ROOFTOP SOLAR POWER POTENTIAL OF A MUNICIPAL AREA IN BANGLADESH

A Thesis report is submitted in partial fulfillment of the requirements for the award of Degree of Bachelor of Science in Electrical and Electronic Engineering.

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DECLARATION

We hereby declare that this thesis "**Rooftop solar power potential of a municipal area in Bangladesh**" represents our own work which has been done in the laboratories of the Department of Electrical and Electronic Engineering under the Faculty of Engineering of Daffodil International University in partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical and Electronic Engineering, and has not been previously included in a thesis or dissertation submitted to this or any other institution for a degree, diploma or other qualifications. We have attempted to identify all the risks related to this research that may arise in conducting this research, obtained the relevant ethical and/or safety approval (where applicable), and acknowledged my obligations and the rights of the participants.

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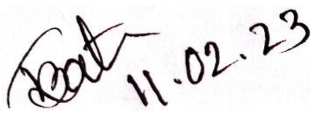
APPROVAL

The project entitled **"Rooftop solar power potential of a municipal area in Bangladesh"** submitted by **Tahzib Hamim (ID:191-33-5029) & Md. Iqramul Hossain Jahlak (ID:191-33-4975)** has been done under my supervision and accepted as satisfactory in partial fulfillment of the requirements for the degree of **Bachelor of Science in Electrical and Electronic Engineering** in **February, 2023.**

Signed



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Dedicated

To

Our Parents & Teachers

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LIST OF ABBREVIATIONS

GDP	Gross Domestic Product
PV	Photovoltaic
GIS	Geographic Information System
RS	Remote Sensing
DEM	Digital Elevation Model
DSM	Digital Surface Model
BFA	Building Footprint Area
PVA	Photovoltaic-Available Roof Area
DNI	Direct Normal Irradiation
DHI	Diffuse Horizontal Irradiation
GHI	Global Horizontal Irradiation
ERSI	Environmental Systems Research Institute
PR	Performance Ratio

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ABSTRACT

A dependable, inexpensive, and secure energy source is essential for socioeconomic development of a country. As a country experiencing a severe power shortage, Bangladesh is eager to develop its renewable energy sources in addition to its usual fossil fuel sources. It has very limited nonrenewable energy sources, but renewable energy sources such as biomass, wind, hydro, and sun insolation are abundant. Bangladesh is a south Asian small country with a large population. As a result, it has a problem of land shortage but due to its geographical location Bangladesh is boon to solar insolation. So, rooftop solar panels would be the best solution to reconcile the electricity demand. The following research paper is based on the rooftop solar potential of a municipal area in Bangladesh. To estimate the potential a four-step methodology has been followed: 1) Irradiation estimation, 2) Area estimation, 3) PV modules technology efficiency estimation, 4) Performance ratio. A total irradiation of 4.65 kWh/ m^2/day has been estimated through PVsyst and solar electricity handbook. A total area of 48000 m^2 with 532 buildings has been estimated through ArcGIS software. System efficiency for different types of PV technology such as mono-Si(22.44%), poly-Si(18.13%), a-Si (11.96%), CdTe (17.15%) has been shown. Among them, mono-Si is the most preferable. Inverter efficiency is also an important factor in estimating solar potential. In general inverters' conversion efficiencies range from 97% to 99% for best output 98% of inverter efficiency has been chosen. The performance ratio for Asia region is ranged between 84%-86% and for best performance, 86% of PR value has been taken. Finally, it is shown that a total potential of 15739 MWh has been found for mono-Si PV panels.

Keywords: Solar Potential, PVsyst, ArcGIS, Efficiency, Performance Ratio.

CHAPTER 1

INTRODUCTION

1.1 Introduction:

Bangladesh is a country in South Asia with a total land area of 148,460 square kilometers (57,320 sq. miles). The country is eighth on the list of the most populous countries in the world, with a population of 162 million [1]. The nation again has very few natural resources. Nevertheless, despite these limits, the country's economy continues to expand daily. Bangladesh's GDP growth rate for the last 10 years has been 6.5%, transforming the country into a middle-income country by the end of 2015, and has since increased to 8.15% in 2019 [2]. Furthermore, Bangladesh contributes 0.58% of global GDP, with a GDP of 302.57 billion US dollars estimated by the World Bank in 2019 [3]. This remarkable economic growth is due to the expansion of industries, particularly export-oriented businesses, and the creation of new jobs. On the other hand, the country's advancing economy and vast population have a significant impact on its energy needs. Bangladesh still has a lower per-capita energy use than other South Asian nations [4]. Additionally, Bangladesh uses 33 kWh less electricity per person than any developed nation like: USA (11,730 kWh) [5] [6]. Even in major cities and other industrial locations, residents often see a steady decline in power supplies. Besides, Bangladesh is also following the developed countries to reduce its carbon emission from the atmosphere enhancing the usage of its renewable energy sources for the generation of electricity. The government of Bangladesh has already taken numerous efforts in this direction, and solar energy is one of them.

Particularly, the direct conversion of sunlight into electricity using solar photovoltaic (PV) technology has significant untapped potential and promises a theoretically feasible and sustainable solution to the world's energy needs. For utility planning, accommodating grid capacity, deploying finance plans, and creating future adaptive policies, understanding the rooftop PV potential is essential. Nonetheless, the maximum energy potential if PV is installed on every suitable roof in a region is unclear due to the lack of data regarding roof area in the majority of regions. Besides, irradiation, performance ratio and efficiency are also a great concern.

To address these issues, this study will demonstrate a system that combines geographic sampling with object-specific image recognition to assess available rooftop area for PV deployment in Narayanganj, a municipal area of Bangladesh. It will use the ArcGIS Feature Analyst extension to create powerful feature classification algorithms for extracting rooftop features from batches of high-resolution digital orthophotos. It will also demonstrate the simplest technique to locate a construction shapefile. An estimation of rooftop PV potential will be generated based on total roof area, taking into account parameters such as average solar insolation in the region, PV panel efficiencies and performance ratio.

This study focuses on determining the total area of suitable rooftops, assessing the PV potential of a region, and demonstrating the contribution of solar PV panels to carbon emission reduction.

1.2 Global Potential of Rooftop Solar PV:

The sun is undoubtedly the most powerful energy source. Everywhere on Earth, there is solar energy. Nowadays, coal, natural gas, oil, nuclear, wind, and hydro power are the main energy sources used to produce electricity. For a number of reasons, solar energy is more preferable than fossil fuels. Most of the region of Asia and the Pacific are good places for solar PV technology, which is also a low-carbon way to get energy. Many countries in the region have the right conditions for using solar energy because large parts of the area get a lot of sunlight. Solar PV panel can be used to convert this large amount of sunlight into electrical energy. Most PV systems fall into one of two categories. Utility-scale installations are the first type. They usually have a capacity of more than 1 MW. They need a lot of open land with little shade. The second type is called distributed generation and it can be set up on the ground or on roofs. During the day, they make electricity and send any extra power back into the power grid. Small systems of up to 20 kW are usually enough to power a home. Larger public, commercial, and industrial buildings may have systems with a capacity of up to 1 MW [7].

Solar energy is becoming more popular around the world due to its low cost and eco friendliness. Photovoltaic(PV) solar arrays are expected to produce 5% of the world's electricity by the end of 2021, a small but growing share. Experts estimate that countries throughout the world installed between 133 and 175 GW of new solar power in 2021, with another 200 GW expected by the end of 2022 [8]. Solar also has enormous growth potential. According to a World Bank 2020 research, nearly every country in the world has the appropriate combination of geographic circumstances, weather, and sunlight to generate all of the electricity it requires and more using solar power installations located within its boundaries [8].

Table 1.2(a) shows the top 10 countries that produce the most solar PV capacity in MW by the year 2021.

Table 1.2(a): Top 10 Countries that produce the most solar PV capacity in MW [8].

Country	Production (MW)
China	306,973
United States	95,209
Japan	74,191
Germany	58,461
India	49,684
Italy	22,698
Australia	19,076
South Korea	18,161
Vietnam	16,660
Spain	15,952

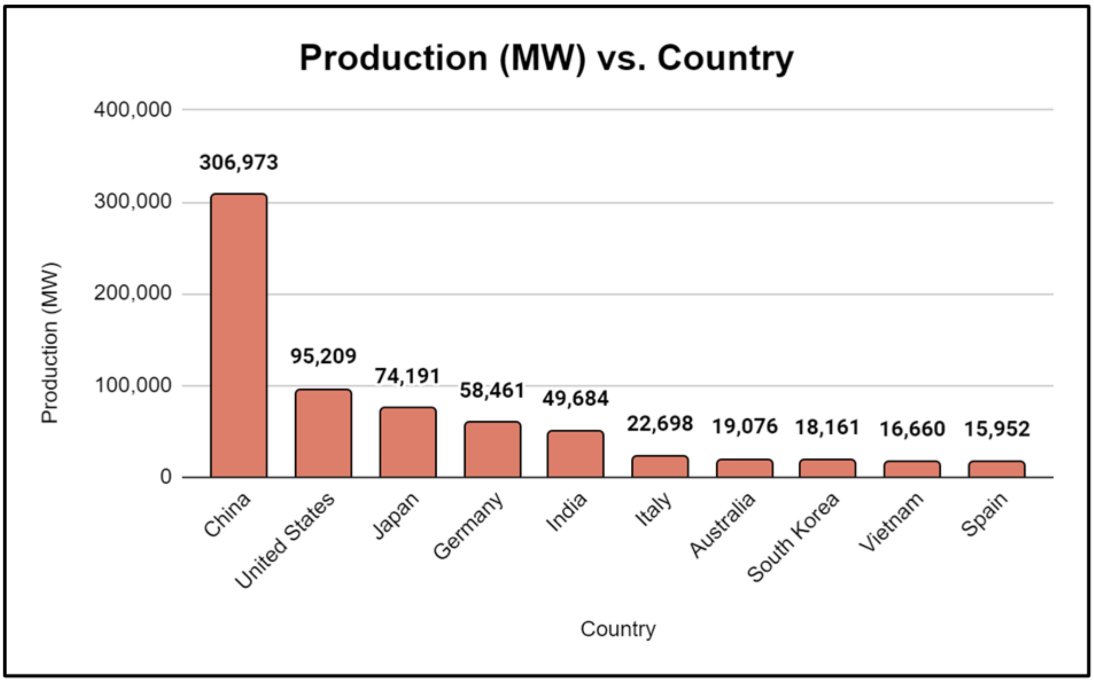

Figure 1.2(b): Top 10 countries that produce the most solar PV capacity in MW[8].

Table 1.2(c) shows Top 10 nations with the highest solar energy inclusion rates (2021 IEA).

Table 1.2(c): Top 10 countries with the highest percentage of solar PV capacity[8].

Country	**Production (%)**
Australia	15.5
Spain	14.2
Greece	13.6
Honduras	12.9
Netherlands	11.8
Chile	10.9
Germany	10.9
Japan	9.4
Italy	9.3
Israel	8.9

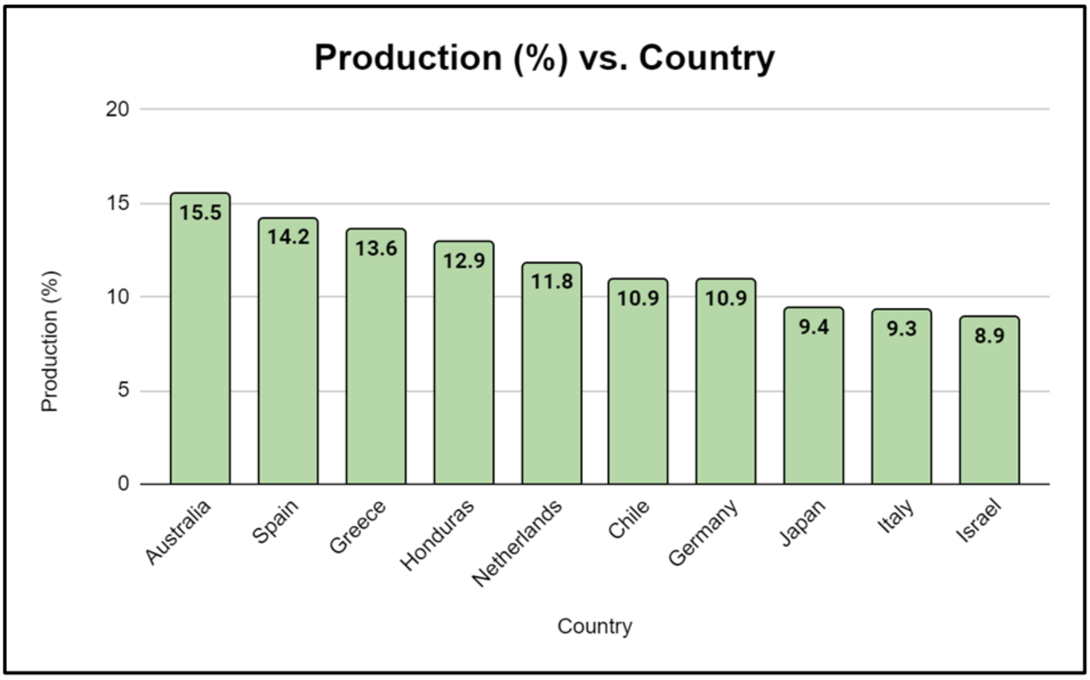

Figure 1.2(d): Top 10 countries with the highest percentage of solar PV capacity[8].

So, it can be clearly understood that solar energy is the best alternative to fossil fuel and it is the most sustainable and available renewable energy. If we utilize the solar energy on our roofs it will be beneficial for both our country and the world.

1.3 Objectives:

The main objective of this study is to estimate the total suitable rooftop area which will be utilized to estimate the rooftop solar potential, finding the solar irradiation, analyze the PV panel efficiency for different types of solar PV technologies, discussing the performance ratio and finally estimate the solar potential in an easiest method. This paper also discussed the contribution of PV panels in carbon emission reduction.

1.4 Research Questions:

Several questions about the work arise during the course of the study. The following are the main research questions:

- Why is it necessary to know rooftop solar potential?
- How to estimate solar irradiation?
- How to collect shapefile data?
- How to run the required files in ArcGIS?
- How to estimate the amount of CO_2 emission reduction?

CHAPTER 2

LITERATURE REVIEW

2.1 Research Background:

Numerous studies by scientists from all over the world have proven the efficacy by using GIS tools and techniques to estimate rooftop PV potential using various algorithms and models. Brito et al. (2011) and Luka et al. (2012) assessed rooftop solar potential by constructing 3-D GIS-based models utilizing remote sensing (RS) technology [9]. As inputs for sun irradiance measurement, digital elevation models (DEM) were constructed using LiDAR point measurements. In addition to RS and GIS, Wong et al. (2016) evaluated the citywide PV potential in Hong Kong by incorporating current supplementary data [10]. They initially utilized LiDAR data to generate DSM and DEM as inputs, then constructed a sun radiation map using the Solar Analyst extension module of ArcGIS. J. Khan and M.H. Arsalan (2016) emphasizes strategies for combining geographic information systems (GIS) and object-based image recognition to identify the accessible rooftop area for PV deployment in a small-scale location of DHA Phase 7 Karachi [11]. R. Singh and R. Banerjee (2015) proposed an approach for calculating a region's rooftop solar photovoltaic potential. The methodology has been implemented and presented for Mumbai, India (18.98°N, 72.83°E) [12]. It estimates the Building Footprint Area (BFA) Ratio using publicly accessible high-granularity land use data and GIS-based image analysis of sample satellite photos. The Photovoltaic-Available Roof Area (PVA) Ratio was calculated using PVsyst simulations and compared to relevant values from the literature. Data on solar irradiation (DNI and DHI) and ambient temperature were obtained from the Climate Design Data 2009 ASHRAE Handbook. The effect of tilt angle on the received plane-of-array insolation has been examined to determine the optimal tilt angle.

It is important to note that none of the published research has addressed the use of GIS tools and techniques for the evaluation of rooftop PV potential in Narayanganj, Bangladesh. With millions of urban dwellings and a lack of available electricity for its residents, Narayanganj has a tremendous potential for rooftop PV systems.

2.2 Softwares:

In this analysis, two key softwares are used to estimate the solar potential: 1) PVsyst and 2) ArcGIS pro. PVsyst is used to estimate irradiation, and ArcGIS Pro is used to estimate suitable area.

The details about these softwares are illustrated below:

2.2.1 PVsyst:

PVsyst is a program used for modeling solar systems. One of the primary considerations during solar plant design is the expected output, which can be broken down into three categories: total annual output, monthly output, and even daily output in some cases.

When it comes to solar panel layout programs, PVsyst is up there with the most popular options. There are a number of solar design simulation programs available today, including Helioscope, Aurora, and PVsyst, with the latter being one of the oldest and most widely used. For larger utility-scale projects, PVsyst delivers excellent results and is thus highly recommended.

- **Data Source of PVsyst:**

  PVsyst's built-in source of meteorological data is the program METEONORM. This program provides monthly meteorological data for nearly every location on the planet, and if no other source is explicitly specified, PVsyst will use this source by default. It is also possible to select satellite data from the NASA-SSE project as an alternate data source. In addition, PVsyst provides easy access to a number of publicly accessible Web resources, including SolarGIS and Satellite, among others. Self-measured data and data from other providers, such as national meteorological offices, can also be imported from text files using a tool that can accommodate various data formats.

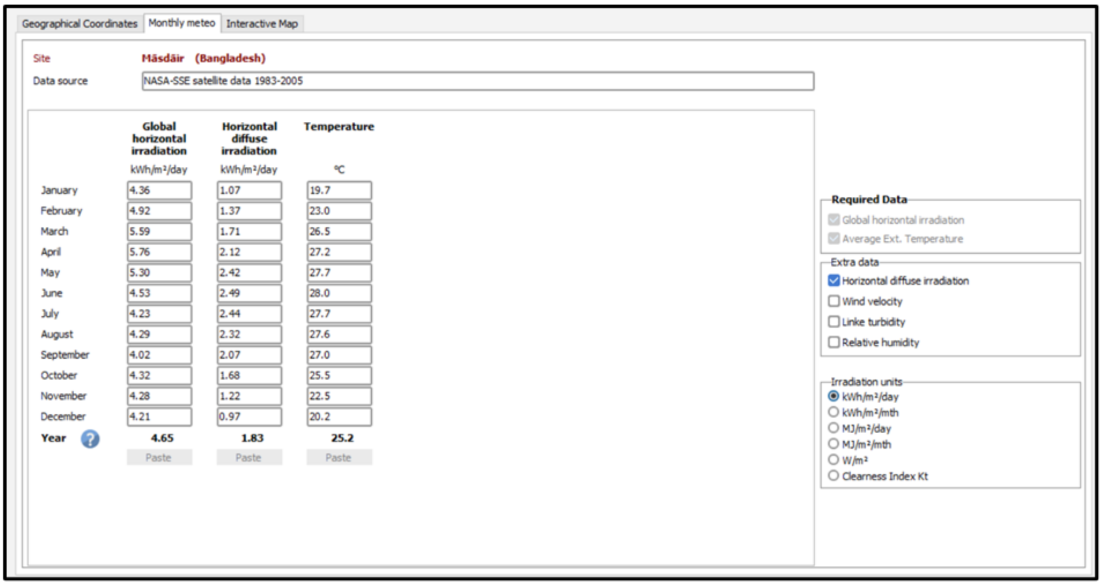

Figure 2.2.1(a): NASA-SSE satellite data in PVsyst.

- **Solar Irradiation by PVsyst:**

PVsyst was a fantastic platform that provided solar irradiation based on the latitude and longitude of any location. PVsyst has estimated solar irradiation using various types of **"Meteo Data"** such as **"Meteonorm 8.1" "NASA-SSE" "PVGIS TMY" "Solcast TMY" "NREL"** and so on.

This system provides irradiations in various units such as **kWh/m²/day, kWh/m²/mth, W2/m², MJ/m²/day, MJ/m²/mth**, and so on.

The required solar irradiation data in the **kWh/m²/day** unit is required to estimate the solar potential.

The estimated solar irradiation in this analysis is also known as global horizontal irradiation, and it is estimated for **tilt angle** and **azimuth** angle of **0 degree**.

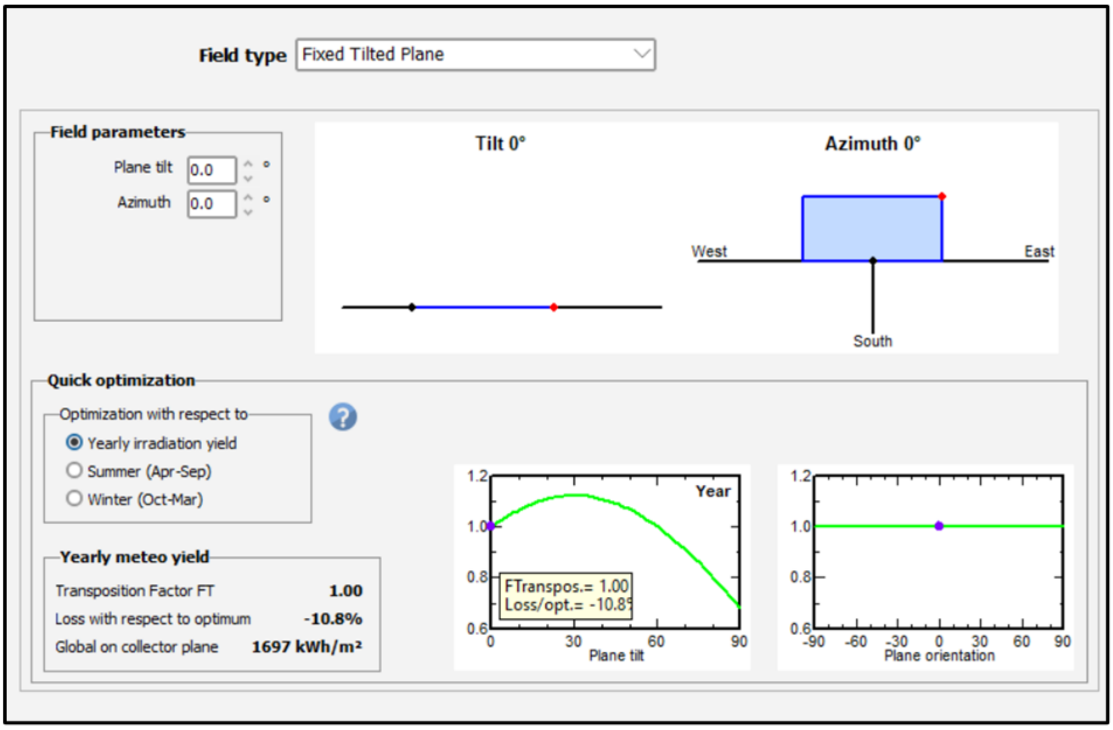

Figure 2.2.1(b): Tilt and Azimuth angle in PVsyst.

2.2.2 ArcGIS:

ArcGIS from ESRI is a robust and adaptable GIS platform. It's a strong and adaptable framework for developing functional GIS that runs on a comprehensive software platform. ArcGIS is composed of four major software components: a geographic information model for modeling aspects of the physical world; components for storing and managing geographic information in files and databases; a set of out-of-the-box applications for creating, editing, manipulating, mapping, analyzing, and disseminating geographic information; and a collection of web services that provide content and capabilities (data and functions) to networked software clients. ArcGIS software may be used on smartphones, tablets, desktop computers, and even servers.

- **Overview of ArcGIS:**

  The core of the ArcGIS system is referred to as Arc/Info and consists of the programs Arc, ArcEdit, and ArcPlot (Figure 1.10). These programs utilizes the coverage data model and construct a database program called INFO that appears primitive today. All of the programs are command-based, which means that the user type commands into a window to operate them.

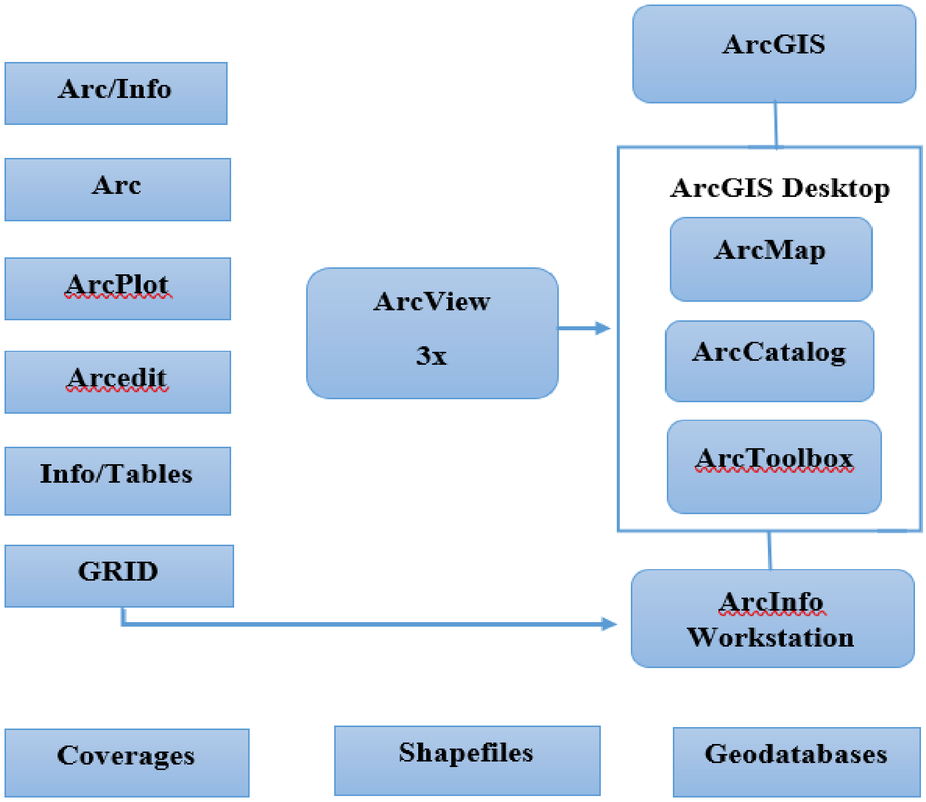

Figure 2.2.2(a): Relationship between Esri products and data format.

In addition, ArcGIS Desktop includes ArcToolbox, which is a collection of tools and functions for performing operations in ArcCatalog and ArcMap. These operations include converting between different data formats, managing map projections, and carrying out analyses. Users have the ability to create and add their own customized tools or scripts to accomplish specialized or frequently used tasks. Downloadable scripts and tools can be found in abundance on the ESRI website, which can be accessed at www.esri.com. These can be used to extend the capabilities of ArcGIS.

- **Data Files in ArcGIS:**

ArcGIS is capable of reading a wide range of file types. These are mostly left over from previous software iterations. Some may be imported from external applications like picture editing software or CAD programs.

Many of the data sets that can be utilized in ArcGIS are listed in the table 2.2.2(b).

Table 2.2.2(b): Types of files and data sources used by ArcGIS.

File Type	Description
Shapefiles	The early version of AreView was responsible for the development of the vector feature classes known as shapefiles, which have since been incorporated into ArcGIS.
Coverages	The oldest of the available data formats is called a coverage and it was the vector data format that was designed for Arc/Info.
Geodatabases	Geodatabases are an altogether new model for the storage of spatial information, and they come with a number of additional features.
Database Connections	Users are able to log in to an RDBMS geodatabase and use the data because the database connections allow them to do so. Geodatabases are an altogether new model for the storage of spatial information, and they come with a number of additional features.
Layer Files	A layer file contains information on the properties of a feature class, such as how it should be displayed.
Rasters and Grids	Thematic maps and images can be represented by arrays of numbers in binary format, which are called "rasters" (base 2). The Spatial Analyst add-on makes use of a specialized raster format called a "grid."
Tables	Tables are able to exist on their own as distinct data objects that are not connected to any particular spatial data set.
Internet Servers	A growing number of companies now make their data accessible over the internet. Users are able to connect to these data sources and download information that can assist them in their work.
TINs	TINs are Triangulated Irregular Networks that utilize nodes and triangles to hold JD surface information, like as elevation.
CAD Drawings	ArcGIS has the ability to read data sets that were produced by CAD systems; however, in order to edit or analyze these data sets, they must first be transformed to either shapfiles or geodatabases.

- **Application of ArcGIS:**

As a market-leading platform, the suite of applications and tools at the heart of this program is utilized by the vast majority of businesses, institutions, and departments engaged in geographic information analysis. However, the simplicity of its interface has also increased its value in the media and journalism.

ArcGIS has a solid reputation and a long history. This simple fact makes it an essential piece of software for businesses that deal with geographic information systems. It is utilized by state and local governments worldwide, including the United States.

- **Introduction to ArcMap:**

ArcMap is the tool for creating, viewing, querying, editing, composing, and publishing maps. Most maps present several types of information about an area at once.

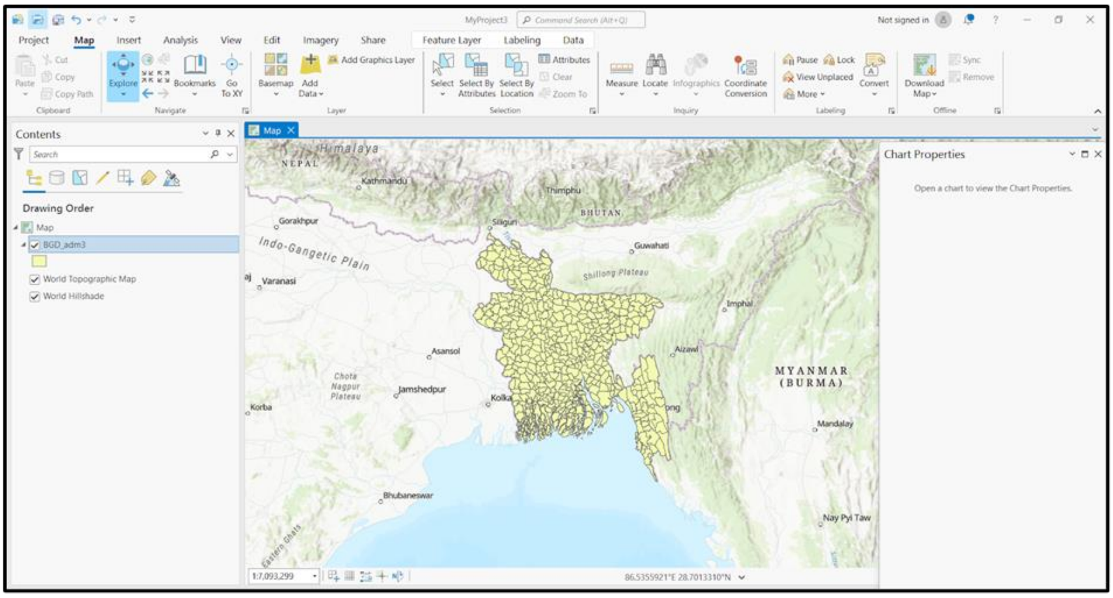

Figure 2.2.2(c): An overview of ArcMap.

ArcMap is basically used for estimating rooftop solar potential if the estimating area has **"lidar data"**.In this analysis, for Bangladesh there is no lidar data provided by the government or any organization. That's why it was difficult to estimate solar potential by arcgis.

On the other hand, ArcGIS has a variety of useful applications, one of which is area estimation. ArcGIS is used in this paper to estimate the suitable area.

ArcGIS area estimation is fairly simple if the building footprint shapefile is open as an input. The process is then simplified by performing geometry calculations on the attribute table of the building footprint shapefile.

According to Esri analysis, areas larger than 30 m² are more suitable for panel installation, which is also measured by the **"Layer by Attribute Tool"** if a required expression with an area greater than **30 m²**. And the actual rooftop area size for PV installation is 50% of the suitable area [13] [14].

- **Rooftop Potential by ArcMap:**

If lidar data or DSM data are available for a given region, estimating the rooftop potential using ArcMap is quite simple. ArcMap is also used to estimate the suitable area and solar irradiance, and these values can be used to calculate the rooftop solar potential.

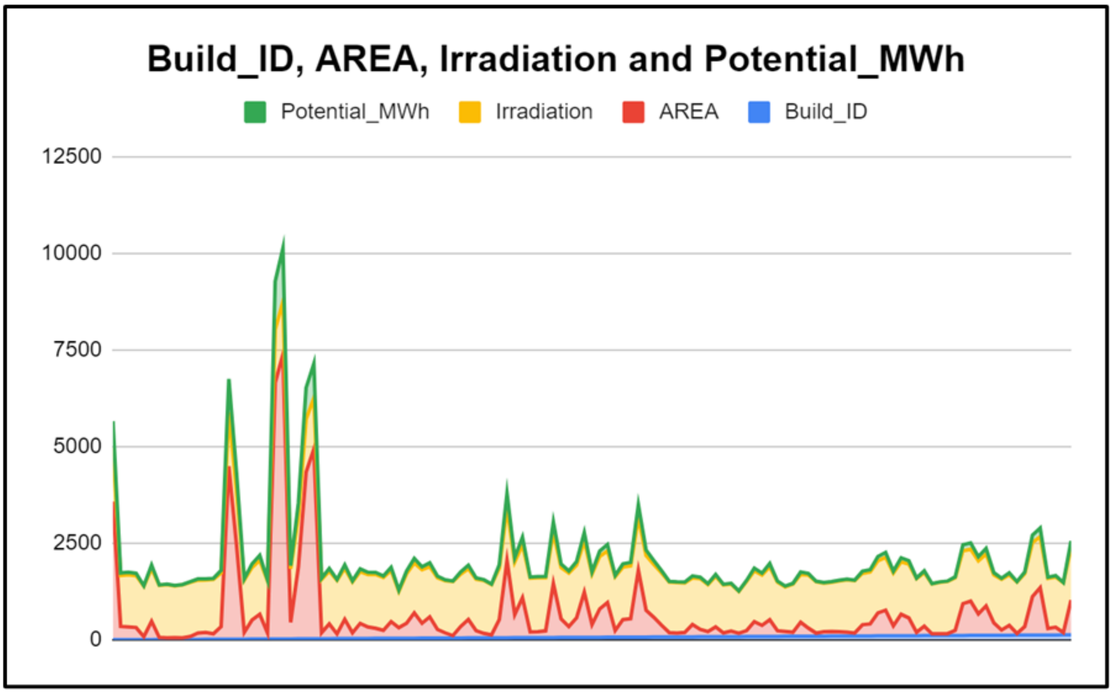

Figure 2.2.2(d): An overview of different types of output features of ArcMap.

CHAPTER 3
RESEARCH METHODOLOGY

3.1 Methodology:

To calculate the rooftop solar potential, four important elements must be estimated. The first is irradiation, followed by correct area estimation, efficiency, and performance ratio. Estimating rooftop solar potential is described in detail in the section that follows. Methodology is shown figure 3.1:

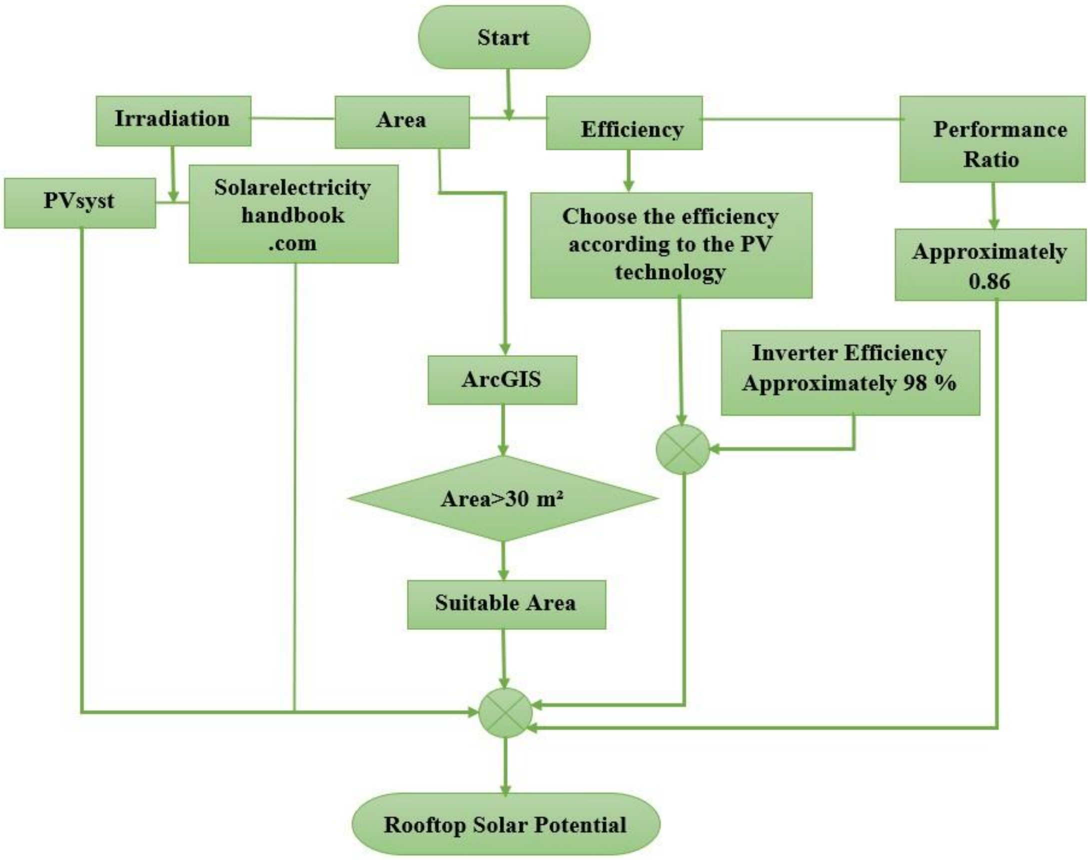

Figure 3.1: Flow Chart of Methodology.

3.1.1 Irradiation Estimation:

Irradiation is measured using two methods: 1) PVsyst and 2) SolaElectricityHandbook.com

In the PVsyst technique, select the values of latitude and longitude from Google (wikipedia.com). The data is then entered into PVsyst. This software provides us with ROI (region of interest) irradiation data.

The method of using solarelectricityhandbook.com website also can calculate the irradiation simply by putting our desired location and solar panel direction into a particular section of the website which is discussed below.

- **Process for PVsyst:**

Step one in PVsyst's procedure is to obtain the latitude and longitude information from Google. Initiate the PVsyst software. Simply select "database" from the list of **“Utilities”** to get started. An additional window will open. Then in this new window under ‘**New Meteodata**’ section choose **“ Geographical Sites”** . Now click on the **“New”** option. A new window named **“Geographical Site Parameters”** will open. Now enter the latitude and longitude value (23.6238° N, 90.5000° E) in the **“Locality”** field. Just pick **“Accept the specified point”** and move on. The **"Geographical Coordinates"** pane will now open. Select **NASA-SSE** from the list of **“meteo data import”**. Import the data. Make the selection of irradiance in **kWh/m²/day**. Finally, save the data.

Table 3.1.1: Average Irradiation per day.

Month	Global Horizontal Irradiation kWh/m²/day
January	4.36
February	4.92
March	5.59
April	5.76
May	5.3
June	4.53
July	4.23
August	4.29
September	4.02
October	4.32
November	4.28
December	4.21
Yearly	4.65

The second method is using a website named Solar electricity handbook.com

- **Process for Solar electricity handbook:**

To view the sun irradiance data by this method, please visit the link:

(http://www.solarelectricityhandbook.com/solar-irradiance.html)

Choose the nation for which to estimate the solar irradiance. Choose any desired city. To set the orientation of the panel, select "**Directly South**" After the wait is finished, the required information has been obtained. Remember to note down the details.

3.1.2 Actual Suitable Area Estimation:

To calculate the area, first generate a building shapefile from (https://extract.bbbike.org). The shapefile is then opened in **ArcGIS Pro** (the rooftop has been shown as red). The "**attribute table"** of this shape file is then selected. Then add a **new field,** renamed by **area**, and save it. Then, from the **attribute table**. Select the area column and then **calculate geometry**. In the unit section, Choose the **square meter** unit and run the file.

Figure 3.1.2(a): Total Rooftop Area.

Now to determine the size of the suitable area on each building's rooftop, use one more criterion to determine the suitability of solar panels. If a building has less than 30 square meters of suitable roof surface, it is generally not suitable for solar panel installation because the installation investment is not worth it. Using the Select Layer By Attributes tool, will be found the buildings with enough suitable roof surface. Confirm that building shapefile is selected in the "Select By Attributes" window for "Input Rows". Also confirm that New selection is selected for Selection type. Create an expression where the **area is greater than or equal to 30** [13].

Right-click on the building shapefile in the **contents pane**, point to Data, and select **Export Features**. Confirm that "**Building Shapefile**" is selected for Input Features in the Export Features window. Enter "**suitable buildings**" as the **Output Feature Class**.

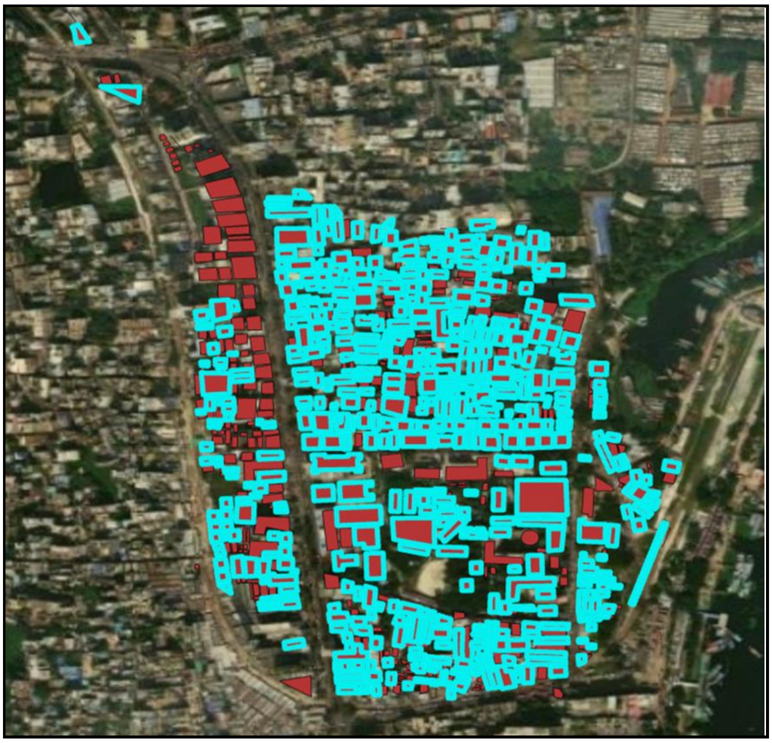

Figure 3.1.2(b): Suitable rooftop area.

After completing the entire process the suitable area is shown in Figure 3.1.2(b) (blue bordered buildings).

At this time, only **half of the entire area** that would be appropriate for PV installation is being utilized on the rooftop [14].

3.1.3 Panel Efficiency:

The efficiency of a PV module used to produce solar power is a major factor in determining the rooftop PV potential. As a result, picking a solar panel with high efficiency and good performance is crucial. PV panels range in efficiency and performance based on the technology and materials used in their production. The table below highlights the efficiency of several PV panel types to illustrate several solar power generation scenarios for return on investment.

Table 3.1.3: Efficiency of different types of solar PV technologies [15].

Name of Solar Panel	Efficiency (%)
Mono-crystalline Si	22.9
Poly-crystalline Si	18.5
Amorphous Si	12.2
Cadmium-Telluride Cells	17.5

3.1.4 Inverter Efficiency:

The inverter converts direct current (DC) electricity into alternating current (AC), which results in the loss of some energy in the form of heat. Inverters for higher-quality solar power are more efficient, meaning they can convert a greater quantity of electricity without suffering significant losses in the process.

Inverters' conversion efficiencies range from 97% to 99%, depending on the making and model, therefore the amount of energy lost is negligible. However, the efficiency of the energy system can be affected by shade and other variables, and the photovoltaic inverter can help to reduce those effects [18].

3.1.5 Performance Ratio:

The performance ratio (PR) is a percentage that compares the PV plant's actual energy output to its predicted output. The performance ratio also informs about how energy efficient and reliable your PV plant is.

The performance ratio (PR) can be anywhere from 60% to 90%, with around 90% being very common in Germany, according to (learn.arcgis.com) 84%-86% very common in Asia and South Africa, and 71%-72% being very common in Malaysia[16].

CHAPTER 4

RESULT AND DISCUSSION

4.1 Experimental Results & Analysis:

According to the methodology for calculating the solar potential of rooftops, four crucial elements must be assessed. First is irradiation, then area estimation, efficiency, and performance ratio. Each calculated parameter is listed below in detail:

4.1.1 Global Horizontal Irradiation Calculation:

According to PVsyst NASA-SSE, the solar irradiation that Narayanganj receives on a daily basis is an average of 4.65 kWh/m²/day. As can be seen in the illustration below:

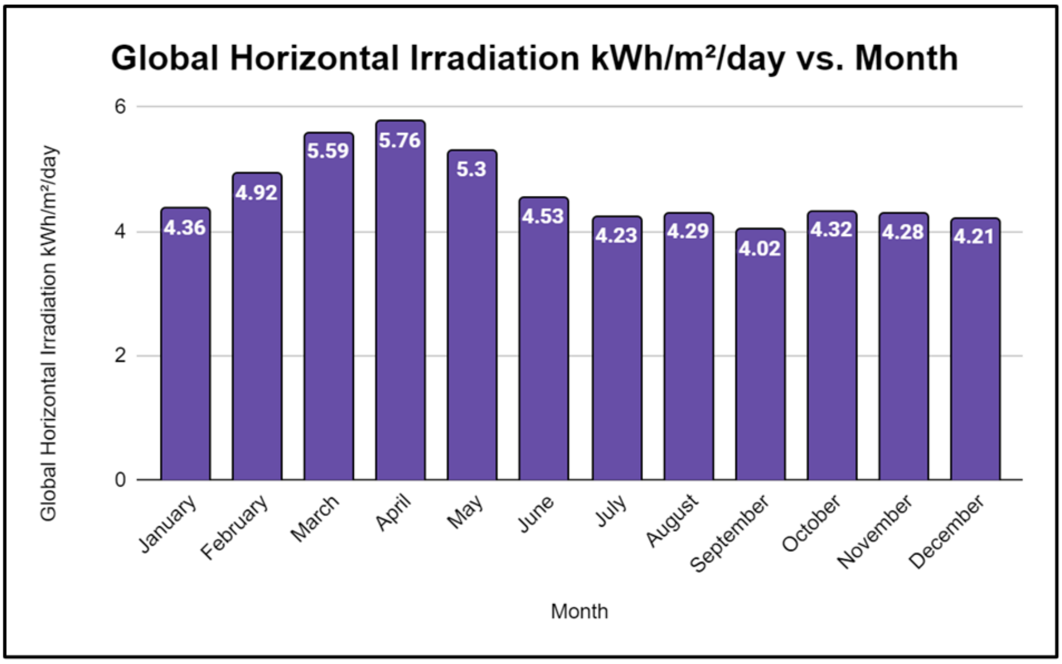

Figure 4.1.1: Global Horizontal Irradiation per day of Narayanganj

4.1.2 Actual Suitable Area Calculation:

Methodology suggests that areas larger than 30 square meters are optimal for solar panel installation. According to this, Narayanganj has a total adequate area of about 96,000 m² for 532 buildings. This can be seen in figure as well:

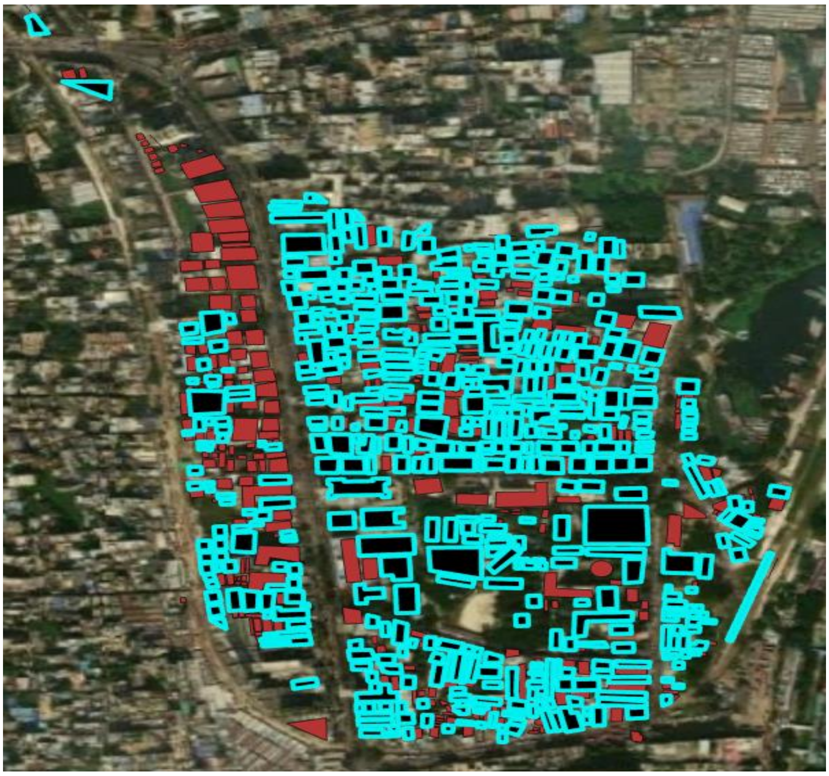

Figure 4.1.2(a): Suitable area of Narayanganj

Here, the black area with blue border represents the suitable rooftop areas of Narayanganj that are greater than 30 m².

On the rooftop, only **50 %** of the suitable area that may be used for PV panels has been put to use. That’s why the actual suitable area is about **48000 m²**.

The actual suitable areas for PV installation according to the number of building are shown in below table:

Table 4.1.2(b): Total actual suitable area according to number of buildings.

Number of Buildings	**Suitable Area (m²)**	**Actual Suitable Area (m²)**	**Number of Buildings**	**Suitable Area (m²)**	**Actual Suitable Area (m²)**
1	183.8111	91.90554	7	146.8469	73.42345
2	177.6404	88.8202	8	186.444	93.22198
3	103.1097	51.55485	9	45.41592	22.70796
4	52.49816	26.24908	10	94.72858	47.36429
5	79.40581	39.70291	11	181.7594	90.87968
6	42.69469	21.34735	12	193.0086	96.5043

Number of Buildings	Suitable Area (m²)	Actual Suitable Area (m²)	Number of Buildings	Suitable Area (m²)	Actual Suitable Area (m²)
13	54.34312	27.17156	38	272.3722	136.1861
14	56.42672	28.21336	39	1691.701	845.8503
15	100.8396	50.4198	40	162.4481	81.22406
16	35.90459	17.95229	41	112.6331	56.31653
17	34.16999	17.085	42	158.0191	79.00953
18	109.7931	54.89656	43	288.5921	144.2961
19	68.11351	34.05675	44	284.5653	142.2826
20	45.88277	22.94138	45	366.2239	183.112
21	37.95276	18.97638	46	354.194	177.097
22	269.6856	134.8428	47	166.0561	83.02807
23	97.73422	48.86711	48	500.4327	250.2164
24	115.9369	57.96844	49	222.601	111.3005
25	230.9256	115.4628	50	454.1212	227.0606
26	131.8826	65.9413	51	219.5095	109.7548
27	192.3706	96.18528	52	442.4489	221.2245
28	372.175	186.0875	53	794.638	397.319
29	262.6436	131.3218	54	129.8832	64.94161
30	72.10488	36.05244	55	219.8542	109.9271
31	70.59997	35.29998	56	154.5081	77.25405
32	189.765	94.88252	57	206.2716	103.1358
33	85.35113	42.67556	58	83.15456	41.57728
34	125.3591	62.67957	59	94.44688	47.22344
35	175.2924	87.64621	60	174.6057	87.30285
36	110.9054	55.45271	61	109.6512	54.82559
37	375.768	187.884	62	143.9488	71.9744

Number of Buildings	Suitable Area (m²)	Actual Suitable Area (m²)	Number of Buildings	Suitable Area (m²)	Actual Suitable Area (m²)
63	89.53687	44.76844	87	126.9745	63.48724
64	339.7501	169.875	88	67.09175	33.54587
65	116.5081	58.25406	89	78.54824	39.27412
66	162.7317	81.36584	90	98.29763	49.14882
67	283.0675	141.5338	91	36.45552	18.22776
68	59.86748	29.93374	92	107.9542	53.97708
69	206.8593	103.4297	93	286.8675	143.4337
70	128.4649	64.23244	94	155.8325	77.91623
71	168.4429	84.22145	95	215.5027	107.7513
72	297.8616	148.9308	96	252.2723	126.1361
73	65.05006	32.52503	97	178.8746	89.43728
74	55.02516	27.51258	98	135.6416	67.82078
75	256.3337	128.1669	99	96.24203	48.12101
76	116.1274	58.06368	100	177.7137	88.85687
77	292.9301	146.465	101	101.7167	50.85836
78	136.4759	68.23797	102	282.7346	141.3673
79	69.68507	34.84253	103	127.7337	63.86687
80	169.3689	84.68443	104	130.3971	65.19855
81	171.9686	85.98429	105	244.05	122.025
82	150.7289	75.36444	106	92.13617	46.06808
83	326.7267	163.3634	107	226.1668	113.0834
84	117.251	58.62548	108	111.5219	55.76093
85	138.9441	69.47206	109	310.0892	155.0446
86	88.63809	44.31904	110	162.2918	81.14589

Number of Buildings	Suitable Area (m²)	Actual Suitable Area (m²)	Number of Buildings	Suitable Area (m²)	Actual Suitable Area (m²)
111	331.0711	165.5355	135	111.2056	55.60282
112	209.5711	104.7856	136	124.4984	62.24921
113	230.0471	115.0236	137	89.38642	44.69321
114	71.82282	35.91141	138	161.5657	80.78284
115	553.5695	276.7847	139	128.8255	64.41273
116	155.8992	77.94958	140	223.789	111.8945
117	243.8863	121.9431	141	219.9233	109.9616
118	766.3522	383.1761	142	173.7627	86.88134
119	1253.872	626.9362	143	104.6163	52.30817
120	460.0377	230.0188	144	83.71867	41.85934
121	855.7566	427.8783	145	414.8551	207.4275
122	1084.523	542.2617	146	74.62514	37.31257
123	83.36057	41.68028	147	134.8109	67.40547
124	67.52322	33.76161	148	173.5209	86.76044
125	85.71654	42.85827	149	108.2775	54.13875
126	71.71863	35.85932	150	64.9217	32.46085
127	247.6865	123.8432	151	153.561	76.78048
128	634.4569	317.2284	152	223.8353	111.9176
129	135.1972	67.59859	153	95.46132	47.73066
130	165.3852	82.69258	154	513.8917	256.9458
131	241.4838	120.7419	155	150.7334	75.36671
132	107.0419	53.52096	156	177.6471	88.82355
133	90.60921	45.30461	157	259.3271	129.6636
134	76.30424	38.15212	158	38.17277	19.08639

Number of Buildings	Suitable Area (m²)	Actual Suitable Area (m²)	Number of Buildings	Suitable Area (m²)	Actual Suitable Area (m²)
159	120.7336	60.36681	183	102.0473	51.02364
160	281.8889	140.9445	184	196.0214	98.01069
161	147.9262	73.9631	185	177.8574	88.9287
162	203.5512	101.7756	186	403.3549	201.6774
163	198.7995	99.39974	187	139.3409	69.67046
164	159.108	79.55402	188	62.50942	31.25471
165	192.5455	96.27276	189	135.6858	67.84291
166	142.5481	71.27407	190	67.85453	33.92727
167	130.4853	65.24267	191	77.97562	38.98781
168	157.9711	78.98555	192	35.30903	17.65451
169	188.5545	94.27725	193	164.8861	82.44305
170	213.3259	106.6629	194	259.8704	129.9352
171	70.03138	35.01569	195	151.4717	75.73583
172	355.7814	177.8907	196	65.06283	32.53142
173	138.5781	69.28905	197	36.18613	18.09307
174	219.4362	109.7181	198	55.96953	27.98476
175	81.33368	40.66684	199	45.78193	22.89096
176	78.29507	39.14753	200	123.5466	61.77331
177	377.2939	188.6469	201	46.22949	23.11474
178	171.8333	85.91663	202	64.12009	32.06004
179	55.66358	27.83179	203	130.4999	65.24995
180	187.3052	93.65261	204	236.9358	118.4679
181	367.9723	183.9861	205	124.9761	62.48803
182	121.1257	60.56287	206	195.4191	97.70955

Number of Buildings	Suitable Area (m²)	Actual Suitable Area (m²)	Number of Buildings	Suitable Area (m²)	Actual Suitable Area (m²)
207	145.8862	72.9431	232	76.67903	38.33952
208	122.4939	61.24696	233	44.55744	22.27872
209	229.7463	114.8731	234	144.2042	72.10209
210	379.5591	189.7795	235	167.9811	83.99054
211	181.6095	90.80474	236	122.9137	61.45685
212	299.593	149.7965	237	247.7858	123.8929
213	282.0168	141.0084	238	227.3077	113.6539
214	239.1914	119.5957	239	147.5975	73.79877
215	338.6564	169.3282	240	175.4166	87.70831
216	152.8622	76.43109	241	85.64672	42.82336
217	187.5063	93.75316	242	152.4563	76.22815
218	125.1056	62.55281	243	100.475	50.2375
219	94.15361	47.0768	244	462.8028	231.4014
220	84.47746	42.23873	245	310.0928	155.0464
221	95.44635	47.72318	246	158.7705	79.38523
222	80.21272	40.10636	247	129.7733	64.88664
223	96.4975	48.24875	248	245.4692	122.7346
224	175.1104	87.55518	249	234.1291	117.0645
225	667.614	333.807	250	183.1644	91.58221
226	214.907	107.4535	251	221.0056	110.5028
227	204.0052	102.0026	252	128.8194	64.4097
228	243.6376	121.8188	253	66.41773	33.20886
229	202.4719	101.236	254	139.0882	69.54411
230	132.5485	66.27424	255	192.7928	96.3964
231	246.8622	123.4311	256	176.5983	88.29915

Number of Buildings	Suitable Area (m²)	Actual Suitable Area (m²)	Number of Buildings	Suitable Area (m²)	Actual Suitable Area (m²)
257	94.57342	47.28671	281	253.399	126.6995
258	182.8692	91.43459	282	279.2029	139.6014
259	86.13586	43.06793	283	78.62763	39.31382
260	130.4634	65.2317	284	207.8936	103.9468
261	117.6007	58.80035	285	157.9284	78.96418
262	98.92253	49.46126	286	148.6678	74.33388
263	152.9685	76.48426	287	54.26234	27.13117
264	129.8605	64.93026	288	83.1115	41.55575
265	143.4318	71.71589	289	162.2389	81.11946
266	49.45823	24.72911	290	343.9643	171.9821
267	61.77095	30.88547	291	179.3629	89.68147
268	75.84195	37.92098	292	133.673	66.8365
269	220.7739	110.3869	293	162.7019	81.35095
270	161.5819	80.79094	294	107.3107	53.65537
271	85.85605	42.92803	295	437.7595	218.8797
272	97.60334	48.80167	296	155.0982	77.54908
273	260.6711	130.3356	297	220.7078	110.3539
274	135.8899	67.94496	298	70.12223	35.06111
275	269.5514	134.7757	299	189.2798	94.63991
276	250.4307	125.2154	300	44.41794	22.20897
277	270.1012	135.0506	301	162.3913	81.19565
278	135.1394	67.5697	302	194.1173	97.05865
279	52.28069	26.14034	303	208.9947	104.4974
280	295.881	147.9405	304	137.1479	68.57395

Number of Buildings	Suitable Area (m^2)	Actual Suitable Area (m^2)	Number of Buildings	Suitable Area (m^2)	Actual Suitable Area (m^2)
305	252.298	126.149	329	38.24999	19.125
306	90.74216	45.37108	330	124.6807	62.34037
307	227.5491	113.7745	331	165.9321	82.96604
308	82.38096	41.19048	332	62.38861	31.1943
309	474.1547	237.0773	333	112.6943	56.34715
310	227.2405	113.6203	334	42.69032	21.34516
311	80.73198	40.36599	335	53.92191	26.96096
312	46.26647	23.13323	336	136.3567	68.17836
313	89.36567	44.68283	337	76.98773	38.49386
314	56.86907	28.43453	338	134.2205	67.11027
315	64.20861	32.10431	339	157.5799	78.78997
316	83.35849	41.67924	340	54.17126	27.08563
317	91.98042	45.99021	341	45.91809	22.95904
318	122.4222	61.21109	342	190.0239	95.01195
319	104.8494	52.42472	343	33.06033	16.53016
320	85.38424	42.69212	344	68.26941	34.1347
321	341.3797	170.6898	345	48.24581	24.1229
322	152.5613	76.28064	346	41.74773	20.87387
323	103.9818	51.99091	347	85.20478	42.60239
324	317.6201	158.8101	348	263.8861	131.943
325	157.034	78.517	349	68.08805	34.04403
326	133.6144	66.80718	350	143.0628	71.53139
327	186.0438	93.0219	351	151.2032	75.60158
328	54.43752	27.21876	352	139.3449	69.67244

Number of Buildings	Suitable Area (m^2)	Actual Suitable Area (m^2)	Number of Buildings	Suitable Area (m^2)	Actual Suitable Area (m^2)
353	142.4895	71.24475	377	425.4441	212.7221
354	138.7175	69.35877	378	2795.436	1397.718
355	111.1581	55.57907	379	391.9727	195.9863
356	329.9627	164.9814	380	92.51201	46.256
357	60.94171	30.47086	381	171.9733	85.98667
358	78.48326	39.24163	382	275.9333	137.9667
359	43.00396	21.50198	383	261.9035	130.9517
360	33.70745	16.85372	384	436.2232	218.1116
361	101.8739	50.93697	385	779.7162	389.8581
362	531.6231	265.8116	386	334.5778	167.2889
363	900.8574	450.4287	387	298.8111	149.4056
364	161.8332	80.91658	388	48.09065	24.04533
365	401.799	200.8995	389	99.37493	49.68747
366	263.8756	131.9378	390	61.19167	30.59584
367	140.9007	70.45034	391	88.6936	44.3468
368	138.5045	69.25227	392	226.746	113.373
369	61.25309	30.62655	393	358.5208	179.2604
370	270.2818	135.1409	394	276.9178	138.4589
371	51.93377	25.96689	395	245.3	122.65
372	384.6483	192.3241	396	118.9637	59.48187
373	413.6714	206.8357	397	330.9375	165.4688
374	129.525	64.76248	398	102.0156	51.00778
375	304.2125	152.1063	399	113.6656	56.83278
376	74.99926	37.49963	400	67.16677	33.58338

Number of Buildings	Suitable Area (m²)	Actual Suitable Area (m²)	Number of Buildings	Suitable Area (m²)	Actual Suitable Area (m²)
401	217.9016	108.9508	425	136.9672	68.4836
402	520.3301	260.165	426	54.97335	27.48668
403	714.8008	357.4004	427	117.094	58.54698
404	417.9077	208.9538	428	119.0304	59.5152
405	222.2722	111.1361	429	69.18191	34.59095
406	147.9407	73.97035	430	43.32229	21.66114
407	134.3017	67.15087	431	33.19619	16.5981
408	57.38868	28.69434	432	35.15657	17.57829
409	54.83117	27.41558	433	49.03813	24.51907
410	153.6002	76.8001	434	91.27767	45.63883
411	299.8646	149.9323	435	31.87379	15.93689
412	506.9121	253.456	436	84.29887	42.14944
413	956.4387	478.2193	437	100.1621	50.08107
414	127.2358	63.61789	438	38.74875	19.37438
415	37.62375	18.81187	439	34.73614	17.36807
416	102.7591	51.37953	440	73.65108	36.82554
417	49.26944	24.63472	441	260.9515	130.4758
418	30.42347	15.21173	442	354.5472	177.2736
419	192.2305	96.11527	443	92.8044	46.4022
420	192.311	96.1555	444	142.8225	71.41123
421	516.9339	258.4669	445	52.32182	26.16091
422	87.31376	43.65688	446	65.26979	32.6349
423	174.9412	87.47061	447	73.56968	36.78484
424	104.2681	52.13406	448	60.89331	30.44666

Number of Buildings	Suitable Area (m^2)	Actual Suitable Area (m^2)	Number of Buildings	Suitable Area (m^2)	Actual Suitable Area (m^2)
449	503.1188	251.5594	473	38.05179	19.0259
450	68.14562	34.07281	474	168.3292	84.16461
451	53.2952	26.6476	475	92.99062	46.49531
452	344.7609	172.3804	476	69.65991	34.82995
453	263.653	131.8265	477	32.19308	16.09654
454	127.8292	63.91462	478	91.1303	45.56515
455	172.0235	86.01177	479	41.44786	20.72393
456	171.8636	85.93179	480	288.5921	144.296
457	82.19433	41.09717	481	166.0564	83.02821
458	203.1535	101.5768	482	205.6529	102.8264
459	177.8116	88.90579	483	181.426	90.713
460	202.1357	101.0678	484	309.9035	154.9518
461	172.0604	86.03022	485	309.9955	154.9977
462	46.45513	23.22756	486	58.33381	29.1669
463	32.25371	16.12685	487	36.49429	18.24714
464	44.80365	22.40183	488	36.45554	18.22777
465	90.38805	45.19403	489	36.4943	18.24715
466	88.5354	44.2677	490	214.7442	107.3721
467	217.9018	108.9509	491	172.96	86.48001
468	64.21331	32.10665	492	94.78484	47.39242
469	94.84168	47.42084	493	247.6863	123.8431
470	213.3287	106.6644	494	114.704	57.35198
471	42.69029	21.34515	495	195.292	97.64602
472	42.69029	21.34515	496	57.44415	28.72207

Number of Buildings	Suitable Area (m²)	Actual Suitable Area (m²)	Number of Buildings	Suitable Area (m²)	Actual Suitable Area (m²)
497	57.47588	28.73794	515	43.68816	21.84408
498	57.47591	28.73795	516	38.67501	19.3375
499	122.7752	61.3876	517	87.66381	43.8319
500	257.4437	128.7219	518	44.06641	22.0332
501	154.5916	77.2958	519	76.92933	38.46466
502	91.04109	45.52054	520	107.5067	53.75335
503	89.29773	44.64887	521	56.61856	28.30928
504	92.69724	46.34862	522	104.934	52.46699
505	51.98599	25.99299	523	271.5605	135.7803
506	84.2041	42.10205	524	41.7988	20.8994
507	125.1056	62.55282	525	46.17299	23.0865
508	125.1057	62.55283	526	174.941	87.47048
509	84.47747	42.23874	527	206.2713	103.1357
510	84.47748	42.23874	528	138.7174	69.35869
511	213.4791	106.7395	529	138.718	69.35901
512	52.90248	26.45124	530	138.7178	69.35892
513	94.3703	47.18515	531	107.1597	53.57985
514	58.79366	29.39683	532	117.9016	58.95082
Total Areas				**96106**	**48053**

Total actual suitable areas are represented in graphically in below:

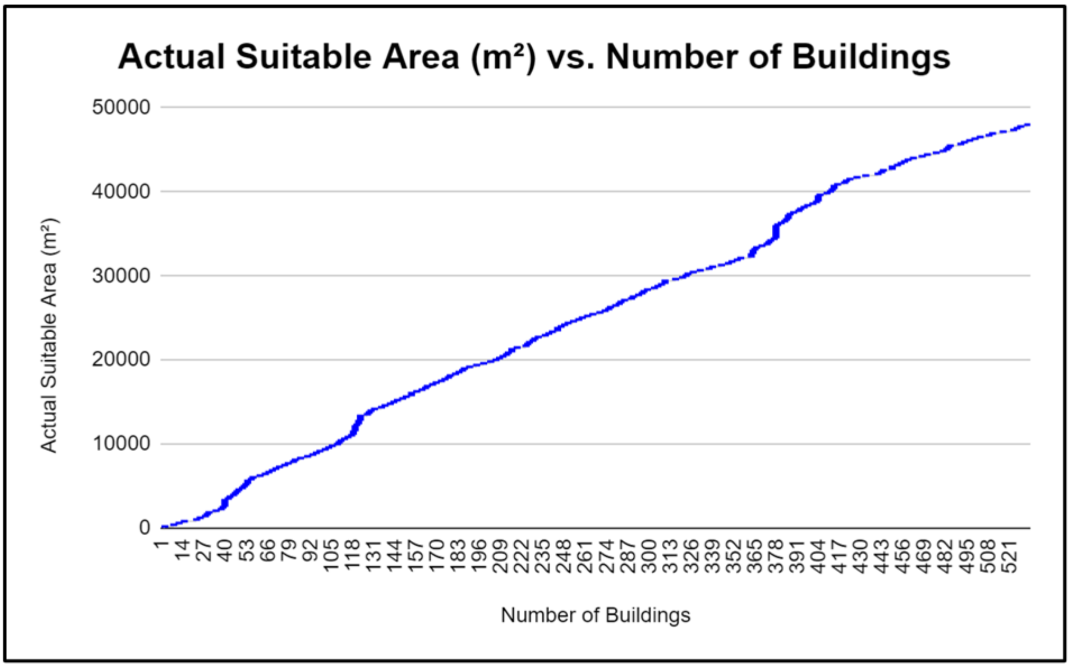

Figure 4.1.2(c): Graphical Representation of total suitable area of Narayanganj.

4.1.3 Efficiency Estimation:

Different types of PV technology have varying levels of efficiency, with the highest quality inverters achieving efficiencies between 97% and 99%. The inverter's efficiency has been chosen to be approximately 98%.

System efficiency is the combination of panel efficiency (η_{Pv}) and inverter efficiency (η_{inv}), system efficiency can be calculated as follows:

$$\eta = \eta_{Pv} \times \eta_{inv} \ldots\ldots\ldots\ldots\ldots\ldots [4.1.3(i)]$$

Table 4.1.3: Overview of efficiencies for four different types of PV technologies

Name of Solar Panel	Panel Efficiency (%)	Inverter Efficiency (%)	System Efficiency (%)
Mono-crystalline Si	22.9	98	22.44
Poly-crystalline Si	18.5	98	18.13
Amorphous Si	12.2	98	11.96
Cadmium-Telluride Cells	17.5	98	17.15

4.1.4 Performance Ratio:

The performance ratio (PR) can fall anywhere between 60% and 90%, with roughly 90% being fairly typical in Germany and 71%-72% being very common in Malaysia. The PR can also be negative.

Within the region of Asia, the performance ratio ranged between 84 and 86 percent. The PR value in Narayanganj was close to 86% during the time [16].

4.1.5 Solar Potential Calculation:

Taking into account all aspects, solar power potential (P) can be calculated as follows:

$$P = I_r \times A \times \eta \times PR \ldots\ldots\ldots\ldots\ldots\ldots [4.1.5(i)]$$

Here,

I_r = Global Horizontal Irradiation per day (kWh/m²/day)

A = Actual Suitable Area

η = Efficiency of the System

PR = Performance Ratio of Solar Panels.

For an annual energy output, solar power potential (P) can be calculated as follows:

$$P = I_r \times A \times \eta \times PR \times 365 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [4.1.5(ii)]$$

Solar potential for different types of PV technologies :

Table 4.1.5: Solar Potential of different types of Solar PV technologies.

Name of Solar Panel	System Efficiency (%)	Potential
Mono-crystalline Si	22.44	15739 MWh
Poly-crystalline Si	18.13	12716 MWh
Amorphous Si	11.96	8388 MWh
Cadmium-Telluride Cells	17.15	12028 MWh

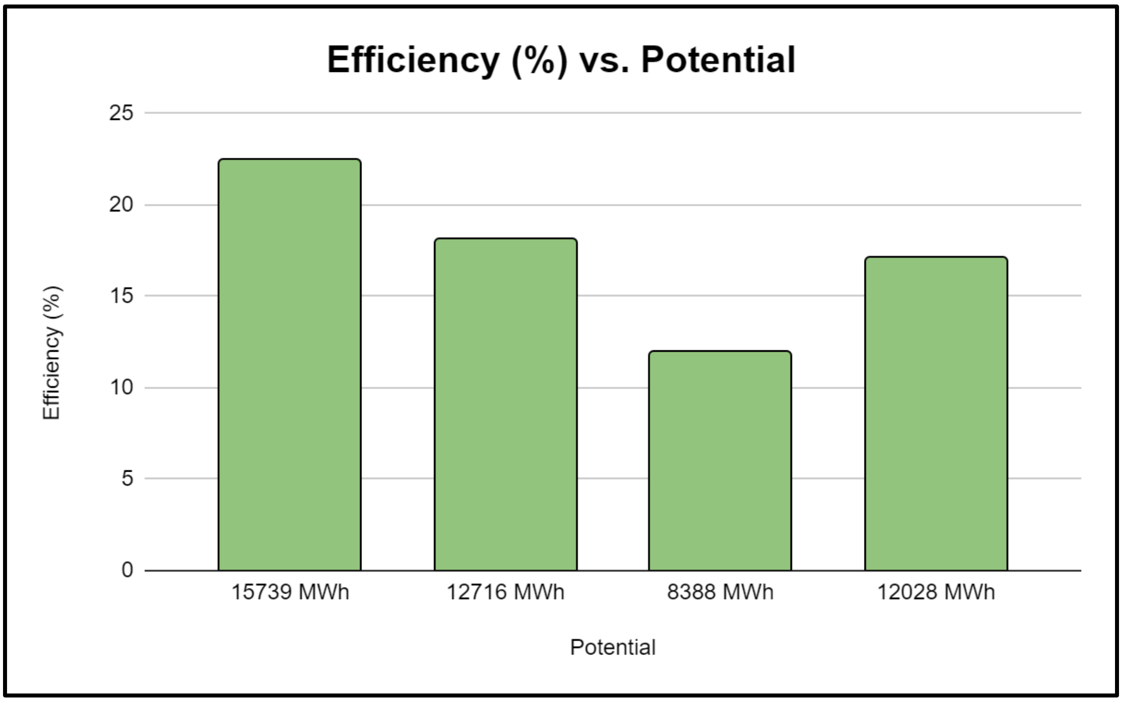

Figure 4.1.5(a): Graphical representation of potential for different types of PV Technologies.

4.2 Validation:

A comparison of the solar power generation capacity of rooftops in the same land area of Karachi, Pakistan it has been determined that the solar potential of Karachi is 1761 MWh higher than that of Narayanganj for the same land area if **Mono-crystalline Si** is used as solar panel.

Table 4.2(a): Comparison of rooftop solar potential with city of Karachi [11].

Karachi Pakistan		**Narayanganj Bangladesh**	
Area	48000 m^2	Area	48000 m^2
Potential	17500 MWh	Potential	15739 MWh

Narayanganj city corporation has an electrical demand per year of about 650 MW, or 15600 MWh, as reported by the Narayanganj DPDC Grid south-1 & Grid south-2. Table 4.2(b) below is a breakdown of how much electricity can be saved by installing Mono-crystalline Si solar panels:

Table 4.2(b): Electricity saving according to the demand.

Objective	**Outcome**
Potential	15739 MWh
Demand	15600 MWh

Approximately 8.9 kWh of energy may be extracted from 1 Liter of fuel and 8.141 kWh of energy may be extracted from 1 kg of coal.

The price of fuel and coal in Bangladesh is expected to be 130 Tk/liter and 12.198 Tk/kg respectively in 2023. Table 4.2(c) shows how much equivalent fuel and coal can be saved and how much profit can be obtained if solar panels are used.

Table 4.2(c): Equivalent saving according to the fuel and coal :

Name	Equivalent Fuel saving	Equivalent money saving (Tk)
Fuel	15617 L	2030210
Coal	17074 kg	208268

4.3 Discussion:

The solar potential of Narayanganj is depicted in Table 4.1.5 for different types of PV technology, and Narayanganj one of the largest cities in Bangladesh. NASA-SSE has provided us with the daily average irradiance of this region. Finding building shapefile for ROI was a key challenge in this research work. In this task (https://extract.bbbike.org) has provided the required building shapefile. Using Arcgis Pro, the suitable rooftop space for solar panel installation has been estimated. Where observed that suitable areas begin at over 30 square meters. The efficiency of several PV technology kinds was demonstrated in this analysis. Such as Mono-crystalline Si (mono-Si), poly-crystalline Si (poly-Si), Amorphous Si (a-Si) ,Cadmium-Telluride Cells (CdTe). Among them, Mono-crystalline (c-Si) solar panels have the greatest potential. However, Mono-crystalline Si (mono-Si) is considerably more expensive than other solar panels. The performance ratio is a variable based solely on its definition, which under the influence of certain factors, may even exceed 100%. With corresponding ambient conditions, such as increased solar irradiance at the site, etc the PR value increases proportionally to the PV modules' efficiency. When the sun is low in the sky, like in the morning, evening, and winter, the incident solar irradiation value is closer to the power dissipation value (the difference between how much power is put in and how much is taken out) than at other times of the day and year. Because of this, the PR value is lower than normal during these times. Due to its geographical location, Bangladesh enjoys year-round sunshine. Consequently, solar irradiation in this country is also relatively high. Therefore, the PR value of roughly 86% was chosen. The primary emphasis of this study was the estimation of rooftop PV potential. Consequently, a fundamental method was utilized to estimate PV power and energy output for a municipal area of Bangladesh. It is pertinent to note that such an analysis may have been accompanied by additional errors, given the analysis's fundamental methodology.

CHAPTER 5

PROJECT MANAGEMENT

5.1 Task, Schedule and Milestones:

Estimating rooftop solar potential for a municipal area in Bangladesh was quite challenging. This required some important factors such as solar irradiation, area estimation. In order to attain the milestone of estimating the solar potential, it should develop a schedule to get there.

From beginning to the end, the tasks, schedule and milestones of the following study are given below table:

Table 5.1: Tabular form of the task, schedule and the cost.

Task	Schedule	Cost
Learn About the Softwares	Irradiation and the area estimation both need to get to their respective destinations. Because of this, the essential data are found by utilizing two different kinds of software, such as PVsyst and ArcGIS. The entire procedure takes about **2-3 weeks**.	This procedure is completely free of charge.
Installation of the Trial Version of Software	The software installation process is complicated because these softwares are not free to use. Because of this, trial versions are installed. This procedure takes about **2-3 days**.	This procedure is completely free of charge just because of install the trial version.
Irradiation Estimation	PVsyst makes estimating irradiation considerably easier because its features are simple to utilize. This procedure takes **less than one day**.	This procedure is completely free of charge just because of install the trial version.

Collect the Shapefile	Because obtaining the necessary shapefiles from BBBike was a simple process, the time required is **less than one day**.	This procedure is completely free of charge.
Area Estimation	Area estimation with ArcGIS is quite tough due to the software's unsuitable features. The duration of the process is approximately **1-2 weeks**.	This procedure is completely free of charge just because of install the trial version.
Printing Costs	The duration of the process is approximately **1 day**.	The entire process will cost between **600-700 BDT**.

5.2 Resources and Cost Management

It is essential to have efficient administration of both resources and costs in order to carry out any research project successfully. Careful planning is being done in order to achieve appropriate cost control with this research. There are two different kinds of software that are utilized in order to achieve the desired results. The fact that PVsyst and ArcGIS are not free to use is the reason why free trial versions of the software are required for installation in order to calculate the outcome and keep the cost low. Other essential costs, such as printing costs, don't add up to a significant amount. Because of this, the whole cost was significantly reduced in its entirety.

CHAPTER 6

IMPACT ASSESSMENT

6.1 CO_2 Emission Estimation:

In an increasingly carbon-constrained world, solar energy technologies represent one of the least carbon-intensive means of electricity generation. Solar power produces no emissions during generation itself, and life-cycle assessments clearly demonstrate that it has a smaller carbon footprint from "cradle-to-grave" than fossil fuels.

According to (bostonsolar.us), the amount of CO_2 emitted by 1 kWh is 0.846 lbs [17]. Table 6.1 demonstrate the CO_2 emissions for several PV panels:

Table 6.1(a): Different types of PV technologies vs CO_2 Emission

Name of Solar Panel	Potential	CO_2 Emission(lbs)
Mono-crystalline Si	15739 MWh	13315194
Poly-crystalline Si	12716 MWh	10757736
Amorphous Si	8388 MWh	7096248
Cadmium-Telluride Cells	12028 MWh	10175688

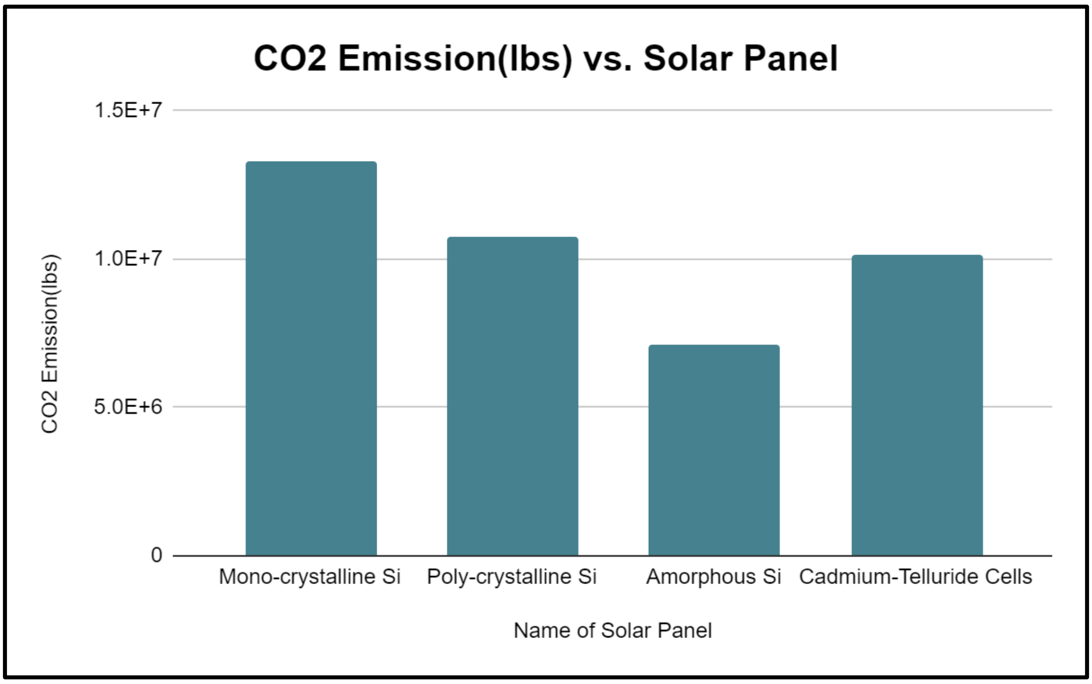

Figure 6.1(b): Graphical Representation of CO_2 Emission.

6.2 Impact of Solar PV on CO_2 Emission Reduction:

- Using the **Mono-crystalline Si** will be equivalent to saving :
  - 99867 tree saplings raised during a decade.
  - 229409 light bulbs were converted to LED.
  - 679591 gallons of gasoline.
  - 13983 barrels of oil.
- Using the **Poly-crystalline Si** will be equivalent to saving :
  - 80685 tree saplings were produced over a decade.
  - 185346 light bulbs were switched to LED.
  - 549062 gallons of gasoline.
  - 11297 oil barrels.
- Using **Amorphous Si** will be equivalent to saving :
  - In a decade,53223 tree seedlings were cultivated.
  - 122262 light bulbs were converted to LED.
  - 362184 gallons of gasoline.
  - 7452 oil barrels.
- Using **Cadmium-Telluride Cells** will be equivalent to saving:
  - 76320 tree seedlings nurtured over a ten-year period.
  - 175318 light bulbs switched to LED.
  - 519355 gallons of gasoline.
  - 10686 barrels of oil.

CHAPTER 7

CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion:

This study proposes a methodology for calculating a region's rooftop solar photovoltaic potential. The methodology uses online data to estimate the rooftop solar potential of a municipal area in Bangladesh. It has the benefit of being basic in nature and relying on public-domain data. The solar potential of Narayanganj is depicted in this paper.

Irradiation was estimated by using two sophisticated methods: PVsyst and solarelectricithandbook.com. Both of them are backed up by the most powerful calculator tools, to make the calculations as straightforward as possible. They use latitude and longitude data available online to estimate the irradiation.

A ROI building shapefile is required to determine a suitable area. The desired building shapefile was discovered on a website (bbbike.org). Buildings with a height of less than 30 m^2 had to be excluded. Unfortunately, such necessary information was not available in the public domain. Thus, rooftops above 30 m^2 of ROI (region of interest) were hand-digitized in the ArcGIS software, utilizing high-resolution imagery to get the desired ROI building rooftops. ArcGIS also assisted in calculating the overall number of acceptable structures as well as the total area suitable.

Rooftop PV potential is mostly determined by the efficiency of the PV module used to generate solar electricity. As a result, selecting the highest efficiency and greatest performance solar panel is critical. The efficiency and performance parameters of various types of PV panels fluctuate depending on the production process and material utilized. This paper also summarizes the efficiencies and characteristics of different types of PV panels to exhibit various scenarios of solar power generation for ROI (region of interest).

With corresponding ambient conditions, such as increased solar irradiance at the site, The Performance ratio (PR) increases proportionally to the PV module's efficiency. Due to its geographical location, Bangladesh enjoys year-round sunshine. Consequently, solar irradiation in this country is also relatively high. Therefore, the PR value of roughly 86% was chosen. The inverter efficiency was also a concern as it converts the direct current (DC) electricity of solar panels into alternating current (AC) which our home runs by. Inverters' conversion efficiencies range from 97% to 99%, depending on the making and models. Here, for best output inverter efficiency of 98% has been chosen.

Carbon emission rate also shown in the paper for different types of solar PV. Due to its geographical location, Bangladesh has a great potential for rooftop solar PV energy but the energy sector of Bangladesh is the largest contributor of carbon emissions, with 93.09 metric tons, equivalent to 55.07% of the total emissions. That is why rooftop solar PV panels would be an excellent countermeasure. This paper also presents the effective results that will be obtained against carbon emission for the use of different types of solar PV panels. In this paper a rooftop solar potential has been estimated for

Narayanganj city. There were some difficulties in estimating the potential. Among them, a lack of enough data was notable. The government should take enough steps to make geographical data available so that we can establish more solar based projects.

7.2 Recommendation for Future Study:

ArcGIS Pro facilitates the entire process of calculating the solar potential of rooftops. But to estimate the potential ArcGIS pro need lidar data which is not available for Bangladesh. Lidar data creating process will be extremely costly but it will be very helpful in order to estimate the solar potential of a region. In the future, if the government or any other organization of Bangladesh provides lidar data. Then, the estimation process for rooftop solar potential will become more easy and hassle-free.

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