Integration of Solar Harvesting System Around Traditional Transportation Infrastructures in Dhaka

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CERTIFICATE OF APPROVAL

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We do hereby solemnly declare that the research work presented in this undergraduate thesis has been carried out by us and has not been previously submitted to any other university/institute/ organization for an academic certificate or degree.

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DEDICATION

We would like to dedicate this thesis to our family members and everyone who has given us unwearied support throughout the entirety of our existence and every situation of our life. They have always been a source of motivation for us. They pushed us ahead and showed us how to make the right decisions. They never fail to inspire us to work hard and move forward to overcome life's difficulties. They have provided us with the protection, wisdom, and fortitude we need to face difficult situations. They have been our partners in life’s joys and sorrows.

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ABSTRACT

As the world continues to grapple with the challenges posed by climate change and the depletion of traditional energy sources, the integration of photovoltaic (PV) panels with urban infrastructures has emerged as a promising solution. This integration involves incorporating solar panels into the design and functionality of buildings, roads, and other urban elements to harness the vast potential of solar energy. Such integration promotes sustainable development by reducing the carbon footprint of cities and decreasing reliance on fossil fuels. Additionally, it enhances energy security and resilience by diversifying energy sources and reducing vulnerability to power outages. In this thesis, feasibility of incorporating PV panels into several roadway infrastructures in Dhaka city was analyzed. Being close to the tropic of cancer, Dhaka city receives horizontal sunlight, which can maximize solar output. Also, as Dhaka city has highest energy demand in the country, producing the energy at the point of demand will result in lower transmission loss and lower cost for overall transmission infrastructures (example: reduced wiring length). Furthermore, as solar energy is emission-free, it will not add to the burden of the city's already heavily polluted air. Three types of structures were chose for the analysis: foot over bridge, flyover and metro rail station. They are some of the most prominent types of roadway structures in Dhaka city, and they provide ample space for installing PV panels. Three software were used for the analysis: PVsyst 7.3, Google Earth Pro and Meteonorm 8.1. From the analysis, it is observed that PV panels installed on metro rail stations have the lowest energy loss among the three structures (6.8% overall system loss, vs 12.7% & 7.5% for the rest two) while panels installed on flyover return the capital within the least number of years (6.9 vs. 14.5 & 7.4). In both of the cases, foot over bridge performs worst. Hence, flyover and metro rail station both can be considered to install PV panels for satisfactory outcome.

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LIST OF ACRONYMS

Abbreviated Form	Description
PV	Photovoltaic
PVSYST	Photovoltaic Systems
SAM	System Analysis Model
HOMER	Hybrid Optimization of Multiple Energy Resources
GIS	Geographic Information System
DNI	Direct Normal Irradiance
STC	Standard Test Condition
PR	Performance Ratio
SLD	Single-Line Diagram
LCE	Life Cycle Emissions

CHAPTER 1
INTRODUCTION

1.1 Introduction

The most important factor to consider when assessing a country's economic and social situation is energy. Unfortunately, Bangladesh has problems when it comes to fulfilling the demand for energy. Historically, the demand supplied has always been less than the required demand. Unfortunately, this trend is set to continue far into the future.

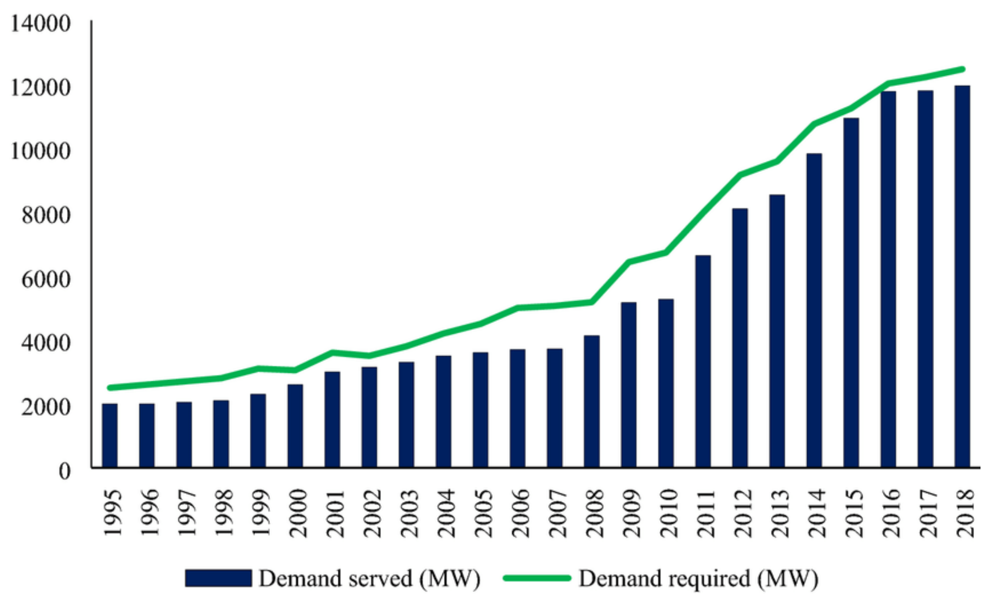

Figure 1.1.1: Power Demand-Supply Gap in Bangladesh [1]

One of the reasons for this inability is the huge population of the country. The population of Bangladesh is increasing day by day and with it, the energy consumption is increasing. Moreover, the power sector of the country is heavily reliant on fossil fuels, which is estimated to be exhausted within the next 10-15 years. Bangladesh is already in the middle of a major energy crisis and due to the current struggle to adopt renewable energy, the future of the country looks bleak.

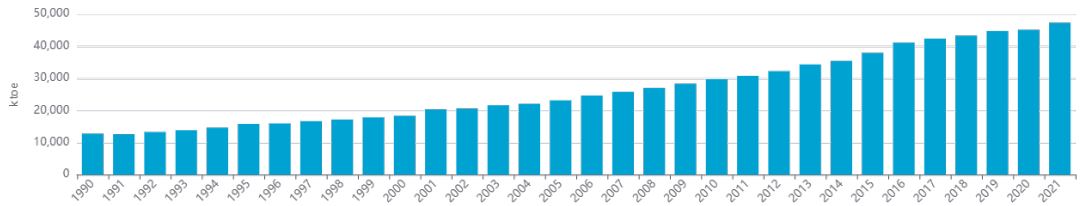

Figure 1.1.2: Yearly Energy Consumption of Bangladesh in kilotons of oil equivalent [2]

The exploration of non-renewable sources of energy like natural gas, oil, coal, and other minerals are causes of environmental pollution, drilling accidents, tanker catastrophes, and equipment failure. Additionally, it causes extremely severe natural disasters including storms, ice fields, and earthquake activity. In addition to the environmental impacts, dependence on non-renewables is harming the economy as well. Due to the inability to meet the country's energy demands, a huge amount of resources and energy are imported from other countries.

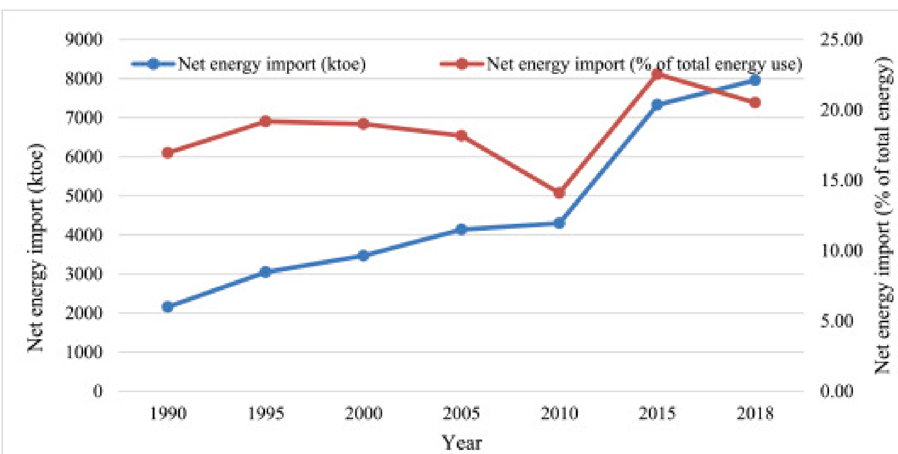

Figure 1.1.3: Net Energy Import and Usage [3]

Renewable energy production in Bangladesh comes from various sources, such as solar, hydro, wind, biogas, and biomass. The government of Bangladesh had set a target of generating 10% of total electricity from renewable sources by 2021. But by that time, it stood at only 3.5%. The aim has now been reset to 40% by 2040 [4].

TABLE 1.1. CURRENT INSTALLED CAPACITY OF RENEWABLE ENERGY [5]

Technology	**Off-grid (MW)**	**On-grid (MW)**	**Total (MW)**
Solar	357.29	579.96	937.25
Wind	2	0.9	2.9
Hydro	0	230	230
Biogas to Electricity	0.69	0	0.69
Biomass to Electricity	0.4	0	0.4
Total	**360.38**	**810.86**	**1171.24**

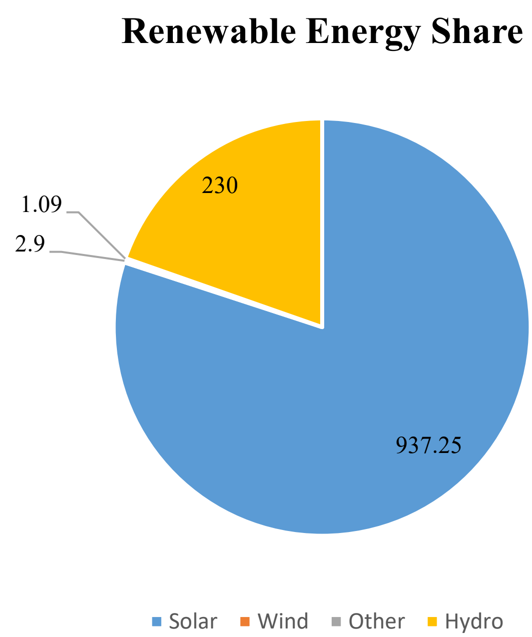

Figure 1.1.4: Renewable Energy Production in Bangladesh [5]

It is seen that almost 80% of the current energy production from renewable energy sources is from utilization of solar energy.

The sun is the ultimate source of energy. The amount of sunlight or solar radiation that strikes the earth's surface in 1.5 hours is enough to fulfill the entire world's energy consumption for an entire year. However, this amount varies from region to region. Solar technologies convert sunlight into electrical energy either through photovoltaic (PV) panels or through mirrors that concentrate solar radiation. However, solar energy technology does not end with simply the production of electrical energy. This energy must be integrated into homes, institutions and existing energy grids. The whole system is called a Photovoltaic (PV) System.

As we have seen before, the vast majority of renewable energy production in Bangladesh comes from solar technology. This is due to a multitude of factors. Solar energy integration with electrical plants is almost standard nowadays. Besides this, there are other initiatives, such as:

- Solar Homes
- Solar Rooftop (Residential, Commercial, and Industrial)
- Solar Irrigation Pump
- Solar Mini-Grid
- Solar Park

These are mainly initiatives by the private sector. There are several other projects to be implemented by the public sector, such as:

- Solar electrification in health centers, religious establishments, remote educational institutions and railway stations and unions e-centers
- Solar PV systems in government and semi-government institutions

Although the present scenario of utilization of solar energy in Bangladesh is limited, there is huge potential for increasing solar energy operations. Taking into account its geographical location, Bangladesh is in a favourable position in respect of utilization of solar energy. Annual amount of radiation varies from 1575 to 1840 kwh/m2, which is more than 50% higher than that in Europe. Data indicates that if 0.7% of the incident radiation can be utilized properly, total requirement of energy in the country can be satisfied [8].

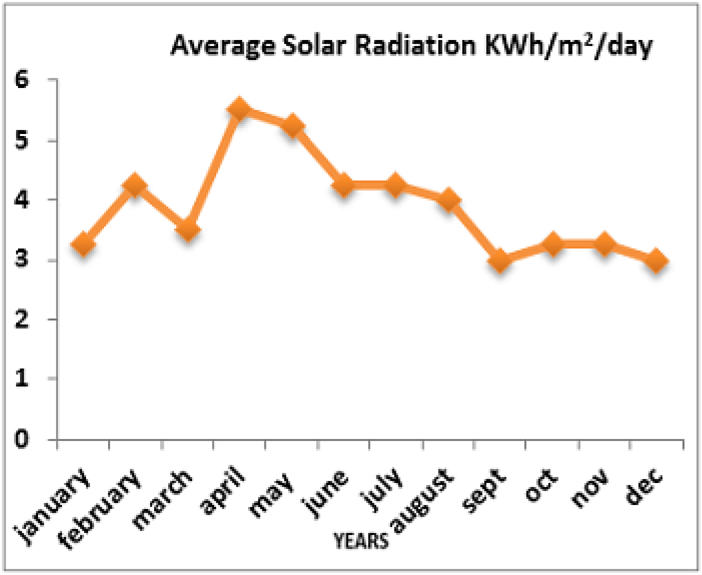

Figure 1.1.5: Monthly Average Solar Radiation in Bangladesh [8]

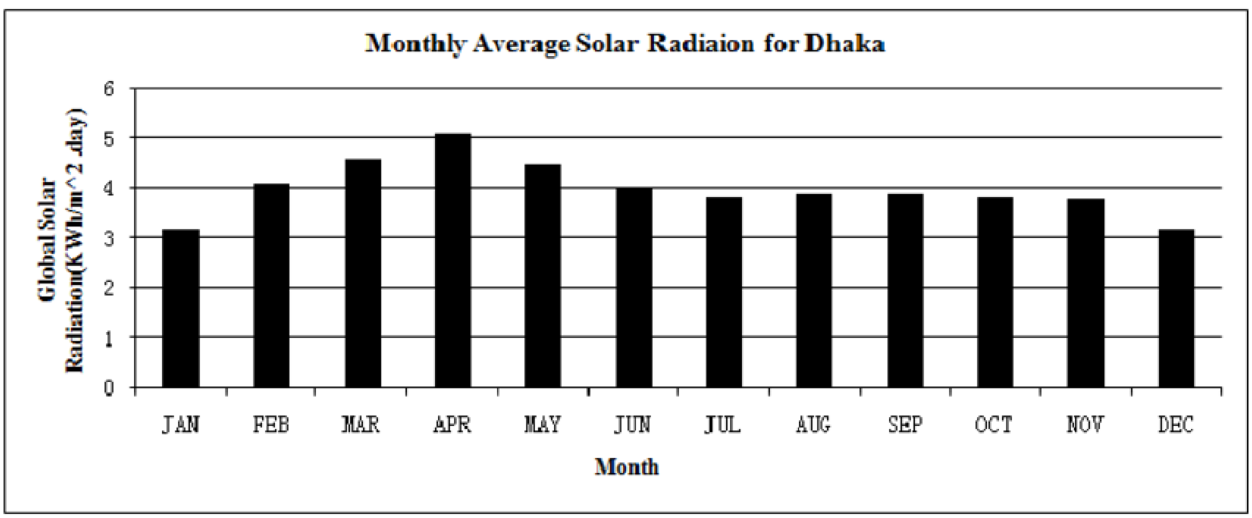

Figure 1.1.6: Monthly Average Solar Radiation in Dhaka City [10]

Dhaka City alone consumes about 46% of the total electricity produced in Bangladesh [65]. Therefore, it would make sense to integrate more means of solar energy production starting from there. Average solar radiation is healthy in Dhaka City. Additionally, it is located close to the

Tropic of Cancer. Because of this, the sun can be directly overhead making it suitable for placement of PV panels.

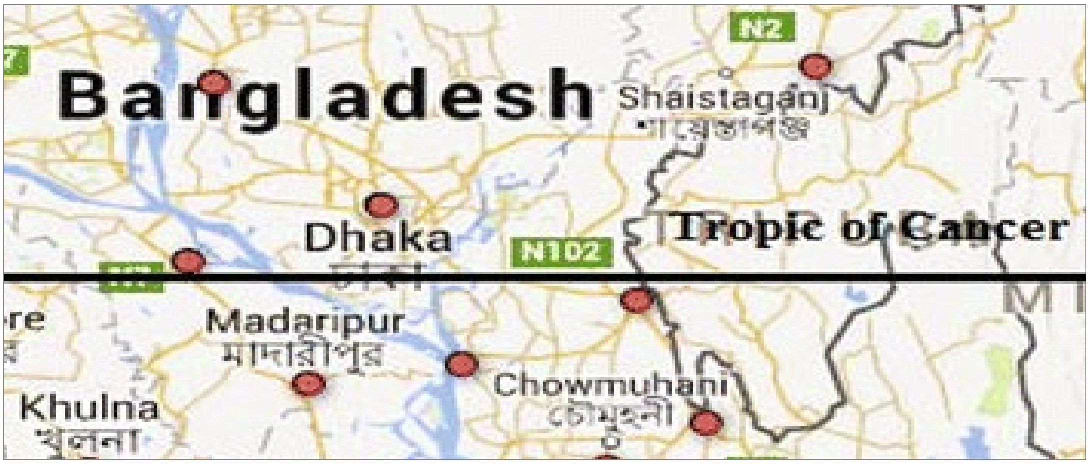

Figure 1.1.7: Tropic of Cancer over Bangladesh

Dhaka City is not only crowded in terms of population, but also in terms of infrastructure. In addition to the compact nature of houses and buildings, there are many roadway structures to mitigate the traffic congestion. Such as, foot over-bridges, flyovers and the newly constructed metro rail system. Cumulatively, it is several dozen kilometers of potentially unused opportunity to integrate PV panels.

1.2 Problem Statement

Bangladesh is currently experiencing a major energy crisis. Traditional means of production of electricity is no longer enough to meet the demands of the growing population. Renewable energy must be incorporated with the current energy production systems. Solar energy integration is showing the most potential. This integration requires use of PV panels. As Dhaka City is the most densely populated area in the country, it would be more practical to focus there first. Adoption of solar energy in Dhaka City requires installing a considerable amount of PV panels. However, installation area is limited, as Dhaka City is a cramped place with a lot of infrastructure.

1.3 Thesis Objectives

The main objectives of this thesis are:

- ✓ Integration of PV system with roadway infrastructure of Dhaka City.
- ✓ Determine suitability of different types of infrastructure for installation of PV panels.
- ✓ Evaluate energy yield from roadway infrastructure integrated PV system.
- ✓ Evaluate economic feasibility and sustainability of roadway infrastructure integrated PV system.
- ✓ Introduce the proposed system as an additional mechanism for increasing production of electricity through renewable means.

1.4 Thesis Organization

This Thesis focuses on integration of PV system with roadway infrastructure of Dhaka City and its evaluation of energy yield and economic impact.

- ✓ In Chapter 2, details of our background study have been made by reviewing conference papers, online publications and other resources.
- ✓ In Chapter 3, photovoltaic (PV) system has been described. This includes types of PV systems, its components, selection criteria for components and installation, and the advantages and disadvantages of using a PV system.
- ✓ In Chapter 4, the roadway structures that have been considered in our Thesis have been discussed. Foot over-bridge, flyover and metro rail system are considered.
- ✓ In Chapter 5, the software required for simulation and analysis of our research have been detailed. The software include PVsyst, Meteonorm and Google Earth Pro.
- ✓ In Chapter 6, the methodology of our research has described.
- ✓ In Chapter 7, our results have been presented along with a thorough discussion.
- ✓ In Chapter 8, the conclusion of the Thesis is included along with some recommendations and goals for future research.

CHAPTER 2
BACKGROUND STUDY

2.1 Literature Review

TABLE 2.1. LITERATURE REVIEW

Ref.	Year	Software/System	Description
[1]	2022	Solar, Hydro, Wind	Evaluation of the potential of green power generation to help solve energy crisis in Bangladesh
[6]	2021	Solar Energy Production Initiatives	Evaluation of current and future conditions for solar energy production
[11]	2016	PV System	Description of grid-connected PV system
[13]	2017	PV System	Description of factors affecting performance of a PV system
[15]	2017	PV Module	Review regarding PV technologies for increased performance in tropical climate
[16]	2022	PV System	Evaluation of model fidelity for solar analysis in the context of distributed PV integration at urban scale
[17]	2017	Geometric Optimization	Determination of optimum geometry of building blocks to ensure viability of integration of solar systems
[19]	2017	PV System	Determination of optimum tilt angle and orientation of PV panels in Bangladesh
[22]	2013	Highway PV System	Evaluation of potential of solar energy generation along national highways
[25]	2019	ArcMap/Site Selection	Map-oriented estimation of solar potential for site selection of PV panels on highway slopes

[26]	2018	PV Bike Path	Performance analysis of infrastructure integrated PV bike path
[27]	2022	HOMER/PV System	Design of hybrid wind-solar street lighting system
[28]	2021	PVsol, PVsyst, SAM/Roadway PV System	Design of bifacial PV system in Marine Drive Road, Cox's Bazar, Bangladesh
[29]	2018	Highway PV System	Design of solar highway in Bangladesh using bifacial PV modules
[30]	2021	Road Structure and Highway PV System	Exploration of strategies to facilitate PV applications in road structures for energy harvesting
[35]	2017	PV Watts, PV-Online, PVGIS, PVsol, PVsyst, SAM	Comparison of simulation software for analysis of PV system
[37]	2020	PVsyst/PV System	Design and simulation of PV system using PVsyst software
[40]	2011	PVsyst/PV Panel	Analysis of different PV panel arrangements using PVsyst software
[42]	2021	PVsyst/PV System	Design of Hybrid PV structure for street lighting system using PVsyst software
[44]	2021	PVsol/PV System	Investigation of grid-connected PV system with electrical appliances and vehicles using PVsol software
[46]	2013	SAM/PV Models	Comparison of different PV models using SAM software
[59]	2014	PV Power Plant	Measurement of soiling losses at PV power plants
[63]	2013	Inflation	Description of how inflation affects solar costs

CHAPTER 3

PHOTOVOLTAIC (PV) SYSTEM

A photovoltaic (PV) system is composed of an array of solar panels combined with an inverter and other electrical and mechanical equipment that uses energy from the sun to generate electricity. The size of PV systems can vary substantially. They can range from small rooftop or portable systems to enormous utility-scale generation plants [47].

3.1 Types of PV Systems

There are 3 common types of solar PV systems:

- **Grid-Connected Solar PV System:** It is also known as on-grid or grid tied PV system. This system is directly connected to the National Grid. It transforms PV solar energy into AC power through the inverter. It is a practical system that reduces the overall electricity consumption [48]. The key advantage of this system is that the National Grid will always support it. However, if the Grid fails, so will the solar system.

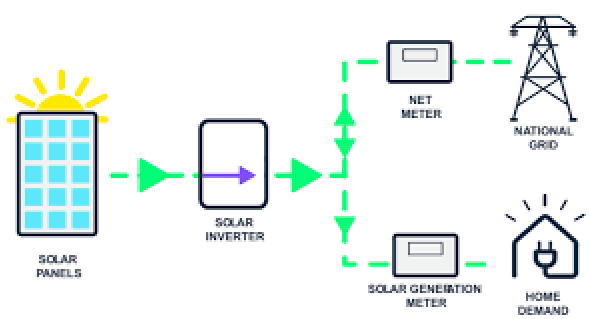

Figure 3.1.1: Grid-Connected Solar PV System

- **Hybrid Solar PV System:** This is a modified version of a grid-connected system and consists of a battery backup. It is combined with diesel generators and converts solar energy to AC or DC voltage [48]. This system offers greater flexibility than grid-connected system and allows expansion of battery storage system at any time. However, it is comparatively more costly and less efficient.

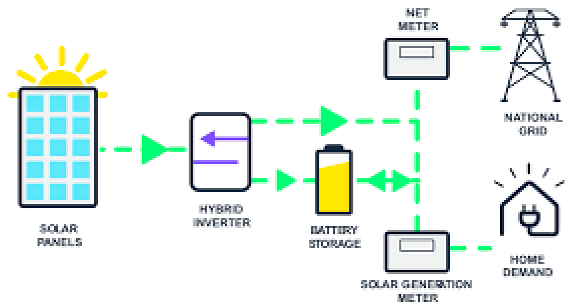

Figure 3.1.2: Hybrid Solar PV System

- **Off-grid Solar PV System:** It is also known as stand-alone PV system. It has no connection whatsoever with the National Grid. This system is ideal for people who cannot use the other PV systems due to high costs or geographical restrictions. Benefits of this system include, having no energy bill and being reliant on environmentally friendly resources. However, this system requires more components and thus, is more expensive.

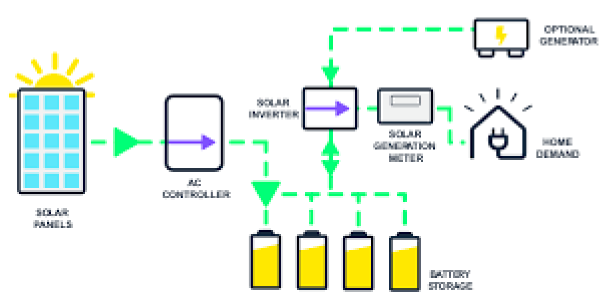

Figure 3.1.3: Off-grid Solar PV System

3.2 Components of PV System

A solar PV system typically consists of 6 components:

- **Solar PV Array:** Consists of any number of PV modules and panels. It helps to convert solar energy into DC.
- **Charge Controller:** Safeguards the battery from overcharging.
- **Battery Bank:** Stores excess solar energy for future use or in case of emergencies.
- **Inverter:** Transforms DC power into AC electricity.
- **Utility Meter:** Determines the current required for household purposes and the amount that is routed to DC.
- **Electric Grid:** Electricity is sent through the electric grid.

a. Solar PV Array **b.** Solar Charge Controller **c.** Solar Battery Bank

d. Inverter **e.** Utility Meter **f.** Electric Grid

Figure 3.1.4: Components of PV System

3.3 Selection Criteria

Selecting equipment for the construction of a PV system and its installation should be based on several criteria including:

- Buying Recognized Manufacturer
- Good Warranty of components
- Accredited Installer with experience
- Size of System
- Output of System
- Financial Considerations
- Panel Orientation
- Tilt angle
- Shading and Ventilation
- Mounting Arrays

3.4 Advantages

A PV system has several advantages. They include:

- Source of energy is renewable. So, it is better for the environment
- Relatively easy to access due to availability
- Ideal for sophisticated energy networks and distributed power generation
- Maintenance cost is relatively lower
- Provides noiseless operation, thus avoiding noise pollution

3.5 Disadvantages

A PV system has some drawbacks. Such as:

- Cannot charge during nighttime and cloudy days
- Needs an open area for accommodation and installation
- Initial cost is high
- Constant maintenance and inspection is required

CHAPTER 4
ROADWAY INFRASTRUCTURE

4.1 Foot Over-Bridge

There are currently 43-foot over-bridges in Dhaka North City Corporation and 31 in Dhaka South City Corporation, according to data from the two Dhaka City Corporations. [51]. This number is scheduled to increase in the future.

Figure 4.1: Foot Over-Bridge in Dhaka City

4.2 Flyover

Dhaka City is home to a total of 8 flyovers, constructed over a period of 20 years. They include Kalshi Flyover, Moghbazar-Mouchak Flyover, Mayor Hanif Flyover, Zillur Rahman Flyover, Kuril Flyover, Khilgaon Flyover, Bijoy Sarani-Tejgaon Link Road Flyover and Mohakhali Flyover. These flyovers have a cumulative length of about 30km [52].

Figure 4.2: Flyovers in Dhaka City

4.3 Dhaka Metro Rail

The Dhaka Metro Mass Rapid Transit (MRT) is a 129km metro rail system being developed in Bangladesh. A total of 5 lines have been proposed and among them, the first phase (Uttara North to Agargaon) of MRT 6 (21.26km in length) has been completed and is now operational. This line extends up to 11.73km in length. The second and third phases of MRT 6 are still under construction along with the other MRT lines [53].

Figure 4.3: Dhaka Metro Rail

CHAPTER 5
SOFTWARE

5.1 PVSYST

Photovoltaic Systems or PVsyst is a PV-centric simulation tool that was originally developed at the University of Geneva. However, it is now a standalone company [36]. PVsyst is designed to be used by engineers, architects, and researchers. It is also an effective educative tool (pvsyst.com). It is a software package that is designed to model, size, simulate, and analyze PV systems. Despite being primarily a software for performance modeling, it also has financial modeling features, which greatly benefits our research.

PVsyst includes a wide array of features including:

- System Design
- System Sizing
- Shading Scene
- Simulation and Results
- Grid Storage
- Meteo Database
- Ageing
- Bifacial
- Optimization and Batch Mode
- Economic Evaluation
- Standalone Systems
- Pumping
- Components

PVSyst offers its users comprehensive reports, analysis and insightful information regarding the engineering aspects of design and deployment, which makes it suitable for our research. In addition to this, its interface is multilingual and accessible in other languages such as German, French, Spanish and Italian, in addition to English [35]. For our study, PVsyst 7.3 will be used.

5.2 Meteonorm

Meteonorm is a data source for engineering simulation programs in the passive, active and photovoltaic application of solar energy with comprehensive data interfaces, Meteonorm delivers global historical hourly values of irradiation, temperature, humidity, wind and precipitation from 2010 to present and is constantly updated. The database consists of over 8000 weather stations, five geostationary satellites and a globally calibrated aerosol climatology and 30 years of experience. Based on this, Meteonorm offers state-of-the-art interpolation models, delivering global weather data with high accuracy (meteonorm.com).

Some of the feature of Meteonorm include:

- Data Sources
- Calculation of Hourly Values
- Calculation of Minute Values
- API and DLL for Digital Applications
- Output Formats
- Data Import
- Interpolation
- Horizon

Although Meteonorm is an independent software, it is an open system, meaning one can import any third party data. It also comes with 36 different predefined export formats including our simulation tool of choice, PVsyst. Moreover, the Meteonorm database is built-in to the PVsyst software as “Meteo Database” feature. For our study, Meteonorm 8.1 will be used.

5.3 Google Earth Pro

Google Earth Pro is software provided by Google that integrates extensive satellite data together into one system to visualize the earth and study various geographic aspects. [57]. Google Earth Pro was originally the business-oriented upgrade to Google Earth, with features such as a moviemaker and data importer. But later, Google decided to make it available for free and is now the default version of Google Earth [58].

Google Earth Pro has features such as:

- Data Management
    - Data Capture
    - Data Storage
    - Data Manipulation
    - Data Visualization
- Map Creation
    - Geocoding
    - Buffer Zone Query
    - Overlaying
    - Publishing
- Analysis
    - Spatial Analysis
    - Reporting
    - Real-Time Streaming

While Google Earth Pro isn't technically a GIS (Geographic Information System), students and scientists around the world use it. It is also relatively easy to use and provides valuable geographical tool for any user. For our study, Google Earth Pro 7.3 will be used.

CHAPTER 6
METHODOLOGY

6.1 Site Selection

To install the PV systems in Dhaka, three (3) different structure types were picked: foot over-bridge, flyover and metro rail station.

A thorough investigation would be necessary before installing solar panels on a foot over-bridge to make sure that the added weight and wind loads won't jeopardize the bridge's structural integrity. Tall buildings or trees frequently surround foot over-bridges, which can create shadows and block sunlight. Since Khilkhet Foot Over-Bridge is located in one of Dhaka City's most crowded regions, it was chosen as the site for the simulation.

Another structural type is the flyover. PV installations may be useful for flyovers' flat or sloping surfaces. Flyovers are frequently positioned in broad spaces with few barriers, which improves solar exposure. This maximizes the solar panels' ability to produce energy. The PV arrangement was put into place using the Banani Flyover.

The Metro Rail Station was chosen to be the second structure type to be examined. Many Metro Rail stations have substantial roof spaces that would be ideal for mounting solar panels. PV installations are suited for flat or slightly inclined rooftops. Electricity is used extensively in metro rail stations for lighting, ventilation, ticketing systems, and other operational requirements. By installing a PV system, we can lessen your dependency on grid electricity and balance some of this energy demand. The PV system was chosen for analysis at Mirpur 10 Metro Rail Station.
From Google Earth Pro software, available space area from each of these systems to implement PV panels was calculated.

TABLE 6.1. SITE DATA

Structure	Available area for PV installation
Khilkhet Foot Over-Bridge	334 m^2
Banani Flyover	400 m^2 for 100 m length
Mirpur 10 Metrorail Station	4368 m^2

6.2 Meteorological Data

Collecting meteorological data is crucial for the successful implementation of a photovoltaic (PV) system. Parameters such as solar radiation, sunshine duration and temperature data provide insights into the amount and variability of sunlight available throughout the year. Data required for all three structures was found from Meteonorm 8.1 software.

The solar irradiance obtained from the direct beam of the sun on a horizontal surface is referred to as direct horizontal irradiance. It represents the amount of solar energy that directly illuminates the Earth's surface without being obstructed by anything or scattered by the atmosphere. The power of direct sunlight falling on a horizontal surface is expressed as watts per square meter (W/m2), where W/m2 is the unit of measurement. To evaluate the potential for harvesting solar energy using photovoltaic or solar thermal systems, it is frequently employed in solar energy applications.

The solar irradiance received from the sky, excluding the direct beam of the sun, on a horizontal surface is referred to as diffuse horizontal irradiance. Diffuse horizontal irradiance, as opposed to direct horizontal irradiance, which depicts the direct sunshine, takes into consideration the indirect or scattered sunlight that comes from all directions of the sky. Because of interactions with molecules, aerosols, and other atmospheric particles, this scattered sunlight develops. The power of the scattered sunlight falling on a horizontal surface is expressed in watts per square meter (W/m2), another unit of measurement for diffuse horizontal irradiance. It is a crucial factor in determining the availability of diffuse solar radiation, which can increase a location's overall solar energy potential.

The solar irradiance received from the direct beam of the sun on a surface perpendicular to the sun's rays is known as direct normal irradiance (DNI). It is a measure of the quantity of solar energy that passes straight through an atmosphere-free surface that is facing the sun.

The strength of direct sunlight that strikes a surface perpendicular to the sun is measured as DNI in watts per square meter (W/m^2). DNI measurements, in contrast to horizontal measures of direct irradiance, are done on a surface that is constantly pointed toward the sun and track its position throughout the day.

TABLE 6.2.1. METEO DATA FOR FOOT OVER-BRIDGE SITE

Site Name	**Khilkhet Foot Over-Bridge**
Coordinates	24.8298°N, 90.4200°E
Direct Horizontal Irradiance	41.8 kWh/m^2
Diffused Horizontal Irradiance	62.2 kWh/m^2
Direct Normal Irradiance (DNI)	78.3 kWh/m^2
Wind Velocity	0.6 m/s
Ambient Temperature	25.4 ℃

Meteor Data on annual basis as graph format was also generated using Meteonorm 8.1. The temperature vs month graph depicts the variation of daily maximum and minimum temperature. A PV cell's power production declines as its temperature increases. The open-circuit voltage drop and, to a lesser extent, the fill factor drop are the main causes of this. When constructing and evaluating the energy output of a PV system, the considerable loss in power output with increasing temperature must be taken into account.

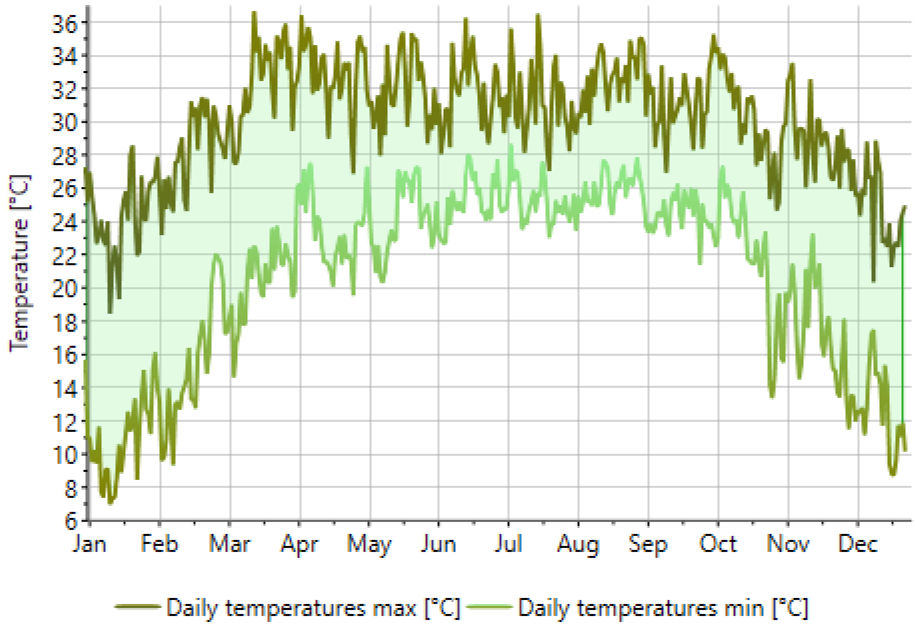

Figure 6.2.1: Monthly Temperature Profile

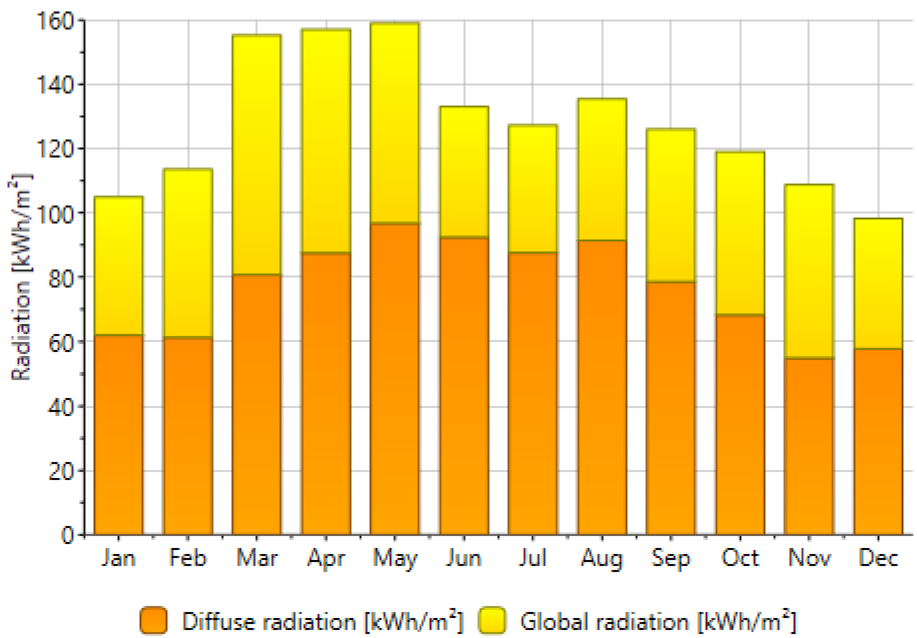

Figure 6.2.2: Monthly Radiation Profile

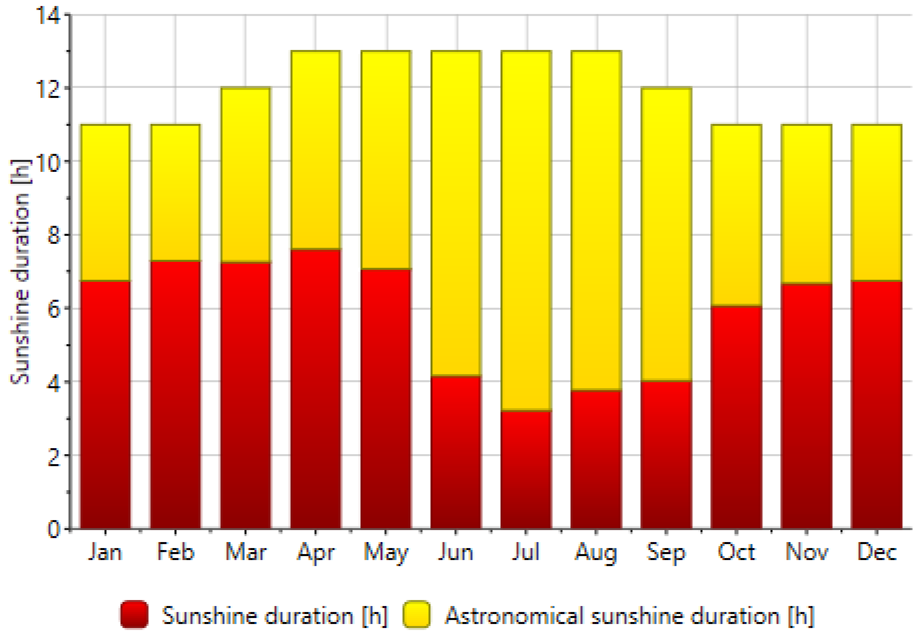

Figure 6.2.3: Monthly Sunshine Duration

The parameters for the rest two sites are also presented in tabular format as below:

TABLE 6.2.2. METEO DATA FOR FLYOVER & METRO RAIL STATION

Site Name	**Banani Flyover**	**Mirpur 10 Metro Rail Station**
Co-ordinates	24.8163°N, 90.4023°E	23.7785°N, 90.3800°E
Direct Horizontal Irradiance	42.8 kWh/m^2	42.3 kWh/m^2
Diffused Horizontal Irradiance	62.7 kWh/m^2	63.4 kWh/m^2
Direct Normal Irradiance	78.5 kWh/m^2	79.1 kWh/m^2
Wind Velocity	0.6 m/s	0.8 m/s
Ambient Temperature	25.5 ℃	25.7 ℃

6.3 3D Shading Scene Construction

To build the 3D structures required for the analysis, “Near Shading” tool is selected. Among the shading options that were provided, linear shading is considered. The shade of solar panels brought on by linear objects, such as surrounding buildings, trees, or constructions, is referred to as linear shading. As the sun's position varies during the day, these shadows can shift across the PV panel's surface, creating dynamic shading patterns.

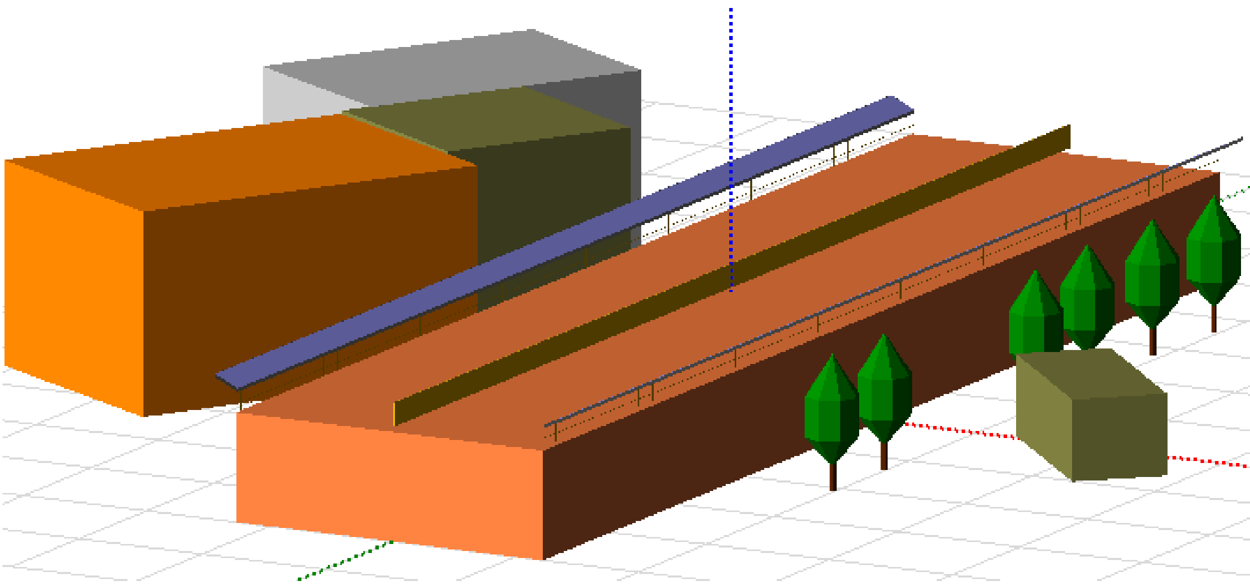

Figure 6.3: Shading Scene for Flyover (Illustration)

In the “Construction/Perspective” section, 3D structures for all 3 models were created according to the data collected from “Google Earth Pro” software. When constructing the shading scenes, the appropriate directions and shading objects were maintained. In a big solar photovoltaic (PV) project, the term "fields tilt" often refers to the tilt angle or orientation of solar panels. The orientation or azimuth angle of solar panels in a sizable solar farm or field is referred to as "fields azimuth". When constructing the structures, the fields tilt varied between 21° to 25°, while fields azimuth varied between 0° to 90°.

6.4 Selection in the PV Sub-Array

For each of the 3 types of structures, same PV panel was used to ease the maintenance and logistics. But, due to the varied estimated output from the 3 structure types, different inverters had to be used to maintain cost efficiency. Thus, a balance between cost and ease of maintenance was utilized.

For all of the simulation, LG 340 N1C-A5 PV module was used, which is monocrystalline in type. High levels of efficiency are typical of monocrystalline solar cells. They have a homogeneous, single-crystal structure that promotes effective electron movement and improves the conversion of solar energy into electricity. When compared to other types of solar cells, monocrystalline cells can produce more electricity per square meter thanks to their normal efficiency rates of 15% to 25% or higher.

TABLE 6.4.1. TECHNICAL SPECIFICATION OF LG 340 N1C-A5

Model	LG 340 N1C-A5
Manufacturer	LG Electronics
Type	Monocrystalline
Nominal Power (at STC)	340 W
Short Circuit Current	10.53A
Open Circuit Voltage	41.10V
Maximum Power Current	9.86A
Maximum Power Voltage	34.5V
Efficiency/Cell Area	21.89%
Temperature Co-efficient	-0.37% / ℃
Number of Cells in Module	60

The inverter is crucial in transforming the direct current (DC) produced by the solar panels into useful alternating current (AC) electricity for consumption or grid connection. Performance of the system is directly influenced by the size of the inverter. Power clipping may occur if the inverter is inadequate and is unable to manage the solar panels' maximum power output. When an inverter is unable to convert all of the DC power produced by solar panels into AC power, power clipping occurs. System efficiency may suffer as a result, which could diminish energy production. On the other hand, a large inverter may not function at its maximal efficiency since it is running at low loads, which can lead to energy loss.

For the inverter to be used in analysis, 3 different size inverters from Huawei Technologies were used: SUN2000-30KTL-M3-380V, SUN2000-70KTL-M3-380V & SUN2000-100KTL-M3-380V.

TABLE 6.4.2. TECHNICAL SPECIFICATION OF SUN2000-30KTL

Model	SUN2000-30KTL-M3-380V
Manufacturer	Huawei Technologies
Minimum MPP Voltage	200 V
Maximum MPP Voltage	1000 V
Power Threshold	75 W
Nominal AC Power	30.0 kW
Maximum AC Power	33.0 kW
Operating Frequency	50 Hz
Maximum Efficiency	98.5%

6.5 Design of the Array

When designing the array, several parameters have to be taken into consideration. When an electrical component or system is run above its rated or planned capacity, it suffers from overload loss, sometimes referred to as derating loss. This can happen in a variety of electrical devices, including inverters, transformers, wires, and other solar photovoltaic (PV) system components.
A PV array's nominal power (Pnom) is its maximum predicted power output under standard test conditions (STC), which are normally defined by the manufacturer. The power that a PV array

really produces under actual operating conditions, which might change depending on variables like solar irradiation, temperature, shading, and system losses, is known as its DC power output. By dividing the PV array's DC power output by its nominal power rating, the Pnom-to-DC ratio is computed. It shows how efficiently the array is operating in relation to its rated capacity. While a lower ratio can signify subpar performance, a greater Pnom-to-DC-ratio shows that the array is working closer to its maximum capacity.

A metric used to assess the effectiveness and performance of a photovoltaic (PV) system is the PR ratio, sometimes referred to as the Performance Ratio. It gauges how well a PV system transforms solar energy into useful electrical energy.

The PV system's actual energy output over a certain time is divided by the predicted energy output based on the available solar irradiation to determine the PR ratio, which is commonly reported as a percentage. The PR ratio is calculated using the following formula:
PR Ratio = (Actual Energy Output / Expected Energy Output) * 100%

The actual energy output, which is frequently expressed in kilowatt-hours (kWh), is the total amount of electrical energy produced by the PV system over a certain time period. This can be discovered through on-site observation or through utility bill information.
The number and module required for each of the structure types are given below:

TABLE 6.5. MODULE DESIGN PARAMETERS

Structure	Foot Over-Bridge	Flyover	Metro Rail
Modules in Series	20	21	19
Number of Strings	10	11	134
Overload Loss	0%	0%	0%
Pnom Ratio	1.10	1.12	1.24
Total Area	334 m^2	400 m^2 (100m)	4368 m^2
Total No. of Modules	200	231	2546

A simplified representation of an electrical system or network is a single-line diagram (SLD), also referred to as a one-line diagram. The different parts and links inside the system are represented by standardized symbols and lines. An SLD offers a brief synopsis of the system's configuration and functionality, even though it might not contain comprehensive details regarding the physical layout or interconnections.

Single-line diagrams for each of the structures are presented below, where it shows the connection between inverters, modules and injection points.

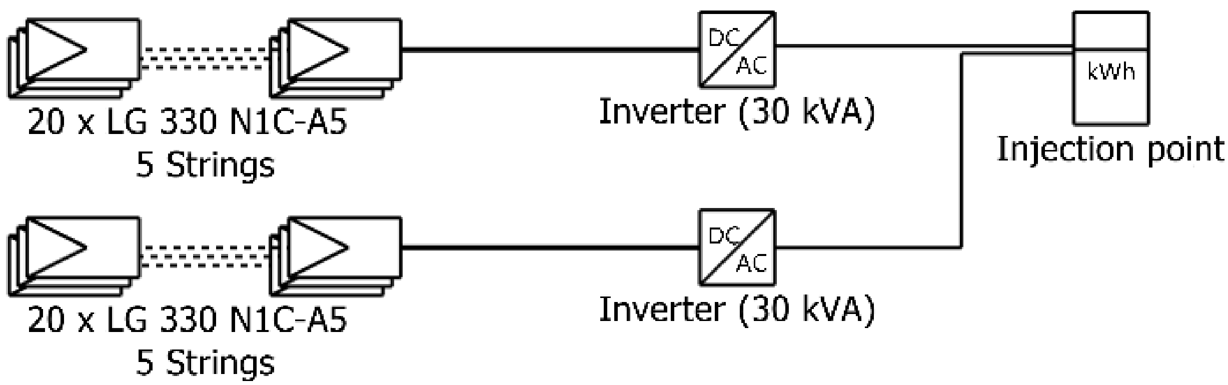

Figure 6.5.1: SLD for PV Array for Foot Over-Bridge

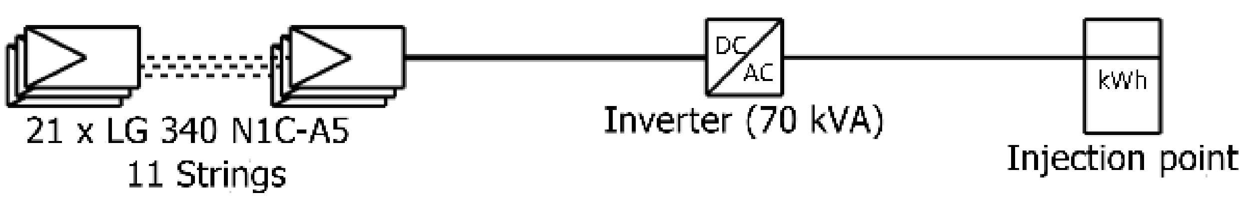

Figure 6.5.2: SLD for PV Array for Flyover

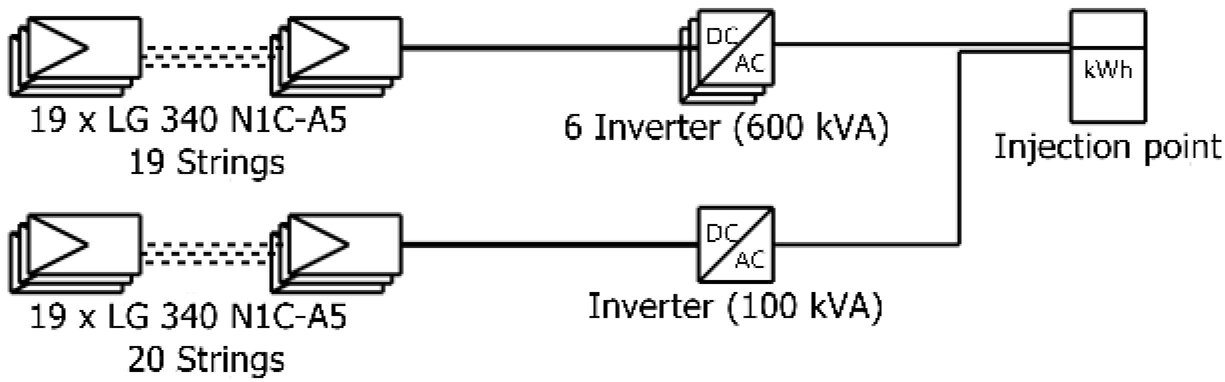

Figure 6.5.3: SLD for PV Array for Metro Rail Station

6.6 Loss Parameters

Loss parameters should be taken into account when building a photovoltaic (PV) array in order to accurately predict the system's performance and energy output. These losses take into consideration a number of elements that lower the PV array's efficiency.

6.6.1 Array Thermal Losses

The goal is to measure the array's (or cell's) temperature during the simulation. One of the fundamental input variables for the one-diode model is the cell temperature. This is assessed using an energy balance that takes into account incoming and outgoing fluxes inside the array. The energy fluxes should be offset by the array's cooling thermal loss, at thermal equilibrium:

$$G_{inc} = \alpha \cdot (1 - Eff.) = U \cdot (T_{cell} - T_{amb})$$

Where,

$G_{inc} =$ The irradiance on the module or PV array, according to the individual meteo data

α = The absorption coefficient of solar irradiance, i.e. (1 - reflection)

$Eff.$ = The PV Efficiency (related to the module area) = 21.89% (from software)

U = The "heat loss factor" = 20 W/m²·k for all three structures

T_{amb} = The ambient temperature, according to the individual meteo data

6.6.2 Mismatch Loss

A PV array's PV modules may have modest variances in their electrical properties, such as output voltage and current. When modules are coupled in series or parallel, mismatch losses happen, which causes subpar performance because of variations in module performance.
A continuous loss factor that applies throughout the whole simulation is the discrepancy brought on by the dispersion of the modules' characteristics. It is quite tough to analyze this factor. A tool for evaluating the Module Mismatch as a function of the Modules' characteristic dispersion is provided by PVsyst. This shows that the loss grows extremely quickly with the dispersion value but is very modest (less than 0.5%) for dispersions below 2%.

6.6.3 Ageing / Degradation Loss

PV modules may degrade and lose efficiency over time as a result of things like sunshine exposure, temperature changes, and environmental factors. For a precise long-term system performance estimation, the degradation rate and warranty information of the modules must be taken into account. For the simulation, by default global degradation factor is considered 9.8%, while mismatch degradation factor at 5.33% [55].

6.6.4 Soiling Loss

The amount of sunlight that reaches the solar cells can be reduced by the build-up of dirt, dust or other material on the surface of PV modules, resulting in a reduction in power output. Keeping the modules clean and maintained on a regular basis can reduce soiling losses. For the simulation, yearly loss factor is considered at 6% [59].

6.6.5 System Unavailability

Due to maintenance and other emergency reasons, PV system may not be able to provide power for several days in a year. A constant unavailability of 7.50 days / yearn (default value) is considered throughout the whole simulation period to make the calculation easier.

6.7 Module Mounting

A design strategy that combines solar modules and an air ventilation system is known as a semi-integrated PV system with an air duct behind it. In this setup, an air duct or channel is built behind the PV modules, which are integrated into a building structure like a roof or façade.
The air duct's function is to let air to flow behind the PV modules, which aids in heat dissipation and lowers temperature-related losses. The performance and longevity of the PV system can be improved by installing an air duct behind semi-integrated PV modules in order to reduce temperature-related losses.

6.8 Economic Analysis

Economic analysis helps determine the financial feasibility of installing a PV system. It assesses the upfront costs, ongoing expenses, and potential revenue streams associated with the system. By considering different factors, such as installation costs, maintenance costs, expected energy generation, and potential savings on electricity bills, economic analysis provides insights into whether the PV system is a financially viable investment. For evaluating economic feasibility, several data was collected through internet. Some values were estimated based on the data available for similar kind of systems. Here, 1 euro = 100 taka is used for currency conversion.

TABLE 6.8. DATA FOR ECONOMIC ANALYSIS

Price / Module	27500 taka [60]
Price of Support / Module	1800 taka (Estimated)
Price / Inverter	254000 taka [61]
Project Lifetime	25 years
Inflation	3% / year (Estimated Median Value)
Discount Rate	7% / year (Estimated Median Value)
Production Variation	0.75% / year
Peak Tariff	10 taka / kWh [63]
Off-peak Tariff	0.5 taka / kWh
Annual Degradation	0.8%

The cost of photovoltaic (PV) systems can change over time depending on a number of variables, such as the location, the market, technological improvements, governmental changes, and currency fluctuations. It is typical to take into account an inflation rate of roughly 2% to 3% [63] (estimated at 3% for simulation) per year when calculating the overall system cost. This inflation rate considers elements including inflation in the overall economy, labor expenses and material costs.

The discount rate applied to the evaluation of photovoltaic (PV) systems might change based on the project at hand, the risk profile, the geography, and the organization doing the analysis, among other things. The discount rate reflects the time worth of money as well as the risk involved with the project. It stands for the rate of return necessary to justify the investment. Discount rates for PV systems typically vary between the ranges of 5% and 12% [64] (for simulation, 7% is estimated).

6.9 Carbon Balance Analysis

The Carbon Balance tool in PVsyst is used to calculate the estimated CO_2 emissions savings from a PV system. The "Life Cycle Emissions" (LCE) used in this computation are the CO_2 emissions related to a specific component or amount of energy. The Carbon Balance Tool's justification is that the electricity generated by the PV system will replace an equivalent amount of electricity in the current grid. There will be a net reduction in carbon dioxide emissions if the carbon footprint of the PV installation is lower per kWh than the one for grid power production. The difference between CO_2 emissions that are created and those that are avoided makes up the entire carbon balance for a PV system.

$$E_{grid} \times Project\ lifetime \times LCE_{grid} - LCE_{system} = Carbon\ Balance$$

E_{grid} = The PV Installation's Annual System Production; or energy yield, as determined by the PVsyst simulation.

LCE_{grid} = The average quantity of CO_2 emissions per Energy unit for electricity generated by the grid (LCE_{system} for the PV system)

CHAPTER 7
RESULTS AND DISCUSSION

7.1 Foot Over-Bridge

For foot over-bridge, we found the total energy produced by the array, and total energy injected into the grid over a span of twelve months by PVsyst software. We also found the PR ratio over these months, which is also one of the performance metrics of the system.

TABLE 7.1.1. MONTHLY IRRADIATION & ENERGY PRODUCTION (FOOT OVER-BRIDGE)

Month	Diffused Horizontal Irradiation (kWh/m²)	Energy Produced by Array (kWh)	Energy Injected into Grid (kWh)
January	62.20	3316	2996
February	61.94	3469	3393
March	80.91	4553	4165
April	87.58	4766	4383
May	96.88	5140	5031
June	92.47	4181	4381
July	87.57	4106	4012
August	91.28	4284	4189
September	78.61	3773	3686
October	68.22	3545	3460
November	54.96	3271	3195
December	55.79	3146	3075
Year	918.42	47850	45965

From the table, it is obvious that energy production varies to a considerable extant throughout the year. In December (winter), length of the day is smaller than rest of the months, and Irradiation received is also the lowest, which equals lowest net output of all the months (3146 kWh). Then it gradually increases, and peak output is generated in May (5140 kWh), which also have highest irradiance among all the months. So, a clear correlation between irradiance and output can be noticed here.

MONTHLY IRRADIANCE

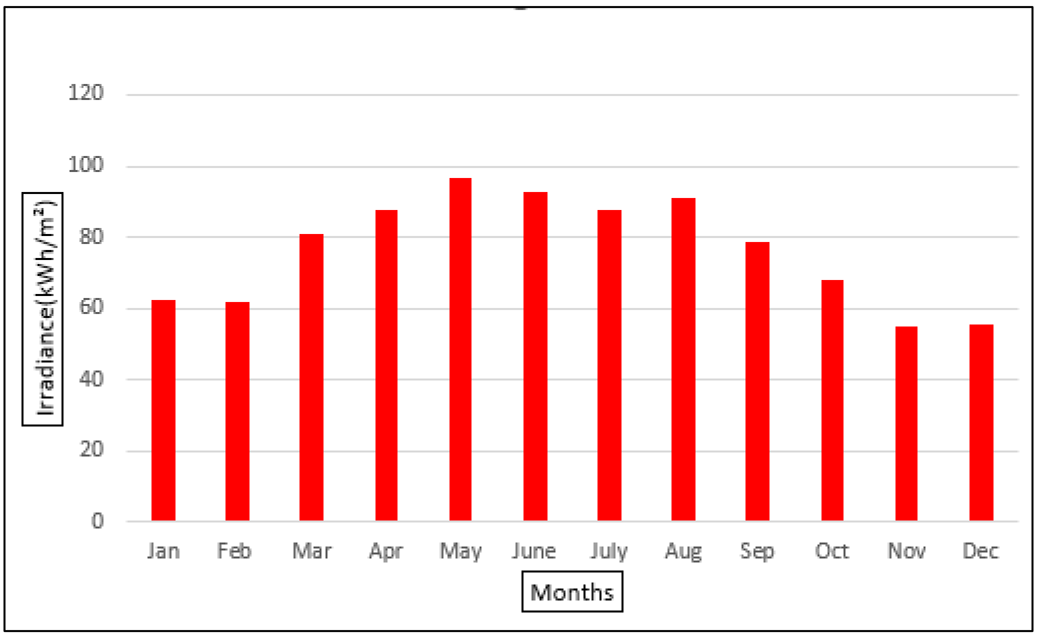

Figure 7.1.1: Irradiance vs Month (Foot Over-Bridge)

MONTLY ENERGY PRODUCTION

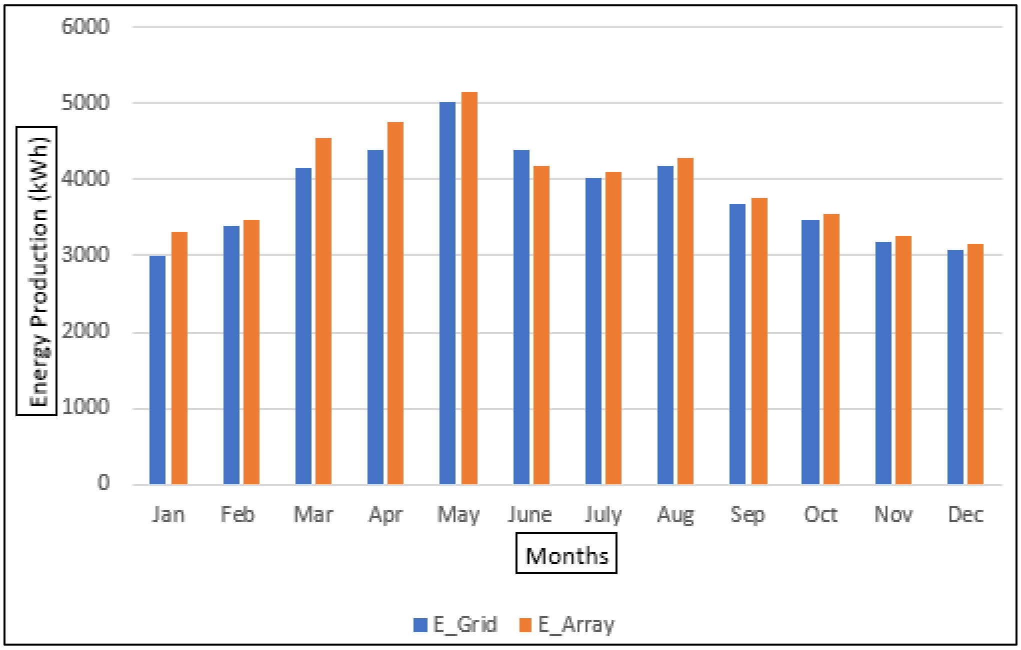

Figure 7.1.2: Monthly Energy Production (Foot Over-Bridge)

PVsyst also provides results about the performance parameters of the systems: Energy Deviation and PR ratio. It calculated these parameters for every month and a tabulated result was generated, from where we can understand the relationship between the said parameters.

TABLE 7.1.2. PERFORMANCE PARAMETERS (FOOT OVER-BRIDGE)

Month	Temperature (°C)	Energy Deviation (kWh)	PR Ratio
January	17.03	320	0.448
February	20.94	76	0.475
March	25.76	388	0.419
April	27.66	383	0.439
May	28.33	109	0.503
June	28.15	100	0.525
July	28.54	94	0.508

August	28.69	95	0.491
September	28.00	87	0.468
October	27.15	85	0.464
November	23.00	76	0.463
December	18.87	71	0.486

There is a relationship between temperature and the Performance Ratio (PR) ratio that affects how well a photovoltaic (PV) system performs. In general, the PR ratio tends to decline as temperature rises. The negative temperature coefficient of solar cells is the main cause of the drop in PR ratio with rising temperature. However, in our case, there was no linear relationship between Temperature and PR ratio. But Energy Deviation and PR ration have a correlation, where higher ED equals lower PR ratio and vice-versa. A graph was generated by entering these parameters into the graphical tool, where we can visualize the relation between these parameters. Some parameters were scaled up for better visualization.

COMPARISON BETWEEN PERFORMANCE PARAMETERS

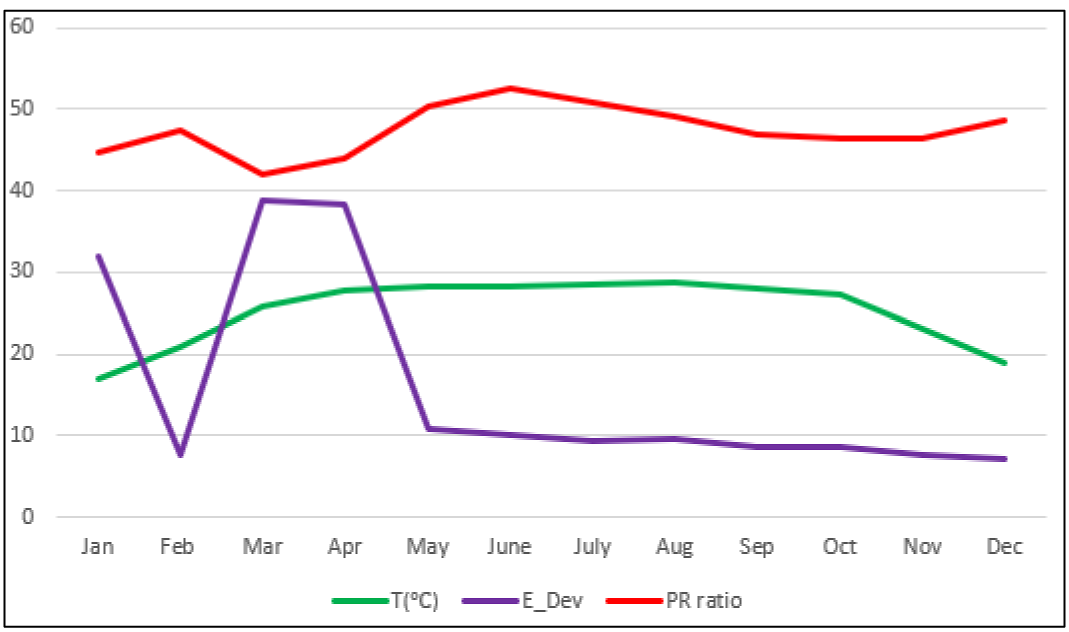

Figure 7.1.3: Graphical Comparison between Temp., E_Dev & PR ratio

From the graph, it can be said that there is an apparent linear relationship between temperature and PR ratio of our designed system, while an apparent inverse relationship exists between Energy deviation and PR ratio.

PVsyst also provided detailed yearly loss values for the designed system, providing values for Module Quality Loss, Module Array Mismatch Loss, Ohmic Wiring Loss, Global Inverter Losses and AC Ohmic Loss. Their values are tabulated below:

TABLE 7.1.3. LOSS PROFILE (FOOT OVER-BRIDGE)

Losses	Values (in kWh)
Module Quality Loss (kWh)	388.708
Module Array Mismatch Loss (kWh)	2849
Ohmic Wiring Loss (kWh)	378.18
Global Inverter Losses (kWh)	2206.6

LOSS PROFILE

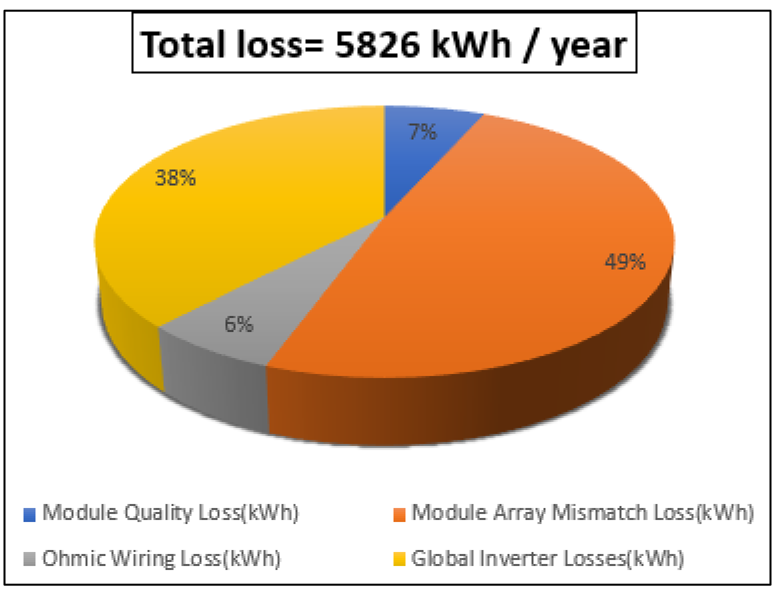

Figure 7.1.4: Pie Chart for all Calculated Loss (Foot Over-Bridge)

From the generated pie chart, it can be seen that most of the losses occurred due to array mismatch, while a small percentage is due to the Ohmic property of the connecting wires.

Economic Analysis shows that PV systems installed on the Foot Over-Bridge requires 14.5 years to return the initial investments, and after the estimated project lifetime of 25 years, 33.4% of the investment will be returned as profit.

RETURN ON INVESTMENT

Return on investment

Net present value (NPV)	21306.00 EUR
Internal rate of return (IRR)	10.38 %
Payback period	14.5 years
Return on investment (ROI)	33.4 %

Figure 7.1.5: Economic Evaluation (Foot Over-Bridge)

Carbon balance analysis for the PV system in PVsyst resulted in 482.098 ton of CO_2 being saved over the project lifetime.

7.2 Flyover

We calculated the total energy generated by the array and the total energy that PVsyst software added to the grid over a 12-month period for foot over-bridge. Another performance metric of the system that we discovered was the PR ratio throughout these months.

TABLE 7.2.1. MONTHLY TEMPARATURE & ENERGY PRODUCTION (FLYOVER)

Month	Temperature (°C)	Diffused Horizontal Irradiation (kWh/m²)	Energy Produced by Array (kWh)	Energy Injected into Grid (kWh)
January	17.04	62.07	7619	7499
February	20.95	61.36	7699	7573
March	25.76	80.78	9686	8772
April	27.66	87.56	9028	8875
May	28.33	96.75	8635	8484
June	28.15	92.43	7043	6914
July	28.53	87.55	6717	6594
August	28.69	91.39	7526	7394
September	28.00	78.60	7357	6579
October	27.14	68.23	7592	7165
November	23.00	54.99	7713	7244
December	18.88	55.89	7189	7074
Year	25.19	916.60	93804	90068

It is clear from the data that energy production changes significantly throughout the year. However, unlike the previous case, the lowest energy produced (6717 kWh) is in month of July, where temperature is also one of the highest. So, this case illustrates the correlation between temperature and efficiency of PV cells better than the previous case. In addition, like the previous case, month of December has one of the lowest energy produced (7189 kWh), while month of March has the highest energy production (9686 kWh).

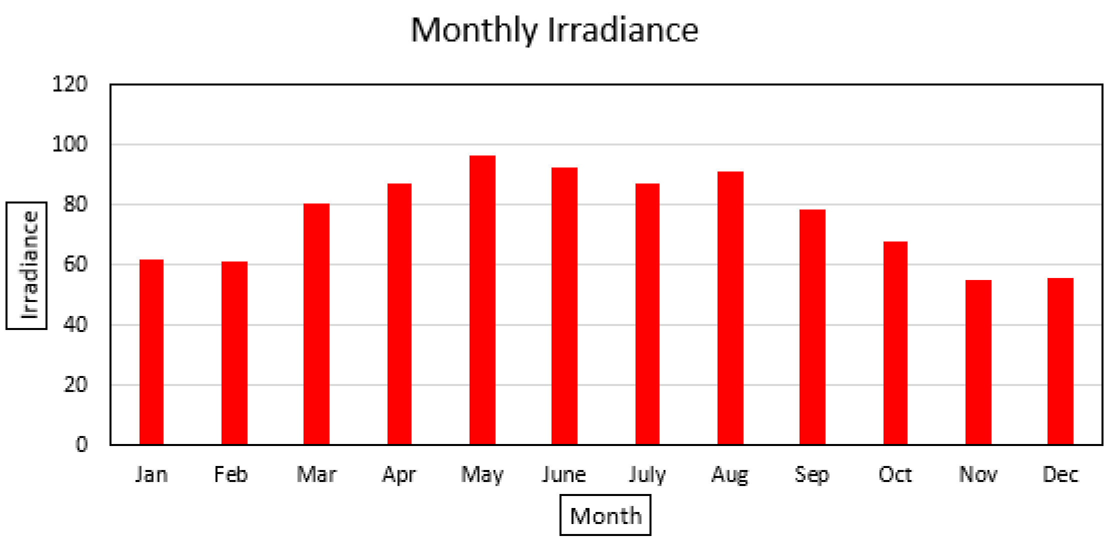

Figure 7.2.1: Irradiance vs Month (Flyover)

The Irradiation and Energy Production for a year is also presented in a graphical manner, from where we can also notice the discrepancy regarding these two parameters, as mentioned before.

COMPARISON BETWEEN E_ARRAY & E_GRID

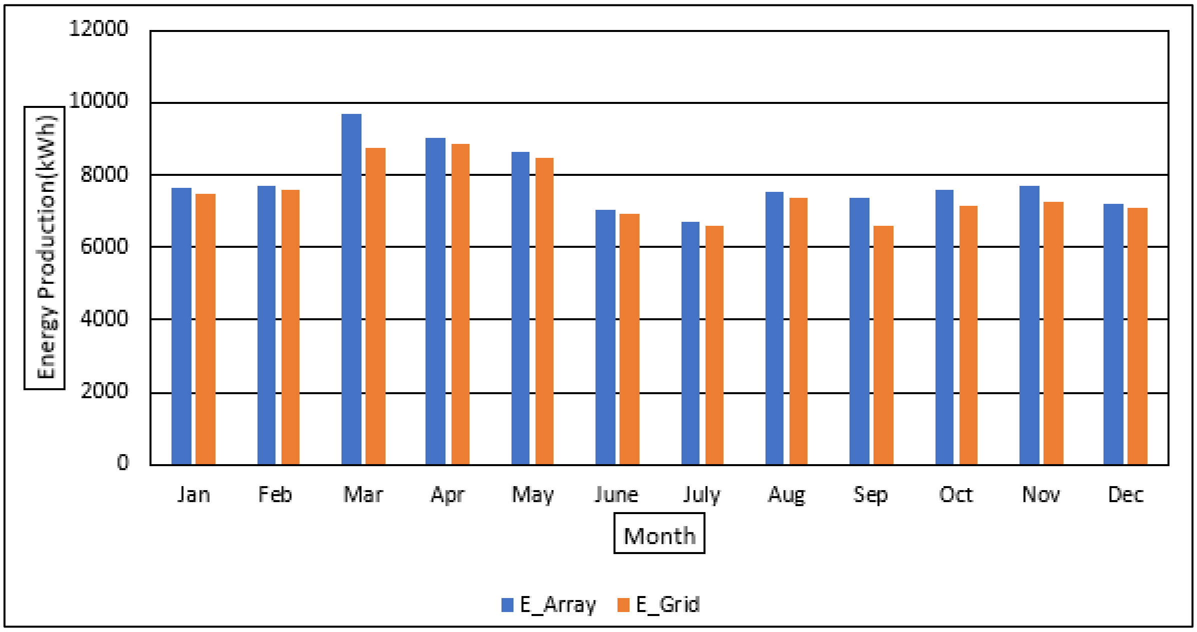

Figure 7.2.2: Monthly Energy Production (Flyover)

TABLE 7.2.2. PERFORMANCE PARAMETERS (FLYOVER)

Month	Temperature (°C)	Energy Deviation (kWh)	PR Ratio
January	17.03	120	0.739
February	20.94	126	0.731
March	25.76	914	0.666
April	27.66	153	0.722
May	28.33	151	0.725
June	28.15	69	0.725
July	28.54	123	0.718
August	28.69	132	0.721
September	28.00	778	0.641
October	27.15	427	0.686
November	23.00	469	0.687
December	18.87	115	0.733

COMPARISON BETWEEN PERFORMANCE PARAMETERS

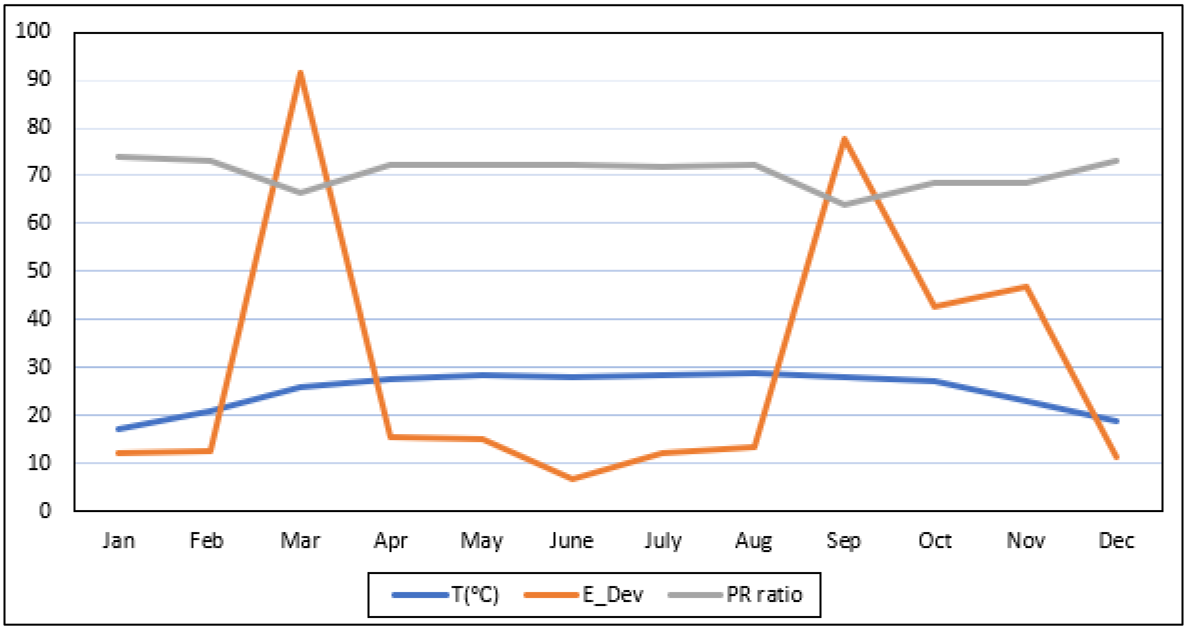

Figure 7.2.3: Graphical Comparison between Temp., E_Dev & PR ratio

In the graph, the parameters are scaled up for better visualization. Here, it is apparent that Energy Deviation and Temperature has inverse relationship with PR ratio.

TABLE 7.2.3. RESULT DATA FOR ALL TYPES OF LOSS (FLYOVER)

Losses	Values (in kWh)
Module Quality Loss (kWh)	745.691
Module Array Mismatch Loss (kWh)	3629.3
Ohmic Wiring Loss (kWh)	796.89
Global Inverter Losses (kWh)	1598.4

LOSS PROFILE (FLYOVER)

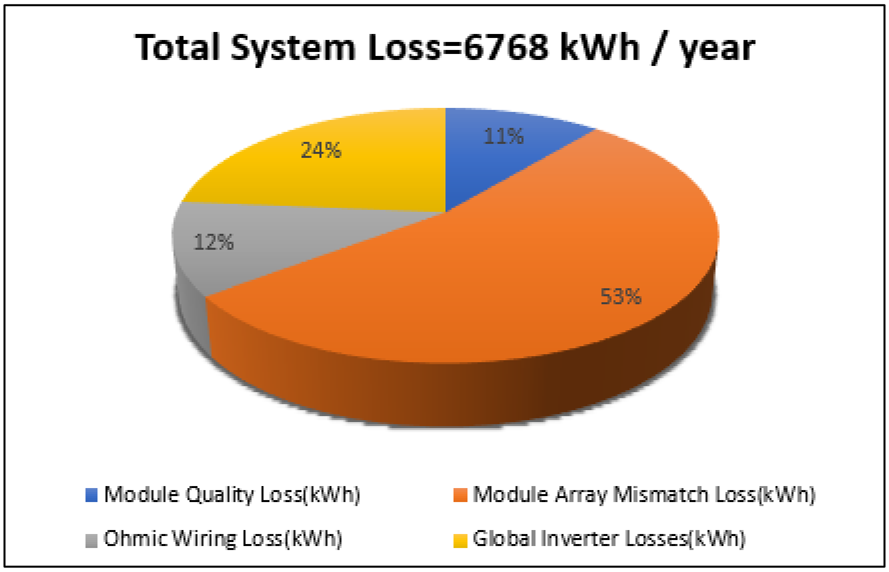

Figure 7.2.4: Pie Chart for all Calculated Loss (Flyover)

From the pie chart, it can be seen that although module mismatch loss is the same as before, inverter loss and module quality loss decreased compared to the previous case in terms of percentage. Also, as energy injected into the grid is 90068 kWh and total system loss 6768 kWh in a year, this makes total loss at 7.5%, which is significantly lower than previous 12.7%. Therefore, PV systems installed on flyovers provided significantly lower loss for same amount of energy injected into the grid than the one installed on foot over-bridge.

RETURN ON INVESTMENT

Return on investment

Net present value (NPV)	**90904.74 EUR**
Internal rate of return (IRR)	**18.70 %**
Payback period	**6.9 years**
Return on investment (ROI)	**125.4 %**

Figure 7.2.5: Economic Evaluation (Flyover)

Carbon balance analysis yielded 1224.33 ton less CO_2 production due to the PV system. Financial analysis shows that PV system installed on Flyovers can return their investment within just 6.9 years, which is also significantly lower previous foot over-bridge case of 14.5 years.

7.3 Metro Rail Station

TABLE 7.3.1. MONTHLY TEMPARATURE & ENERGY PRODUCTION (METRO RAIL STATION)

Month	Temperature (°C)	Diffused Horizontal Irradiation (kWh/m²)	Energy Produced by Array (kWh)	Energy Injected into Grid (kWh)
January	17.04	61.8	78265	76930
February	20.95	62.0	79718	78217
March	25.76	80.6	98918	96938
April	27.66	90.7	93058	91217
May	28.33	102.8	90267	88524
June	28.15	93.4	73288	71890
July	28.53	84.3	70333	68946
August	28.69	98	78189	76726
September	28.00	76.6	75355	73882
October	27.14	69.3	77899	76352
November	23.00	58.1	78372	76878
December	18.88	58.8	74002	72704
Year	25.19	936.5	967664	949204

IRRADIATION PROFILE

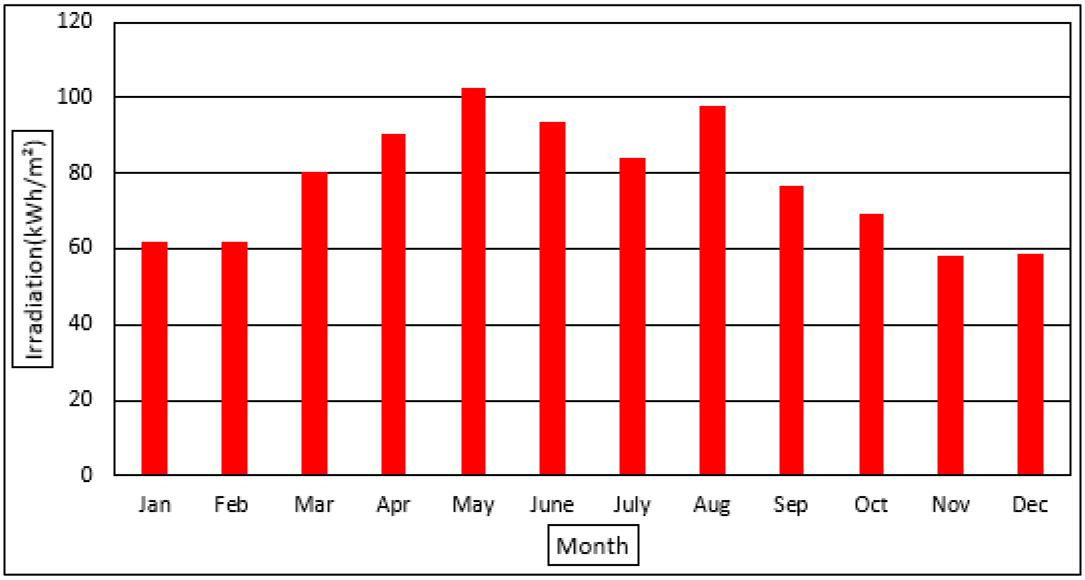

Figure 7.3.1: Monthly Irradiation (Metro Rail Station)

We can also see the previously indicated disparity between these two quantities.

COMPARISON BETWEEN E_ARRAY & E_GRID

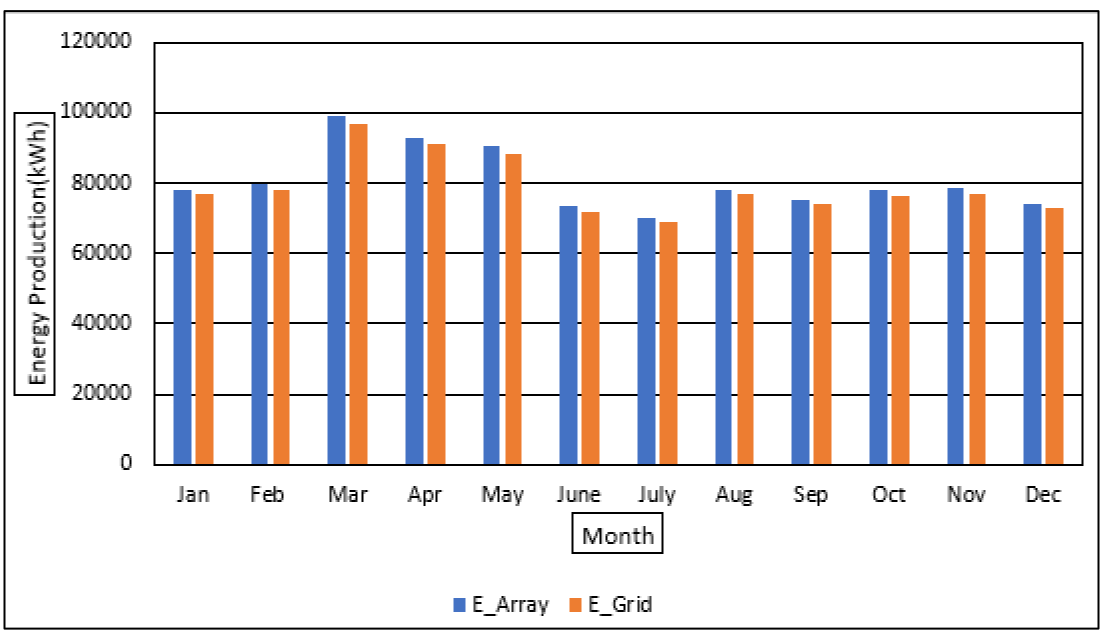

Figure 7.3.2: Monthly Energy Production (Metro Rail Station)

TABLE 7.3.2. PERFORMANCE PARAMETER VALUES (METRO RAIL STATION)

Month	Temperature (°C)	Energy Deviation (kWh)	PR Ratio
January	17.04	1335	0.685
February	20.95	1501	0.684
March	25.76	1980	0.667
April	27.66	1841	0.670
May	28.33	1743	0.686
June	28.15	1398	0.683
July	28.53	1387	0.679
August	28.69	1463	0.681
September	28.00	1473	0.661
October	27.14	1547	0.665
November	23.00	1494	0.664
December	18.88	1298	0.689

COMPARISON BETWEEN PERFORMACE PARAMETERS IN SCALED FORM (METRO RAIL STATION)

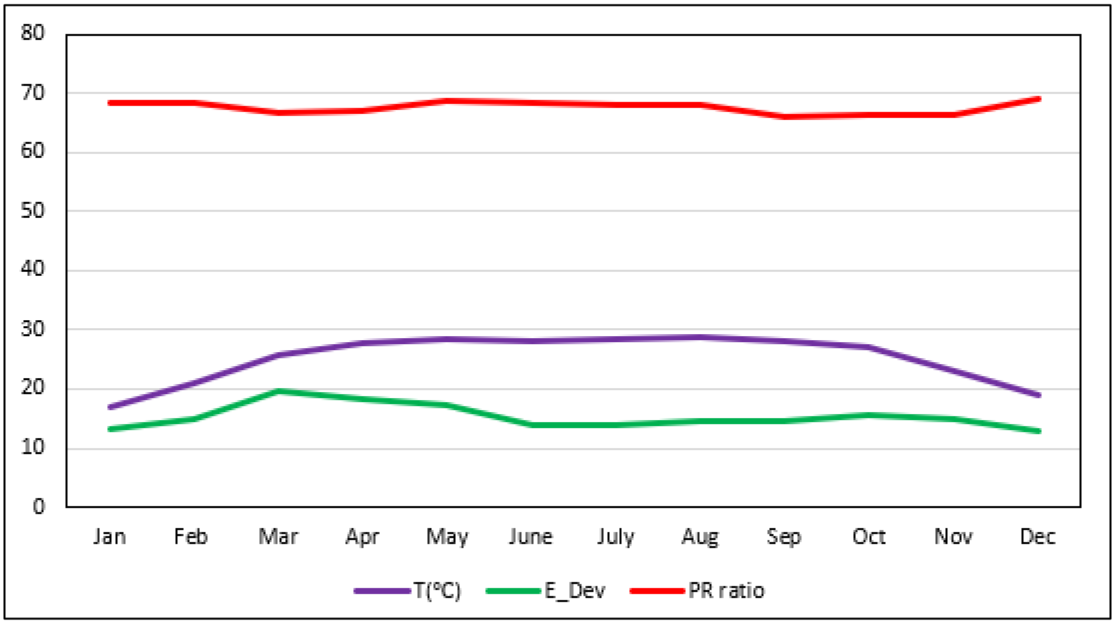

Figure 7.3.3: Comparison among Temp., E_Dev & PR ratio

TABLE 7.3.3. LOSS PROFILE (METRO RAIL STATION)

Losses	Values (in kWh)
Module Quality Loss (kWh)	7648.611
Module Array Mismatch Loss (kWh)	29999
Ohmic Wiring Loss (kWh)	9259
Global Inverter Losses (kWh)	18461

As can be observed, inverter loss and module quality loss decreased compared to the prior situation, even while module mismatch loss remained unchanged in terms of percentage. A year's worth of energy is injected into the grid at a rate of 949204 kWh, while the total system loss is 65367 kWh; this results in a total loss of 6.8%, which is considerably less than the prior rates of 12.7% & 7.5%. Therefore, compared to PV systems deployed on foot over-bridges and flyovers, those installed on metro train stations generated much lower loss for the same quantity of energy fed into the grid.

LOSS PROFILE

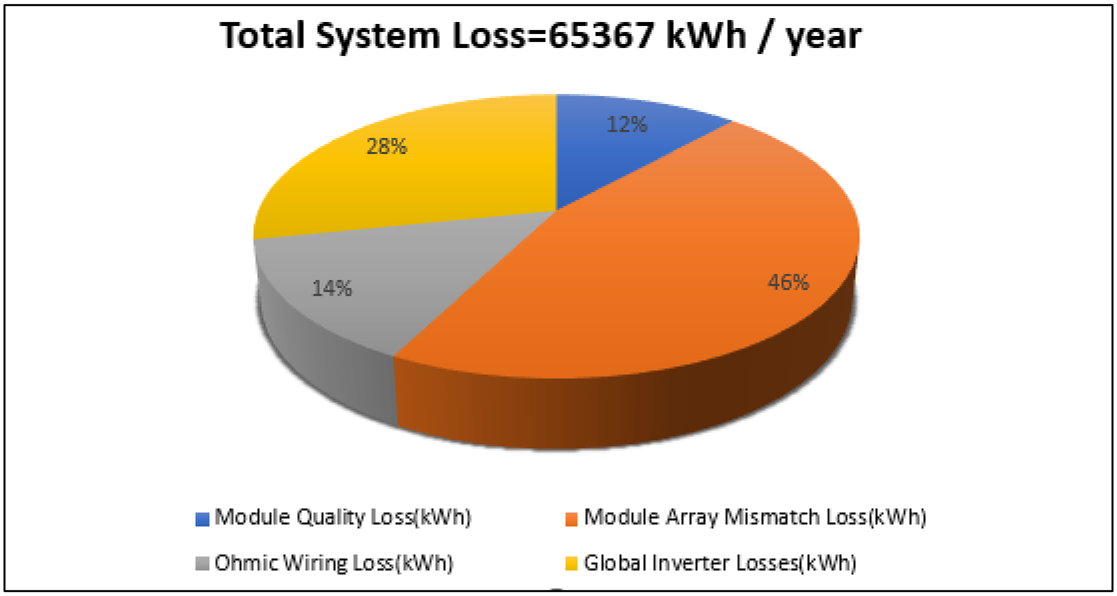

Figure 7.3.4: Pie Chart for all Calculated Loss (Metro Rail Station)

According to financial study, PV systems installed on flyovers can pay for themselves within just 7.4 years, which is also much less time than the prior foot over-bridge scenario of 14.5 years, but slightly higher than 6.9 years. Furthermore, 112.7% of the investment will be returned as profit following the projected project lifespan of 25 years.

RETURN ON INVESTMENT

Return on investment

Net present value (NPV)	**901062.27 EUR**
Internal rate of return (IRR)	**17.62 %**
Payback period	**7.4 years**
Return on investment (ROI)	**112.7 %**

Figure 7.3.5: Economic Evaluation (Metro Rail Station)

Carbon balance analysis yielded 11019.139 ton less CO_2 production because of the PV system implementation.

CHAPTER 8
CONCLUSION AND FUTURE WORKS

8.1 Conclusion

Through this thesis, the possibility of integration of PV panel with Dhaka city roadway infrastructures is explored. For the study, three types of structures are chose: foot over-bridge, flyover and metro rail station. Data was gathered through the help of PVsyst 7.3 and Google Earth Pro software and simulation was performed, from which yearly energy profile, loss profile, economic evaluation and carbon balance was calculated to determine how much energy is produced from the system on yearly basis, how feasible it is economically, and how much beneficial it will be environmentally.

From the result, we are able to draw a conclusion about whether one structure type is more suitable than the other to install PV panels.

TABLE 8.1. COMPARISON CHART FOR THREE STRUCTURES

Structures	Foot Over-Bridge	Flyover	Metro Rail Station
Yearly Energy into Grid (kWh)	45965	90068	949204
System Loss (%)	12.7	7.5	6.8
Payback Period (years)	14.5	6.9	7.4
Return on Investment (%)	33.4	125.4	112.7
Carbon Balance (ton)	482.098	1224.33	11019.139

From the table, it is clear that flyovers are the best structure type to install PV system among the three in terms of payback period. Flyovers have the advantage that they receive nearly unobstructed sunlight. From the analysis performed by Google Earth Pro software, it was noticed that they have significantly higher ground clearance, away from very large buildings and trees (which would cause significantly higher shading loss and impede the view of vehicles at sharper turns), and large surface area, all of which equals higher output rate.

However, in terms of system loss, Metro Rail Station is the best Structure type to install PV panel. Because, from the analysis performed by Earth Pro software, they have very large surface area for comparable amount of length capable of bearing PV systems (4368 m^2 vs 400 m^2 & 334 m^2) and have above average height, thus have less shading loss for same structure length, resulting in low overall system loss.

In all of the cases, Foot Over-Bridges are the worst structure types to install PV panels due to larger system loss and payback period. The reason can apparently be attributed to lower ground clearance (more shading loss due to tall structures) and lower surface area, thus increasing loss due for the individual systems.

8.2 Future Works

This thesis mainly dealt with on-grid system and no energy-storing element (battery) was considered for the simulation to maintain the cost-effectiveness as using and maintaining energy storing element to store some or all of the energy produced in the system would add bigger cost for the overall project, which might not be feasible considering the project lifetime. But, in future, battery storage elements can be implemented into the system, at least on a smaller scale, to evaluate if providing power from the system at night time can be economically feasible or not.
Bifacial modules may also be incorporated into the system in future, as they are more efficient in harnessing solar energy. During economic analysis, many variables such as labor cost, maintenance cost were ignored to get a comparative idea about the three structures. They can be added in future to get a more accurate economic estimation.

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