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Feasibility analysis of grid connected roof top solar system for a metro rail station in Dhaka, Bangladesh

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ABSTRACT

Bangladesh is a growing country with population increasing rapidly and electricity demand alike. A grid-connected PV rooftop system at a metro rail station, Dhaka is a significant way to meet electricity demand and protect the environment. The system might be installed approximately 846 kWh capacity solar panels on a 4410 square meter rooftop. These specific panels will produce around 1350 kWh/kWp/year which will reduce significantly the grid connected electricity consumption. The system will produce electricity for USD $0.03 kWh, which is lower than rooftop PV plants in currently operation in Bangladesh. This article investigated the grid connected rooftop photovoltaic system using the PVSyst simulation software tools and analyzed the economic aspects of the project. This system will reduce carbon dioxide emissions by 1,551 tons per year, which will help reduce environmental pollution. For a grid connected system using the rooftop of a metro rail station is a sustainable solution to meet electricity demand and protect the environment of the country as well to achieve the Sustainable Development Goals of the Government of Bangladesh.

Keywords: Rooftop PV plant; Solar energy; Sustainable energy; SDGs goal; Metro station; PVSyst; Renewable; Cost analysis; Zero emission; Homer pro; Bangladesh energy.

1. Introduction

Bangladesh meets its 59 percent energy demand from natural gas, according to the report of Bangladesh Power Development Board (BPDB). Despite the nation's massive coal reserves, coal is mined and used less frequently in this region. Conversely, although the Furthermore, in order to satisfy the growing demand for gas, the government has already begun importing LNG. In order to meet the energy demand, electricity is also being imported from India [1]. Global adoption of renewable energy has replaced fossil fuels including gas, coal, and oil. The motivation behind this shift to renewable energy is to curtail carbon emissions, to meet environmental standards and to promote sustainable development. The primary issues with these sources are their scarcity and their steady decline [2]. The use of these fossil fuels has a negative effect on the environment because it produces greenhouse gases that cause global warming. The global community has received several policy statements advocating an energy transition from fossil fuels to renewable energy sources [3]. Degradation of energy from traditional (non-renewable) natural resources opens the door to renewable energy sources. Renewable energy is an environment friendly natural resource that usually doesn't pollute the environment and is beneficial for the climate and its unlimited availability such as wind, solar electricity, biogas, ocean wave, hydro and geothermal power [4],[5]. Among the renewable energy plants, solar energy plants are the most common and widely used in various countries [6]. In addition, it also has some challenges in the implementation and production stage of the plant, such as deforestation, bird mortality, corrosion, runoff, and microclimate change [7]. It is also true that a land-based solar power plant is built on farmland, which is not an economical use of land resources [8],[9]. A land- based solar power plant requires on average, 0.5–0.7 MWp/ha of land [10]. The utilization of underutilized metropolitan spaces, such as the rooftops of residential or commercial buildings, may create a burden on urban agriculture consequence due to conflicting uses and the ensuing high costs of land buildings might offer a means of getting around obstacles to development [11]. Overall, a rooftop solar PV system uses less energy—between 21% and 54% less—in its energy intake, produces

18% to 59% fewer CO_2 equivalents in greenhouse gas emissions, and uses less water—between 1% and 12% per kWp. In all regions, rooftop solar systems have an energy payback time that is between 51% and 57% shorter than that of ground-mounted solar systems [12]. Metro rail is a long-term, ambitious initiative by the government to lessen traffic congestion in Dhaka city and its environs. By 2030, the government plans to construct six metro rails in total for this purpose. Under these six, 128.741kilometers of metro rail will be built. Of this, 61.172 km of subway and 67.569 km of flyover will be built.

There will be 104 stations along the line in all. 51 of them will be aerial stations, and 53will be subterranean. The goal of creating this robust network is to help the government decongest Dhaka by 2030. The building of these six metro rails has already begun. MRT Line-6 is already in operation, having opened for passenger traffic from Uttara to Motijheel. On December 16, 2022, the first section, started to run from Uttara to Agargaon in honor of the country's 50th anniversary of independence [13],[32]. The grid-connected rooftop photovoltaic system in the site Uttara South Metrorail Station in Dhaka offers an environmentally friendly and sustainable way to meet electricity demand. By 2041, the government wants to have produced 6,000 MWh of electricity from solar photovoltaic [24]. The Government of Bangladesh's Sustainable Development Goals will be aided by this effort. Following the 2012 Rio+20 Conference, the UN gave states instructions to adopt sensible policies aimed at accomplishing a number of sustainable development goals (SDGs) to direct the agenda for development after 2015 [14],[18]. The intention and division of a set of 17 Sustainable Development Goals (SDGs) into 169 goals included a wide range of topics, including the effects of the environment and how they relate to destitution and marginalization [15].

In this scenario, tackling the economic and environmental challenges associated with the current global crisis—also known as the Anthropocene era—has been found to revolve around the establishment of a ―green economy, which includes elements of circularity and bio based enterprises [16],[17]. The environmental problems associated with fossil fuels and this astounding cost reduction is the main forces behind the sustainable development of renewable energy technology. According to Wood Mackenzie, the number of PV installations advanced by an average of 28% year between 2019 and 2023, with a 56% increase from 2022 to 2023. However, the growth is not anticipated between2024 and 2028. Even while the total amount of solar capacity in the world will still ascend quickly over the next ten years, installation growth will start to slow down in 2024 compared to recent rates. From 2024 to 2028, there won't be any annual growth; nonetheless, there will be some years of contraction. On average, the current pace will be maintained. It is noteworthy that if the European Union (EU) were a single nation, its 178.7 MW solar capacity would rank second in the world. It is noteworthy that in April 2023, China had the largest solar power capacity in the world, with 430 GW of solar power. By 2030, the United States wants to have installed 215 GW of solar power. However, Japan has established a target of being a carbon-neutral society by 2050, and solar energy will be crucial to reach this goal. By 2030, India wants to have 500 GW of solar power capacity [20]. Germany wants to produce 65% of its electricity from renewable sources by 2030, and it will be a leader in this area. Bangladesh, a developing nation, is attempting to cultivate this type of plant. In 2019, the first project, with a 10 kW capacity, was developed in Mongla under the Bagerhat district [23]. These include a 24 MW unit at Rangamati's Kaptai Lake, a 4.5 MW unit at Mohamaya Lake in Chattagram's Mirsharai, a 9 MW unit at Jhenaidah's Joydia Baor, and a 6 MW unit at Bukbhara Baor in Jessore. India already installed 6 MW solar project with the Maharashtra

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Metro Rail Corporation (MMRCL), Nagpur Metro. The solar project is anticipated to replace about 36% of grid power with solar power, translating into an astounding 41% savings per unit. Regarding the project's environmental impact during the course of its lifetime, the carbon offset achieved by this endeavor is estimated to be around 7,000 tons of CO_2 [21],[22].

1.1. Study Objectives

1) Pick the available rooftop space for solar panel installation. Examine sun irradiation and climatic variables in Dhaka to determine energy generation capabilities.

2) Assess the station's offer and forecast electricity usage customs. Determine the percentage of energy needs that can be satisfied with solar power.

3) Conduct a cost-benefit analysis that includes capital spending, operational expenses, and the period of payback. Study the financial models, subsidies, and incentives available for solar schemes in Bangladesh.

4) Calculate the likely decrease in carbon emissions and environmental benefits. Assess the system's contribution to Bangladesh's renewable energy targets.

5) Analyze possible risks such as climate shifts, system performance decline, and grid constraints. Implement risk-mitigation strategies to ensure project sustainability.

2. Materials and Methodology

The study is simply using a case study to demonstrate a photovoltaic (PV) system analysis and simulation using PVSyst software. It is frequently employed in feasibility assessments for rooftop solar systems connected to the grid. To establish the system type (grid-connected), instance location, weather information is needed. Meteonorm's built-in databases or other sources have been used. Using the technical specifications of the panels as a guide, the PV module from the software's database is selected. An inverter whose size and compatibility match the PV module is included. Some other parts such as transformers, cables, and battery storage also accounted for the simulation. The system size is dependent to the available roof area of the site. Key performance indicators such as specific yield, energy losses, PR (Performance Ratio), and system efficiency have been computed by the simulation software. The loss diagrams (losses from shading, wiring, temperature, inverter efficiency, etc.) have been simulated. The year and monthly energy output and contrast it with the anticipated demand is incorporated. With PVSyst, one can create comprehensive reports on PV system's performance, viability, and financial analysis. To assess the project's economic sustainability, additional financial factors such as start-up expenses, energy prices, subsidies, and maintenance costs are also taken as inputs. The payback period, ROI (return on investment), and LCOE (levelized cost of energy) with the aid of the software have been determined.

3. Statement of Novelty

We are focusing on several key components of our feasibility study of grid-connected rooftop solar systems for a metro rail station in Dhaka, Bangladesh, specifically for a public transportation system. While rooftop solar systems have been investigated in various industries, our article focuses on their suitability for metro rail infrastructure in a densely populated and developing metropolis such as Dhaka, which is experiencing fast urbanization and rising energy demand. This situation presents a novel urban and infrastructure problem that has yet to be thoroughly investigated. Our research is expected to employ localized data (such as weather patterns, Dhaka-specific solar irradiation, and the energy requirements of a metro rail station) to develop a model adapted to the Bangladeshi climate. This regional emphasis provides precision and practical value that similar global investigations may overlook. The metro rail system is a critical component of Dhaka's public transportation infrastructure. Our research relates the ecological and economic impact of rooftop solar systems to the metro train network, providing a viable approach for lowering energy costs and carbon emissions. This emphasis on public transportation and renewable energy integration in metro stations is largely unexplored. Our research also sheds light on the possibilities for renewable energy solutions within Bangladesh's energy and urban transport policy framework, which aligns with the government's goals of increasing solar energy use and meeting the Sustainable Development Goals (SDGs). The research could propose a novel technical solution or framework for seamless grid integration of solar electricity tailored to metro stations' dynamic energy consumption patterns, providing new insights into controlling supply-demand changes.

4. Site Location

Uttara south metro rail station is located at 23◦ 50′ 44.2″ N, 90◦ 21′ 47.3″ E, with a latitude of 23.84560°N and a longitude of 90.36314°E in Dhaka city, which is in the north part of the capital city in Bangladesh. The station has a rooftop length of 180m & width of 25m. In the figure 1(a) the proposed site locations Google earth view has been depicted. The site chosen as it is nearby location of the author’s research institution. This metro station is a typical station of MRT Line 6 which has total 17 stations. It has 14 typical and 3 iconic stations which structure is different compared to the typical one. The original view of the metro station can be seen in the figure 1(b).

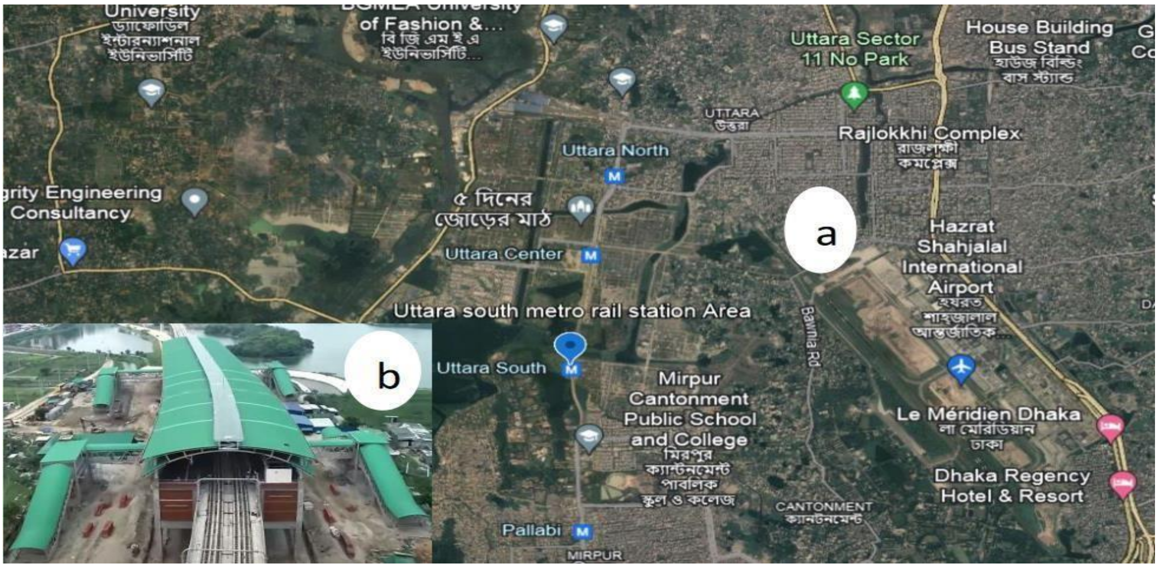

Figure 1. (a) Google Earth satellite view of Uttara south Metro Rail station location, and (b) Uttara south Metro Rail station plaza

5. Climate Data

To assess the performance of any photovoltaic system it is necessary to evaluate the climate data like temperature, rainfall or humidity. The output power of solar panel considerably depends on ambient temperature of the site.

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Figure 2(a) shows the temperature in the span of a year [25]. It can be seen that the maximum temperature is on the month of April where the minimum in the months of December and January. The average temperature 30◦C stays from the month April through September. The average annual temperature of Dhaka is 25.3 ˚C. In general summer season lasts in Bangladesh from the month of March through May. The rainy season starts from June and ends on October. Here the winter season starts on November and ends on February. The humidity graph in the figure 2(b) generated from the PVSyst software which shows highest humidity on the months of June through September. It can be depicted from rainfall graph in figure 2(c) that heavy rainfall occurs during the months of May to September. Highest rainfall around 378 mm occurs on the month of June in Dhaka [33]. Lowest rainfall can be seen in winter season here. The average wind speed data for Dhaka metropolitan area (DMP) from is plotted on the figure 2(d). The maximum wind speed 4.2 m/s stays on the month April. Average high wind speed can be seen from the month April to August.

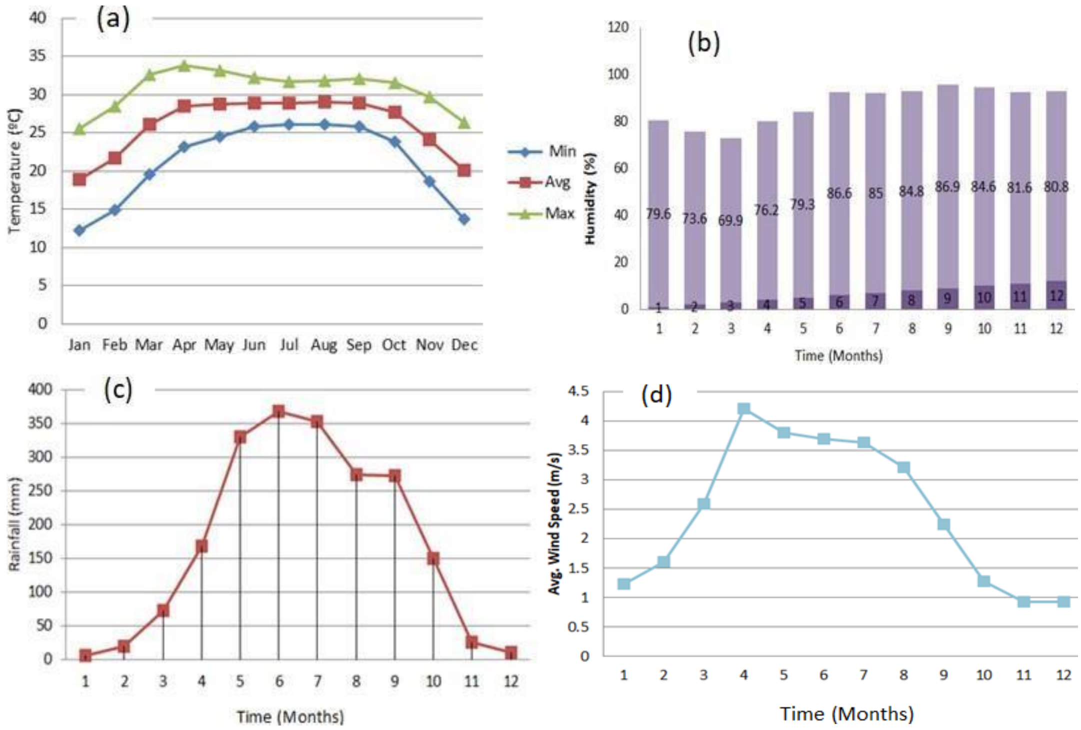

Figure 2. (a) Annual temperature, (b) Humidity, (c) Rainfall [26], and (d) Average wind speed of DMP area [2]

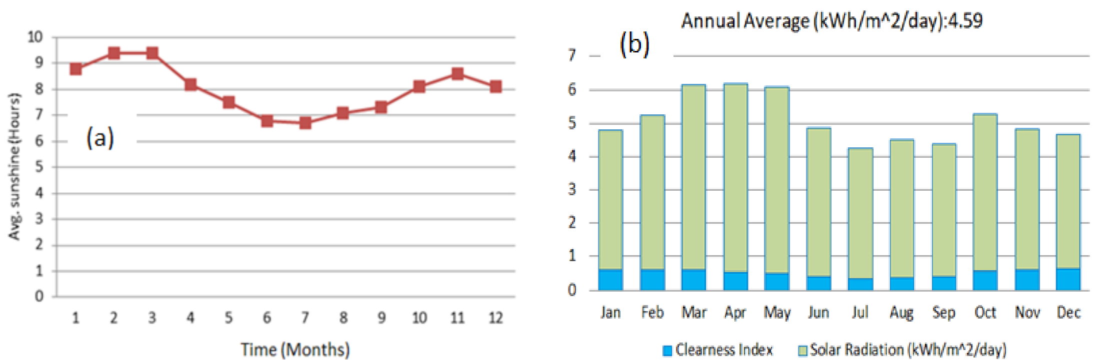

Figure 3. (a) Average sunshine in Dhaka city [26], and (b) Monthly average solar radiation in metro rail station (Homer pro)

6. Solar Radiation

The generation of power from photovoltaic depends on the solar radiation hence the fact on average sunshine hours. Figure 3(a) shows average sunshine hours in a year for Dhaka city [26]. In the middle of the year the average sunshine hours reduced due to heavy rainfall. The maximum sunshine is 9.4 hrs and minimum 6.8 hrs in a month. Another plot in figure 3(b) represents the annual average solar radiation data which is generated from the HOMER Pro software tools using the location of the metro rail station site. More than 6 kWh/m2/day solar radiations can be injected to the solar panel in the site in the month from March to May. The value varies between 4.2 to 6.1 kWh/m2/day. The annual average solar radiation is 4.59 kWh/m2/day for the proposed site.

Figure 4. Animated roof top structure of a typical metro rail station [34]

7. Design Studies

Figure 4 shows the animated roof top structure of a typical metro rail station which is similar to the metro rail uttara south station. Here the roof is divided into two sides which are little bit curved in nature and the small middle portion is flat type. The roof top photovoltaic system will consists of PV modules, the supporting system to hold the PV modules and connecting components. The figure 5(a) shows the roof top structure where the PV modules will lay over in two different ways in the middle row and the sides. In figure 5(b) PV modules and the connection components design is shown. The short bracket can be used to hold the modules in the middle portion which is plain. The long bracket can be used in the two sides of the roof which are curved. According to the PVSyst simulation, there are total 131 strings and each string contains 19 pcs series connected modules. In the rooftop total number of 2489 modules can be accommodated with solar panel rated power of 340 Wp each. To maintain a minimum spacing between two arrays the following formula has been taken into account that has been explained that A1 is the space between the two arrays and A2 is the length of the module with tilt angle of β. The module will be placed at the tilt angle of 26°. Solar declination angle δ, latitude φ and the length l has been assumed:

$A2 = l\ Cos\ Q$ …(1)

$A1 = l\ Sin\ \beta.\ \tan(\delta + \varphi)$ …(2)

$A = A1 + A2$ …(3)

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Solar declination angle δ = 23.5° is assumed for the calculation considering the fact of longest day of the year in the location. The latitude of the site location is φ=23.8456 and the length l of the selected module from PVSyst is 1.762m. After calculation free space between two modules is A1=0.83m.

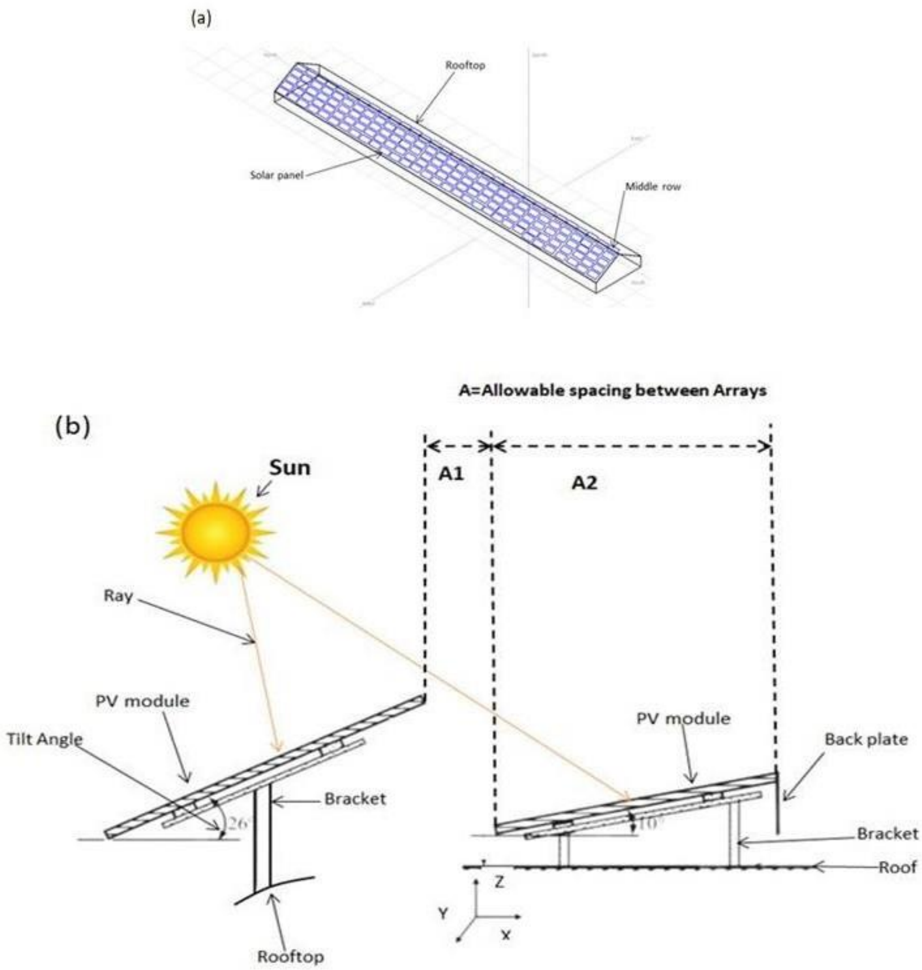

Figure 5. (a) Proposed Rooftop structure scheme, and (b) Unit design layout of rooftop plant system

8. Load Calculation

For the estimation of demand in the site it is needed to know the operating time of the metro rail in the line and the opening hours of the station. The Metro Rail line 6 is started its operation from 28th December 2022 which is first Metro Rail in Bangladesh [13]. The work of some of the phases is still running. For this reason the metro rail in this line is not operating in full swing. As of February 2025, the metro rail is running from 7.30am in the morning to 9 pm in the evening [30]. This timing is considered for the load calculation of the station site. Later it will run on whole day till midnight. The station building has two floor and ground floor. Ground floor is dedicated for parking and road where street lights are used. First floor is for the entry and exit to the platform which is on the second floor. The first floor is also for the operational office room, ticket vending machine, ticket counter, staff room and others activity. The second floor is only for the platform where the rail is running. In second floor it is almost open space and very less amount of electricity is needed in day time. Because of different activities in the first floor, the electricity basically needs in this floor. Besides this, there are escalators, lift and AC’s in some of the room are also running. The pressures of passengers are comparatively less in this Uttara South Metro Station. So considering all the things the running time of different load has been estimated that has been shown in the Table 1. The name of the load, number of items, output rated power, total power, running time of the load and total energy has been shown on the Table 1. The total connected load approximately 105517 W and energy 792.6 kWh/day is calculated using the conventional rule. After starting the operation till midnight the approximate load will increase in this station.

Table 1. Calculated load demand of the uttara south metro rail station site

Load description	Quantity	Power (W)	Total Power (W)	On time (h/d)	Total energy (kWh/days)
Roof top light	170	70	11900	6	71.4
Flat Panel Led Light	510	48	24480	6	146.88
Tube light	60	65	3900	12	46.8
LED Flood Lighting	50	70	3500	12	42
AC	15	1000	15000	7	105
HVLS Fan	4	370	1480	8	11.84
Wall fan	6	65	390	8	3.12
Escalator	6	980	5880	8	47.04
Ticket vending machine	6	300	1800	13	23.4
Automatic Swing Barrier Turnstile Gate	10	300	3000	13	39
Pump	2	3600	7200	3	21.6
Lift	4	5500	22000	5	110
Computer	30	22	660	12	7.92
TV monitor	8	47.8	382.4	24	9.18
Screen door	40	70	2800	12	33.6
CCTV	130	6.5	845	24	20.28
Loudspeaker	30	10	300	10	3
Other (mobile & laptop charging, router, switch, hub, printer, fax machine, etc…)					50
Total	**1081**	**12524.3**	**105517**	**183**	**792.6**

9. PVSyst Simulation

For the analysis of performance of photovoltaic and economic assessment PVSyst simulation software version 7.4.4 is used in this study. The site location data, calculated load has been given as the input of the software tools. The system consists of PV module, inverter and battery which are connected with the grid. The PV module will generate electricity and that will be consumed by the load. In day time there will be excess amount of energy which

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can be injected to the grid. The battery will store energy and will support a portion of load in the evening time that will reduce the grid electricity usage. The total system will act like a micro grid.

Specific photovoltaic and inverter has been selected which characteristics are given on the Table 2. The simulation has been run for 25 years starting from 2024. The system needs total 14 unit inverters with 2489 units of PV modules. The battery is taken one unit with capacity of 98 Ah.

Table 2. PV Array characteristic & Inverter characteristic

PV Array characteristic	Specification	Inverter characteristic	Specification
PV maximum power	340 Wp	Minimum MPP voltage	160 V
Voltage at maximum power	35.7 V	Nominal MPP voltage	600 V
Open circuit voltage	42.63 V	Maximum MPP voltage	1000 V
Short circuit Current	10 A	Maximum AC power	55KVA
Current at maximum power	9.4 A	Maximum Ac current	83.6 A
Panel Dimension (H/W/D)	1960x992x40 mm	Pnom ratio (DC:AC)	1.21
Warranty	25 years	Efficiency	98.5%

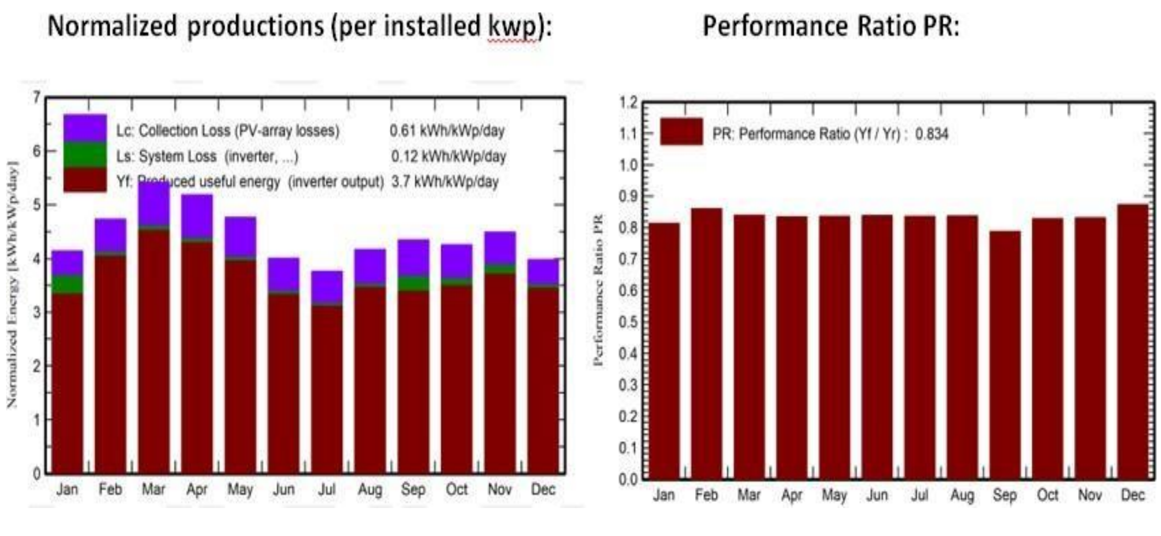

Figure 6. PVSyst analysis for the solar system

The solar power system that is shown in figure 6 has excellent performance metrics. Operating at around 83.4% efficiency compared to an ideal system, it has a robust performance and a normalized production of 3.7 kWh/kWp/day. The system exhibits low losses, with 0.61 kWh/kWp/day for PV array losses and 0.12 kWh/kWp/day for system losses related to the inverter. These numbers highlight how well and efficiently the system converts solar energy into electrical power that may be used. High performance ratios indicate that sunlight is used as efficiently as possible and low collection and system losses show that energy is managed well across the system's components. All things considered, the solar power system provides dependable and sustainable electricity generation, serving as an excellent example of the successful integration of renewable energy technologies.

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Table 3. PVSyst generated yearly solar irradiation and generated output power

Months	T_Amp °C	GlobInc Kwh/ m^2	GlobEff Kwh/ m^2	EArray kwh	E_User kwh	E_Solar kwh	E_Grid kwh	EFrGrid kwh
January	17.03	128.4	125.3	97270	24571	10368	78014	14203
February	20.95	132.4	129.6	98299	22193	10513	85861	11680
March	25.76	167.9	163.8	121586	24571	12397	106830	12174
April	27.66	155.4	151.1	111896	23778	12737	96989	11041
May	28.33	147.6	143.0	106414	24571	13506	90879	11065
June	28.15	120.1	115.7	86849	23778	13106	72092	10672
July	28.54	116.5	112.1	83972	24571	13469	68888	11102
August	28.69	129.1	124.7	93207	24571	13243	78181	11328
September	28.01	130.4	126.5	93870	23778	11525	75358	12253
October	27.14	131.8	128.5	95947	24571	11637	80762	12933
November	23.00	134.6	131.7	99188	23778	10572	84233	13206
December	18.88	123.3	120.4	92830	24571	11318	79699	13253
Year	25.20	1617.6	1572.4	1181327	289299	144388	997812	144911

Legends: GlobHor= Global horizontal irradiation; EArray= Effective energy at the output of the array; DiffHor= Horizontal diffuse irradiation; E_User= Energy supplied to the user; T_Amb= Ambient Temperature; E_Solar= Energy from the sun; GlobInc= Global incident in coll. Plane; E_Grid= Energy injected into grid; GlobEff= Effective Global, corr. for IAM and shadings; EFrGrid= Energy from the grid.

A grid-connected and self-consumption photovoltaic (PV) system installed in the year 2024 exposed anomalous performance, generating a substantial amount of electricity while minimizing reliance on the grid. The system's produced energy of 1,287,111 kWh per year, translating to a specific produced annual of 1350 kWh/kWp/year, underscores its effectiveness in harnessing solar energy. Despite variations in ambient temperatures, ranging from a high of 28.69°C in August to a low of17.03°C in January, the system maintained consistent energy production. The maximum effective energy output of 121,586 kWh in March and the minimum of 83,972 kWh in July reflect the influence of seasonal fluctuations in solar irradiance on the site shown Table 3. Direct use of solar energy accounted for an impressive 98.6%, showcasing the system's ability to meet the user's energy needs directly. Grid consumption, at 50.7%, indicates the system's seamless integration with the grid, supplementing energy requirements during periods of plentiful, solar generation. The system's contribution to grid injection, reaching 997,812 kWh, highlights its role in alleviating the strain on conventional power sources and promoting sustainable energy practices. Additionally, the system's minimal storage usage of 1.4% demonstrates its efficiency in directly utilizing or supplying generated electricity. In conclusion, the PV system's notable performance characterized by high energy production, competent energy utilization and grid integration, establishes its value as a sustainable and cost- effective energy solution.

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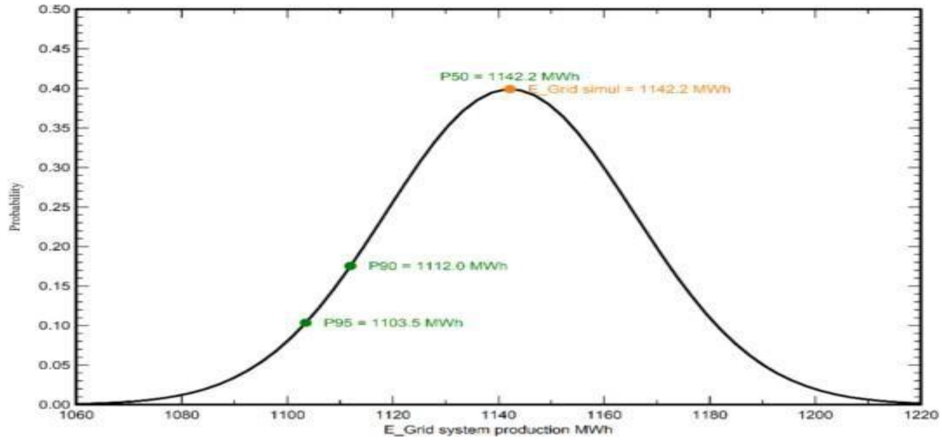

Figure 7. Probability distribution curve

Figure 7 shows the cumulative probability of annual production for the system simulated from the PVSyst software. The x-axis represents the annual production in MWh and the y- axis represents the probability of producing the amount of energy. From the figure it can be extracted that there is a 50% probability of producing at least 1142.2 MWh of energy per year. This is known as the P50 value in the curve. Besides, there is a 90% probability of producing at least 1112.0 MWh of energy per year, and a 95% probability of producing at least 1103.5 MWh of energy per year. The variability of the annual production is 23.5 MWh. This means that there is a 10% chance of producing less than 1118.7 MWh of energy per year, and a 10% chance of producing more than 1165.7 MWh of energy per year. The probability distribution curve can be used to estimate the risk with investing in a solar power system. If an investor is willing to accept a 10% hazard of underperformance, they can expect to produce at least 1118.7 MWh of energy per year. The curve can be used to make finding about the size of the solar power system to install, and the financial hazard with the investment.

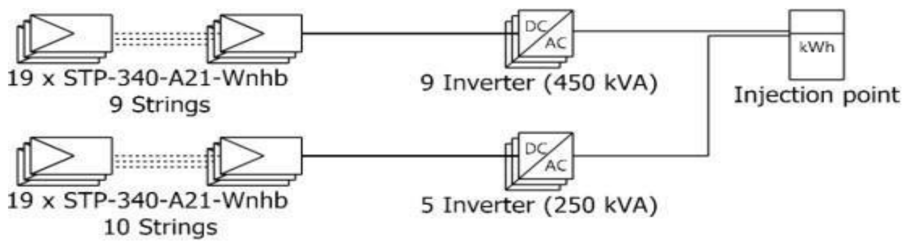

Figure 8. Single-line diagram

The grid connected solar power system consists of 19 strings of solar panels and 14 inverters shown in the single-line diagram on the figure 8. The first inverter is a 450 kVA inverter with 9 strings, and the second one is a 250 kVA inverter with 10 strings. The inverters convert direct current (DC) generated by the solar panels into alternating current (AC), which is the standard form of electricity used in home and industry. The total AC power generated by the system is 700 kVA.

10. Cost Estimation

It is become necessary to analyze the financial assessment of the site for investment. The authority of the project is Dhaka Mass Transport Authority Company limited (DMTCL) which is a government owned company. To invest on the project financial return must be satisfactory. For the economic calculation the PVSyst software tools has been used. The necessary items for the grid connected rooftop photovoltaic system suggested by the software have been incorporated. The price of the major items such as PV modules, inverter and batteries etc. are determined by taking account of the current local market and various online market prices. The prices are given here in USD for the international rate. The USD rate is taken as 115 BDT (local currency) equivalents to 1 Dollar. The following Table 4 has shown the breakdown of all the necessary items and the respective price.

The initial investment cost includes the necessary components and the cost of installation, transport and the commissioning of the items. The total investment cost of the system is approximately 527,980 USD. To run the system for 25 years it is necessary to replace some of the components such as battery and inverter. Some regular maintenance charge is also required for every year. Incorporating all the necessary operating and maintenance cost (OPEX) is 36,515 USD per year that has been shown on the Table 5. From the simulation of the software it is also revealed that the system payback period is 5.7 years. The return on investment (ROI) is 441.3%. For energy calculation the peak and off-peak tariff 0.13 USD/kWh is assumed. The result shows that the useful energy from the solar is 144 MWh/year. And energy sold to the grid is 998 MWh/year. The cost of produced energy (LCOE) is 0.032 USD/kWh which is also very lucrative. The cumulative profit is 93200 USD per year and net 2330009 USD after 25 years.

Table 4. Cost of the system

Equipment	**Quantity Units**	**Cost USD $**	**Total USD $**
PV modules	2489	125	311125
Inverters	14	10,862	152075
Batteries	-	-	10000
Accessories	1	200	200
Wiring	1	3000	3000
Combiner box	1	22,500	22500
Monitoring system	1	300	300
Measurement system	1	100	100
Surge arrester	1	200	200
Environmental	1	100	100
Installation cost per module	2489	10	24890
Installation cost per inverters	14	10	140
Installation cost per batteries	1	50	50
Transport	1	2,000	2000
Settings	1	1,000	1000
Grid connection	1	300	300
Total	-	-	527980
Depreciable asset	-	-	473400

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Table 5. Operating cost

Equipment Maintenance	**Total USD/Year**
Provision for inverter	30415.20
replacement	3000
Salaries	1000
Repairs	100
Cleaning	1000
Others	1000
Total (OPEX)	36515.20

11. CO_2 Emission reduction

Bangladesh is the lowest CO_2 emitting country whereas China is the highest carbon dioxide emitting country. Among them the percentage of share of total emission is 28% for China, USA 15%, India 7% and Bangladesh only 0.09%. Glasgow has instructed Bangladesh to reduce carbon emissions by 89.47 billion, which is 21.85% of CO_2 by 2030. It aims to install more than 6 million solar-home systems in off-grid areas. According to Bangladesh, the Nationally Determined Contributions (NDC) says Bangladesh's total emission is 169.06 million tons of greenhouse gases (GHGs), which are projected to rise to around 409.41 million tons by 2030. Currently, the energy sector is the largest contributor with 93.09 tons, equivalent to 55.07%. Agriculture livestock and forestry contributed 27.35%, amounting to 46.24 metric tons, cement and fertilizers contributed 3.32% or 5.6 metric tons and municipal solid waste and wastewater contributed 14.26%, amounting to 24.11 metric tons. The IPCC 6th Assessment Report is clear- If emissions are not reduced rapidly in this decade, it will increase the risk of dangerous and irreversible impacts on natural and human systems. Bangladesh has said to achieve its carbon emission targets that it will increase renewable energy projects using advanced technologies for power generation [28].

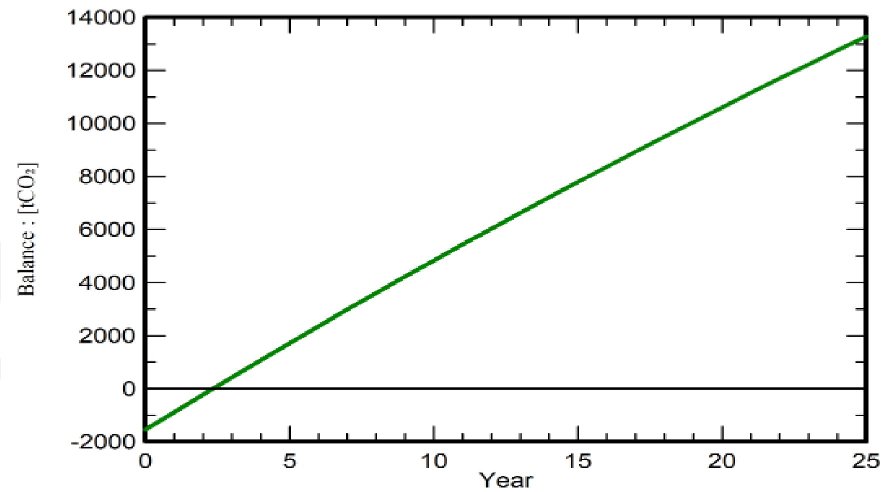

Figure 9. CO_2 Emission Balance

Above the figure 9 shows the relationship between saved CO_2 emissions and time for a photovoltaic power plant (PV plant) in Bangladesh. The PV plant saves CO_2 emissions from the very beginning of its performances, and the total CO_2 emissions saved over the lifetime of the PV plant are 13282.4 tCO_2(IEA list). The grid Emission Factor (EF) of Bangladesh is 0.648 t CO_2eq/ MWh [29]. The saved CO_2 emissions from the replacement of grid electricity increase over time, as the PV plant is producing more electricity over time as the modules demote. The total saved CO_2 emissions are greater than the saved CO_2 emissions from the replacement of grid electricity, as the PV plant is also saving CO_2 emissions from the reduction of transmission and distribution losses. The PV plant has a lifetime of 25 years and plant degradation is 1% produces 1143.27 MWh/yr of electricity. The grid lifecycle emissions are 584 gCO_2/kWh. The PV plant's annualized lifecycle emissions are 62.07 tCO_2/yr, and its greenhouse gas emissions per unit of electricity generated are 0.054 gCO_2/kWh, which is significantly lower than the average greenhouse gas emissions per unit of electricity generated in Bangladesh, which are 584 gCO_2/kWh. Specifically infrastructure of the rooftop plant (modules, supports, inverter), 25- 30% plant disposal. Therefore, the PV plant is a significant source of CO_2 savings in Bangladesh.

12. Result and Discussion

This paper presents an optimized solution of photovoltaic hybrid system for a metro rail station to reduce the energy consumption from national grid as well economically viable condition for long run in the site. This paper focuses on the usage of renewable energy in existing structure for the proper use of land or site. For the use of photovoltaic system, it is necessary to assess the annual average solar radiation which is 4.59 kWh/m^2/day in this site. The analysis demonstrates that the generation total effective energy at the array's output produces 1142 MWh/year with just one metro station structure. Around 144 MWh of solar energy are used annually. Following grid injection, 998 MWh of energy each year can be sold to the national grid for 2.17 Tk per kilowatt- hour [31], significantly raising the nation's percentage of renewable energy consumption and assisting in the SDGs' achievement. The projected investment cost is 527,980 USD and cumulative profit is 93200 USD per year. The cost of produced energy is 0.032 USD/kWh only with the payback period of 5.7 years. The per unit cost of energy is much lower than other such rooftop structure in the country. The projected saving of CO_2 emissions of the rooftop PV plant is 13282.4 tCO_2 which will also help the country to achieve its goal to reduce carbon emission.

13. Conclusion

These feasibility study shows the reduction of the per unit cost of energy which is much higher when buying from the state owned electricity. Given the state of the nation's electricity production, it makes sense to concentrate on hybrid systems for electric conveyances like metro rail, which eventually require continuous power supply to function. In the future, we are suggesting some features that can be developed- Firstly, advance rooftop solar installation to many metro stations throughout Dhaka. After that, execute smart grid and net metering keys to maximize solar energy use. Then, Regard public-private partnerships (PPPs) to fund large-scale solar installations. Finally, elevate metro rail as a green transportation solution that includes 100% renewable energy sources.

Declarations

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Competing Interests Statement

The authors declare no competing financial, professional, or personal interests.

Consent for publication

The authors declare that they consented to the publication of this study.

Authors' contributions

All the authors made an equal contribution in the Conception and design of the work, Data collection, Simulation analysis, Drafting the article, and Critical revision of the article. All the authors have read and approved the final copy of the manuscript.

Availability of data and material

Authors are willing to share data and material according to the relevant needs.

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