a result, the world's top priority is to consume and manage energy in a sustainable manner. The wastewater from homes and businesses, sometimes referred to as sewage water, as well as the precipitation that falls on a city, may be able to produce power in an environmentally acceptable way as a remedy to this issue. The fight against persistent pollution has substantially increased. As a result, the world's top priority is to consume and manage energy in a sustainable manner. The wastewater from homes and businesses, sometimes referred to as sewage water, as well as the precipitation that falls on a city, may be able to produce power in an environmentally acceptable way as a remedy to this issue. Many other countries use wastewater as a source of electricity generation.

Implementing a renewable energy generator is unquestionably the best option for a future energy source and reducing greenhouse gas emissions, but renewable generation is weather-dependent and unpredictable. Numerous studies have been done based on historical data, some of them using Homer software, showing us the financial value of the Renewable Energy System (RES) system and the rate of power consumption [5]–[7]. In 2014, another study was conducted with a rooftop mapping system to evaluate the efficiency of solar panels was insufficient to provide much power [8]. In 2021, another hypothetical small hydro-power plant using sewage water will be constructed using a Gravitational Water Vortex Power Plant (GWVPP) while taking into account case studies of Dhaka City [9]. However, there are certain drawbacks to this model when addressing the water shortage issue in Dhaka city while considering the assumption-based water flow rate for the model. Many countries have sewage treatment facilities combined with hydro turbines to produce power [10] where 20% of total wasted water processes by the Sewage Treatment Plant". The development of different approaches to ensure the coexistence of the wind turbines and the communications services is made possible, however, by the projection of the probable influence of a turbine farm on those services prior to its construction. Each unique installation and its associated services must be thoroughly analyzed before potential implications can be assessed. The location of wind turbines and telecommunications infrastructure, the elevation and topography of the land, the height of telecommunication towers, the frequency and modulation of services, the properties of emitting systems, and reception conditions are all important factors to take into account. To fully comprehend and assess the potential implications for every circumstance, a case-by-case approach is required. The average tower construction suppliers are very worried about the overall cost of energy required to operate a telecom site even though the wind speed is not as powerful as the coastal area in Dhaka city.

The telecommunication industry is being forced to look for alternatives by a combination of factors including increased operating costs, logistical difficulties, upcoming pricing privatization, and the negative environmental effects of using diesel. Because of its height, this structure can harness the greatest wind energy, use it to meet the power requirements of a site, and lessen the demand for diesel generators. Because of its height, this structure can harness the greatest wind energy, use it to meet the power requirements of a site, and lessen the demand for diesel generators.

The main objective of this research is the feasibility analysis by HelioScope using the different RES methods to reduce the pressure on the national grid in the aspect of Dhaka city:

- To design and analyze the effectiveness of a rooftop solar system using meteorological data.
- To analyze the feasibility of telecommunication tower self-energizing by using wind Airdolphin Turbine.
- To assess the financial model for the proposed model.

II. Modeling of Systems

A. Roottop Solar PV System

Since a large solar PV system requires a lot of area, it cannot be erected in Dhaka due to its dense population. Rooftop PV systems can be installed on both public and private sites to address the issue of land scarcity. A PV module and inverter model are built using the free drawing program Sketch Up, and the chosen location is chosen using Google Maps. The shading analysis of PV panels is assessed using HelioScope's 3D model, which offers suggestions for how many panels and inverters are required for such a design, the maximum amount of electricity it could produce, and its overall performance ratio on an annual and monthly basis.

1) Selected Site: The primary goal of our studies is to make Dhaka city's loads self-sufficient by reducing the demand on the national electrical grid. The entire city of Dhaka has a massive amount of rooftop space that we may use to generate enormous amounts of power using PV solar, but for the sake of this case study, we chose three main places where we test the feasibility of the rooftop PV system.

a) Govt. Property (Dhaka Judge Court Building): Nearly all of the Govt. buildings' rooftops are empty and unoccupied. If an on-grid solar power plant with a smart meter is installed in those vacant spaces, it will provide the necessary energy during business hours and electricity to the utility grid during the holidays. The total amount of electrical power consumed and delivered to the grid can be determined using the smart meter. The heat map of the selected area is shown in Fig 1.

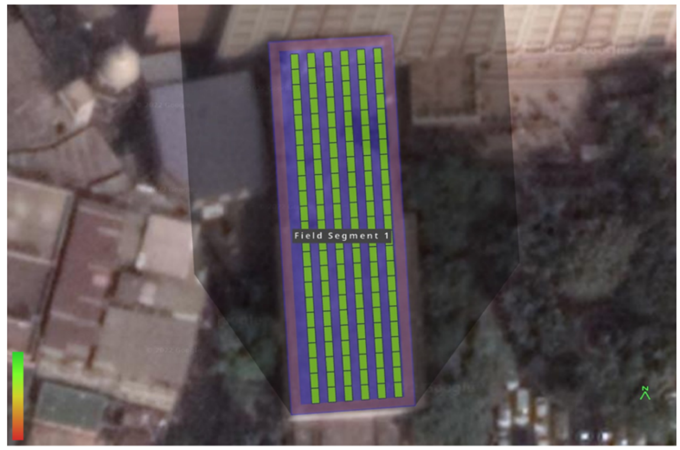


Fig. 1: Dhaka Judge Court Building Heat Map.

b) Private Property (Commercial Building Banani): Numerous private garment companies, particularly in Chattagram, made rooftop solar investments because Bangladesh is still unable to guarantee 100% production uptime. They can reduce their electricity costs by adding rooftop solar, which also relieves the strain on the national grid. The heat map of the selected area is shown in Fig 2. Implement the systems for monitoring the performance of solar installation and establish a maintenance plan to ensure the panels continue to operate efficiently.

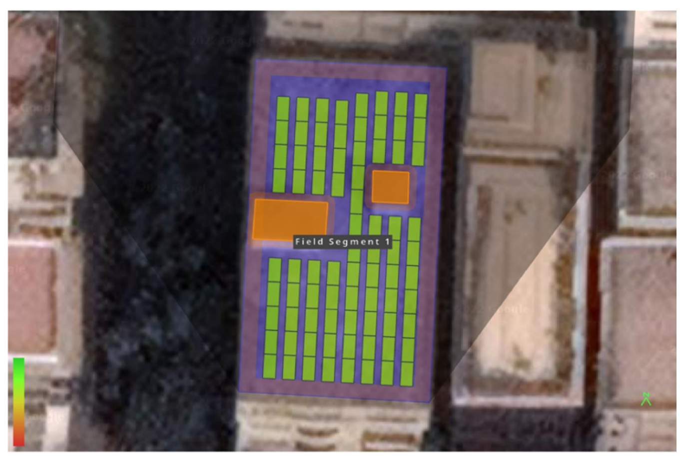


Fig. 2: Commercial Building Banani, Dhaka Heat Map.

c) Private Property (Filling Station): The global market for automobiles will be dominated by electric vehicles in the near future, and the rising demand for electric vehicles will have a significant impact on the need for power. A fueling station is seen to be a good candidate for a rooftop solar PV system because it also has open space on the roof. To give a consistent power supply to the gas station or pump in order to reduce electricity consumption by installing solar PV systems. The heat map of the selected area is shown in Fig 3.

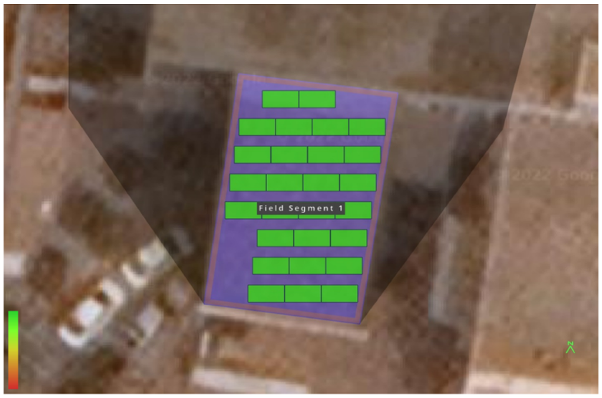


Fig. 3: Filling Station Heat Map.

B. Wind Turbine Modeling

Due to a variety of factors, including the fact that many local natural areas close to the shore are windier than coastal areas, the availability of wind resources is far less predictable than that of solar. However, the wind speed in Dhaka City is not the same as that in the Coastal region. therefore, in terms of wind energy, In this study, a wind-turbine-connected telecommunication tower shown in Fig 4 is taken into consideration since it receives good wind speed despite the low wind speed in Dhaka city.

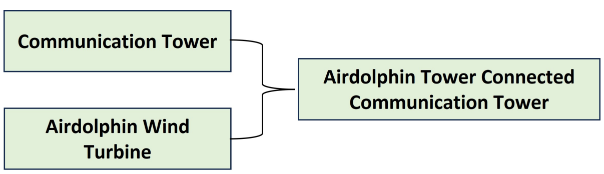


Fig. 4: Airdolphin WT connected Telecommunication Tower Model.

During a 30-day trial period, MTC's trial site (Okapuka, just outside of Windhoek) had good wind rates of 2 *to* $9\ m/s$ (daily average). During the testing period an average wind speed of 4.7 m/s daily generation of electricity average of 2.4 kWh was obtained using the Airdolphin WT connected Telecommunication Tower Model [11]. Telecommunication towers typically rise 25 meters above the ground, with an average top wind speed of 5 meters per second. The energy generation (G_{wind}) by a wind turbine can be estimated using the wind function. Manufacturers of wind turbines provide the necessary specification required to estimate the energy generated by a wind turbine model using the quadratic model of wind function shown in EQ. (1) [6]. Matlab software environment is used to simulate the hourly output from a wind turbine using the EQ. (1).

$$G_{wind}(t) = \begin{cases} 0 & V(t) \leqslant V_{in} \text{ or } V(t) \geqslant V_{out} \\ P_{wt} & V_{rated} \leqslant V(t) \leqslant V_{out} \\ P_{wt} \times \left(\dfrac{V(t) - V_{in}}{V_{rated} - V_{in}}\right) & V_{in} \leqslant V(t) \leqslant V_{rated} \end{cases} \tag{1}$$

Here, The Vestas V2.0 turbine model is taken as reference model for simulation, $P_{wt} = 2MW$, $V_{in} = 4m/s$, $V_{rated} = 12m/s$, $V_{out} = 25m/s$ [6]. The average hourly wind speed $V(t)$ for different locations in Bangladesh is given in Table I, which is used to estimate wind generation.

TABLE I: Average Wind Speed (m/s) at 20 Meters Height [12].

Stations	**Annual Avg. Wind Speed (m/s)**	**Available Wind (Theo.) (m/s) Power Density P/A=0.6A.**
Barisal	2.66	11.29
Teknaf	3.17	19.11
Bogra	2.82	13.45
Satkira	4.37	50.07
Sandwip	2.76	12.61
Patenga	7.48	251.12
Kumbdia	2.32	7.49
Dinaipur	2.83	13.6
Khulna	2.89	14.48
Chittagong	4.65	60.33
Jessore	4.93	71.89
Cox's Bazar	3.81	33.18
khepupara	4.24	45.76
Hatiya	3.74	31.39
Comilla	2.78	12.89
Dhaka	4.52	55.41
Thakurgaon	6.59	171.71

An essential feature of a wind turbine is its power curve, which shows the relationship between output power and wind speed at the hub height for the selected AirDolphin Wind turbine. The power curve shown in Fig 5 supports energy evaluation, insurance composition, and rotor assessment of effectiveness.

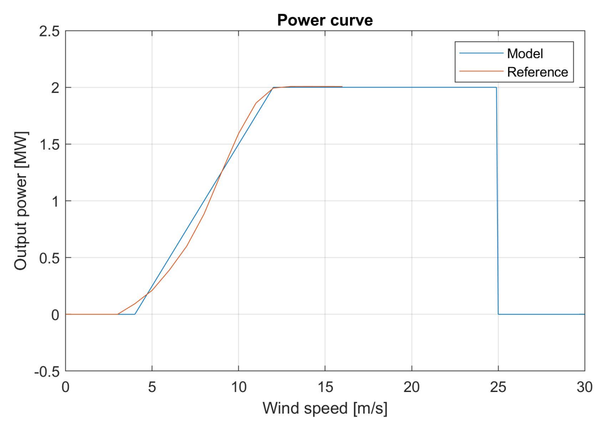
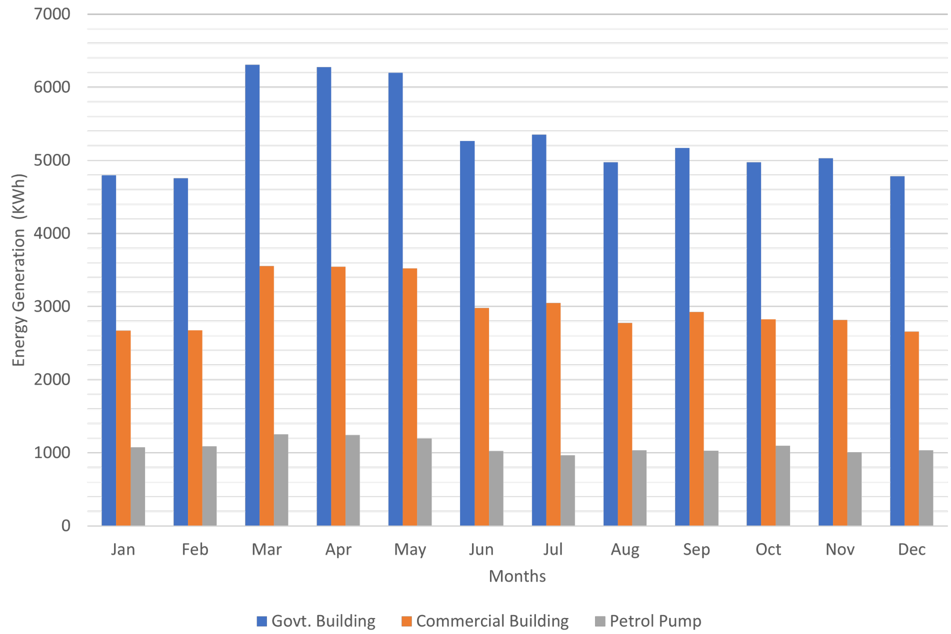


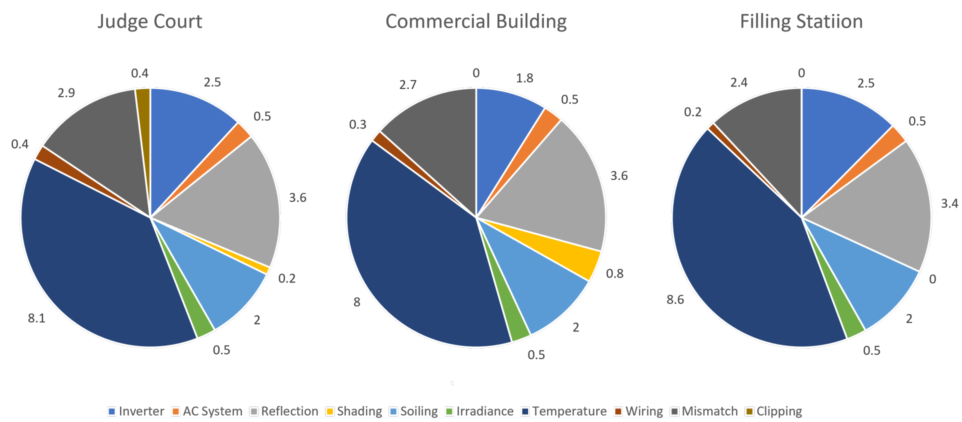
Fig. 5: Wind Turbine Power Curve.

III. Results and Analysis

According to a conservative estimation based on the Quickbird Scene 2006 of Dhaka, the city of Dhaka provides approximately 10.554 km2 of sunlit roof-tops within the Dhaka City Corporation (DCC) region, out of a total area of 134.282 km2. As of the year 2022, the total land area



(a) Monthly Generation.



(b) Source of System Loss.

Fig. 6: Rooftop PV System

of Dhaka City encompasses approximately 306.4 square kilometers. The size has increased by more than twice its 2006 value. We utilized the rooftop area measuring 9887 square feet for the installation of photovoltaic (PV) panels, which is approximately equivalent to 0.000919 square kilometers. The aggregate surface area has the capacity to produce approximately 66.6 kilowatts of energy through the utilization of three inverters, each with a power rating of 72.2 kilowatts.

The monthly total electrical energy generation of Rooftop Solar for three selected locations is given in Table II. The monthly total generation is visually plotted in Fig 6a along with the losses that might be factors on the build system on Fig 6b. The HelioScope tools are used to analyze losses namely - AC system loss, inverter loss, wiring loss, mismatch loss, temperature loss, irradiance loss, shading loss, soiling loss, and reflection loss, and the results are plotted in Fig 6b.

TABLE II: Rooftop Solar PV Energy Generation

Months	**Rooftop Solar PV Generation (kWh)**		
	Dhaka Judge Court (Govt. Building)	**Commercial Building, Banani, Dhaka**	**Petrol & CNG Filling Station, Dhaka**
Jan	4799.8	2673.7	1076.6
Feb	4756	2674.8	1088.2
Mar	6309.9	3554.9	1253.8
Apr	6277.8	3544.6	1242.3
May	6199.5	3522.9	1196.7
Jun	5268.4	2982.6	1024.2
Jul	5355.1	3050.2	967.4
Aug	4973.4	2775.4	1033.2
Sep	5169.5	2925.7	1028.2
Oct	4975.3	2826.2	1097.9
Nov	5032	2819.9	1005.9
Dec	4783.2	2658.9	1034.4

Radiation loss is the amount of yearly irradiance that may potentially damage the modules if they were tilted and oriented correctly for the intended site. Shading is the loss of irradiance caused by shadow. Trees, impediments, walls, or roofs, as well as additional components, may cast a shadow on an array, reducing the total amount of irradiance. The accumulation of dust on solar panels, known as soiling, lowers the efficiency of the rooftop PV system. The balance between the thermal energy that a PV module generates and the heat it exchanges with the environment determines the temperature at which it operates. Conduction, convection, or radiation are the three ways heat can be transferred from a PV module to the air around it. The materials used in the PV module's manufacture, its emissive characteristics, and the location in which it is situated particularly the wind speed, all have an impact on these loss processes. Mismatch losses occur when solar modules or cells with different operational properties or physical qualities are connected. The number of rooftop solar units, the shaded irradiance, tilt angle, azimuth angle, installed capacity, and the total amount of electrical energy generated in the simulation run for the selected site needed for the system to run economically affordable and feasible are given in Table III.

TABLE III: Rooftop Solar PV Simulation Results

Location	Shaded Irradiance	Tilt Angle	Azimuth Angle	Number of PV Modules	Rated Capacity	Total Energy
Dhaka Judge Court (Govt. Building)	1783.8kWh/m^2	10.0°	266.7°	138	44.2 kWp	63.9 MWh
Commercial Building, Banani, Dhaka	1783.8kWh/m^2		272.8°	78	25.0 kWp	360 MWh
Petrol & CNG Filling Station, Dhaka	1854.8kWh/m^2		180°	27	8.64 kWp	13.0 MWh

Helioscope was able to ascertain the ideal system size and the quantity of capacity that must be put at the chosen sites based on the three locations that were chosen. Additionally, it included the base variable factor that is used to calculate the simulation's overall energy generation.

The average energy generation from the AirDolphin turbine is estimated using the reference data. Power generated using the model with respect to the input wind speed given in Fig 7.

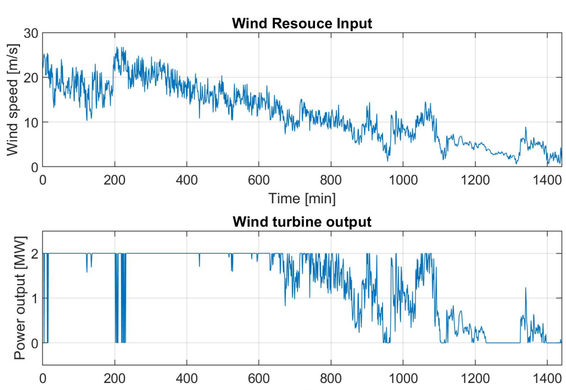


Fig. 7: AirDolphin Wind Turbine Tower Output.

The monthly total estimated generation of AirDolphin is visually plotted in Fig 8. The highest amount of wind generation is seen in the months of June, July, and August. Only one unit of WT was considered to simulate the wind turbine results where the annual total generation is around 509.08 GWh.

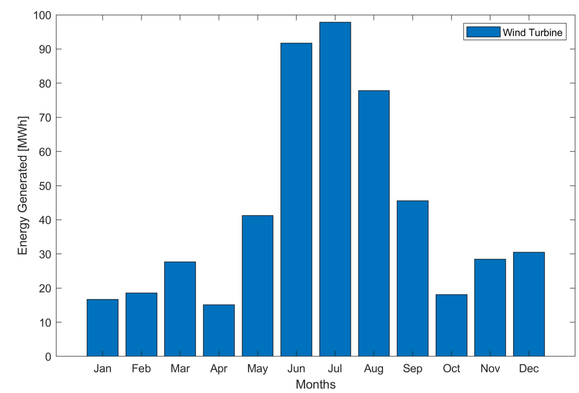


Fig. 8: Monthly Generation AirDolphin Wind Turbine.

Renting your power by paying for utility services. The utility has the authority to set prices, and costs continue to rise over time. You may now control your energy expenditures in a new, more cost-effective way thanks to solar energy. According to HelioScope, the net present cost for the proposed system will be around $38,046.92 for 7.6 years and the break-even for the investment will be 32.58% which will be the returning value of total investment cost.

Fig. 9: Financial Analysis.

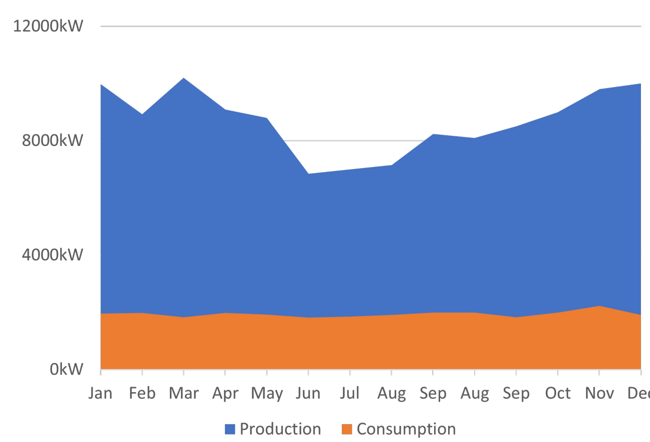


Fig. 10: Consumption vs Generation Comparison.

Analyzing the amount of power produced by the solar energy system and contrasting it with the building's overall electricity usage over a predetermined time frame, such as a month or a year, is required to compare rooftop PV and consumption is shown in Fig 10. Cash flow analysis for the designed system is shown in Fig 11. This illustrates that the planned rooftop model may break even with a few installation expenses and then turn a profit economically. In January, the cash flow will be around \$10,000, after a slight decrease in February, the cash flow will reach its peak in the month of March exceeding the \$10,000 threshold. After that, the cash flow sought decreased till June and dropped below \$7,000. The cash flow experienced a gradual increase till December.

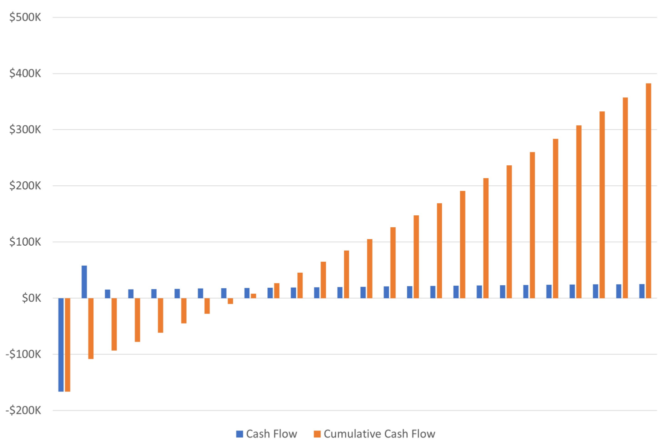


Fig. 11: Cash Flow vs Cumulative Cash Flow .

Dhaka city's total surface area is 10.554 km^2. The area of the site we chose is 9886.25 square feet (or 0.0009184 km^2). Annually, 103.2 MWh of energy can be generated in our simulation. We are getting 103.2 MWh against a 0.0009184 km^2 area. We will get approximately 1185945.99 MWh = 1185.946 GWh power against 10.554 km^2 area. The combined energy from the solar system and wind turbines makes up a hybrid energy system's entire annual power of around 1190.986 GWh.

IV. Conclusions

In this study, a feasibility analysis consisting of rooftop PV and AirDolphine wind turbines is tested against the renewable resource value of the selected site. By using Heliscope, the heat map and their respective optimized component needed for the rooftop PV system to run economically feasible is tested along with the monthly and annual energy generation through the instilled PV unit and the performance analysis is done using the source of losses in the HelioScope Feasibility estimating algorithm. Secondly, average wind speed data is tested with annual wind speed potential and estimated the monthly total wind generation along with the annual wind generation with an AirDolphine turbine connected to a telecommunication tower. The total amount of energy generated can be estimated with the economic and cash-flow analysis, and the economic feasibility of the system is determined. An annual generation of 1190.986 GWh is generated from our simulation which is very positive for the fact that renewable generation is not responsible for any carbon dioxide emissions.

There is a newly emerging technology that offers sustainable generation such as Sewage treatment plants and Biomass generators (Waste-to-energy generation). Future works should be focused on estimating the annual output of the Vortex Sewage Treatment Plant and Biomass generator for sustainable generation and subsequently calculating the feasibility of the system in the aspect of Dhaka City.

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