Study of Bifacial Solar PV Based Energy Harvesting System in the Perspective of Bangladesh: A Software Based Approach

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It is hereby declared that this thesis or any part of it has not been submitted elsewhere for award of any degree or diploma.

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DEDICATION

We would like to dedicate the thesis book to our respective family members.

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First and foremost, praises and thanks to the Allah the Almighty, for His showers of blessings throughout our research work to complete the research successfully.

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ABSTRACT

This paper proposes a concept for a bifacial solar photovoltaic panel-based energy harvesting device for university residences and coastal areas, as well as software simulations. The rooftop of the Islamic University of Technology's (IUT) North Hall of Residence and Cox's bazar's marine drive road are being considered as potential locations for the proposed scheme. The PVSOL software is used to build a 3D model of the sites. The monthly energy output is calculated using three software programs: PVSOL, PVsyst, and System Advisor Model (SAM). In addition, the monthly consumption of the residence is tabulated and shown graphically. The efficiency of each software is assessed, and a deviation analysis is carried out to gain a better understanding of solar energy harvesting. Hence, a cost-effective and self-reliant solar energy model for the rooftop of a university residence and coastal area is proposed by utilizing bifacial solar PV panels efficiently to provide a eco-friendly alternative sources of energy in challenging places.

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Introduction

1.1 Introduction to Energy

1.1.1 Energy

Energy is the ability to do work. It can exist in various potential types, kinetic, thermal, electric, chemical, atomic, or otherwise. Furthermore, there is heat and function, that is, energy to move from one body to another. Energy after it has been transferred is always marked by its definition.

Motion is linked with all forms of energy. For example, if anybody is in motion, it has kinetic energy. Although at rest, a tensioned system such as a bow or spring has the potential to create motion; due to its structure, it contains potential energy. Also, nuclear power is potential fuel because it comes from the subatomic particle structure in an atom's nucleus.

Energy can't be produced or destroyed; it can only be changed from one form to another. The first law of thermodynamics is known as energy conservation. When a box falls down a hill, for example, the box's potential energy from being high up on the slope is transformed into kinetic energy, or motion energy. The kinetic energy from the box's movement is transformed into thermal energy, which heats the box and the slope when it comes to a halt due to friction.

Energy can be transformed from one form to another in a variety of ways. Many types of machines, such as heat engines, generators, batteries, fuel cells, and magnetohydrodynamic systems, generate accessible mechanical or electrical energy.

Energy is expressed in joules in the International Unit System (SI). One joule is equal to the work performed over a one-meter distance by a one-newton force.[1]

1.1.2 Energy Sources

Renewable and non-renewable energy sources can be distinguished. Electricity is typically produced in people's homes by burning coal or natural gas, a nuclear reaction, or a river-side hydroelectric project. The energy source is petroleum (gasoline) refined from crude oil and may include fuel ethanol provided by growing and processing corn. Coal, natural gas, nuclear, hydropower, coal, and ethanol are referred to as sources of energy.

Energy sources are divided into two groups:

- Renewable energy sources.
- Non renewable energy sources

Renewable and nonrenewable energy sources can be used as primary energy sources to generate useful energy including heat, or as secondary energy sources to generate electricity.

1.1.3 Renewable Energy

There are five main renewable energy sources:

- Solar Energy from the sun
- Geothermal Energy
- Wind Energy
- Biomass
- Wave Energy

1.1.4 Non-Renewable Energy

- Petroleum product
- Hydrocarbon gas liquid
- Natural gas coal
- nuclear energy

Crude oil, natural gas, and coal are classified as fossil fuels because they were formed over millions of years by the action of energy from the earth's core and rock and soil stress on the remains (or fossils) of dead plants and animals, such as microscopic diatoms.

Nuclear energy is produced from uranium, a non-renewable energy source whose atoms are split (through a nuclear fission process) to generate heat and, eventually, electricity.[2]

1.1.5 Energy Scenario in Bangladesh

Bangladesh's power sector is heavily reliant on fossil fuels, with natural gas and coal serving as the country's primary energy sources. Natural gas accounts for approximately 62.9 percent of Bangladesh's electricity generation, with diesel accounting for 10%, coal for 5%, heavy oil for 3%, and renewables accounting for 3.3 percent.

Despite the fact that the Bangladeshi energy sector uses and covers a broad range of items, including electricity, petroleum products, natural gas, coal, biomass, and solar, policymakers and decision-makers are primarily concerned with electricity, which is the country's most widely used source of energy. Accordingly, because there is a continuous and rapidly widening gap between electricity supply and demand, therefore it is a major challenge for the energy sector in Bangladesh.

The total number of grid-connected users was 21.8 million in 2016. Domestic connections (households) account for 16 million of the 21.8 million people, or roughly half of all Bangladeshi households. An additional 15% of households have access to electricity.

Table 1: Bangladesh's Daily Power Generation, and the Generating Institutions

Institution	Supplied Demand (MW)
Power Development Board	4332
Electricity Generation Company Bangladesh Ltd	622
Ashugani Power Station Co. Ltd	1617
Independent Power Producers (IPPs)	325
Small Size Producers	1987
Rental Power Producers	825
Total Daily Generated Average Power	10390

The main issue with the grid extension is power outages and poor power supply efficiency. Even with newly installed capacity (11,532 MW total; 13, 540 MW including captive power generation) and India's 500 MW import capacity.

While there has been a substantial expansion of grid infrastructure and other electrification measurements, the electrification rate is about 75%, many households continue to experience intermittent electricity supply, with power outages lasting up to 14 hours per day. However, the number of connections is steadily growing, with about 250.000 new connections added each month.

In comparison to countries with similar economies, the availability of modern energy to the population and industry is very limited. Since 2010, per-capita commercial energy output has risen to 371kWh, but it remains one of the lowest in the world.

Bangladesh would almost certainly need to triple that amount by 2021 in order to achieve its goal of becoming a middle-income economy. Simultaneously, avoidable energy waste in the industrial and household sectors reduces a large portion of the benefits that this energy might provide to the nation.

Natural gas is only available to around 6% of the population, mainly in urban areas. As access to local biomass becomes increasingly difficult, biomass fuels such as wood, cow dung, and agricultural residues have become a traded commodity as cooking fuel. Kerosene lamps, which are inefficient, are the most common light sources. The price of kerosene has risen from 42 tk to 70 tk since the end of 2010. (July 2014). In 2009, the supply of new gas connections to factories was halted, but it was resumed in April 2012. New gas connections to homes were also halted for a period of time.

Table 2: Source of Lights (in %)

Source	2011	2004	1991
Grid Electricity	53; 56.6	39.77	14.37
Solar Energy	6.9; 3.3	-	-
Kerosene	39.5[	59.93	84.73
Biogas	0.1	-	-
Others	0.5	0.31	0.89

Table 3: Source of Cooking Fuels (in %) Unknown Object

Fuel Type	2011	2004	1991
Wood	34.8	31.76	44.27
Kerosene	1.0	1.79	0.57
Gas/LPG	12.6	9.09	2.36
Electricity	0.4	0.76	0.88
Straw/Leaf/Dried cow dung	51.2	55.91	-
Bio-gas	0.1	-	-

1.1.6 Electricity Production in Bangladesh

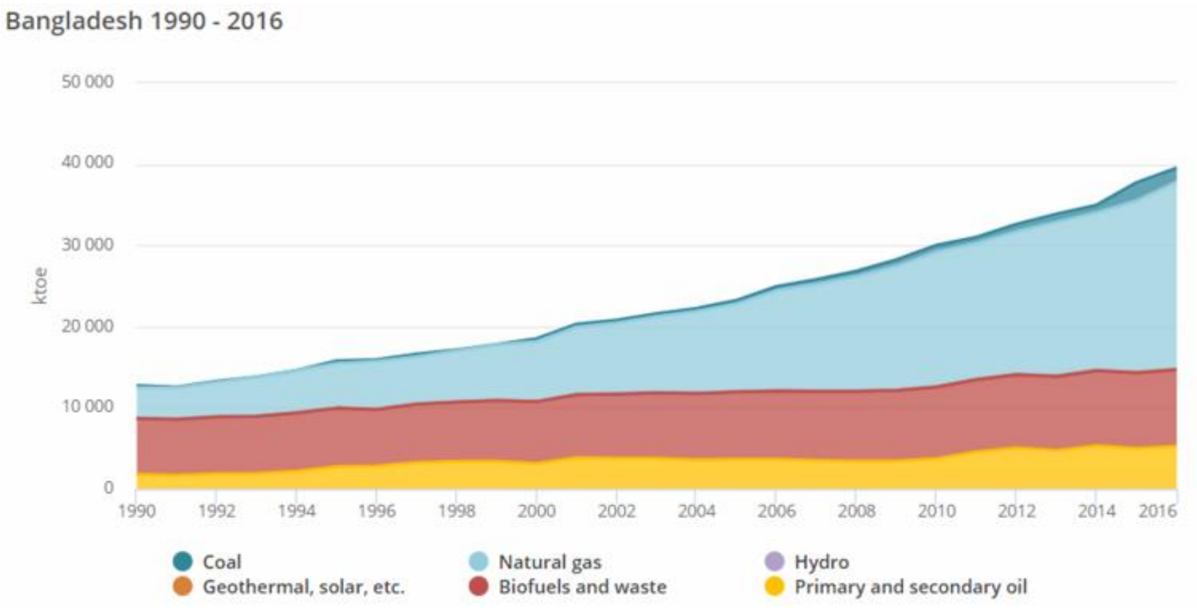


Figure 1: Bangladesh's Total Primary Energy Supply by Source 1990-2016 (IEA, 2018)

Bangladesh's energy output, from both different oil products and biofuels, has remained almost constant over the last two decades, while natural gas has become more dependent and accelerated since the early 2000s, as seen in the previous figure.

The following figure shows an example of the country's energy production from different sources during the few past fiscal years, in particular the fiscal year 16/17, and as shown, natural gas is highly dominant [3].

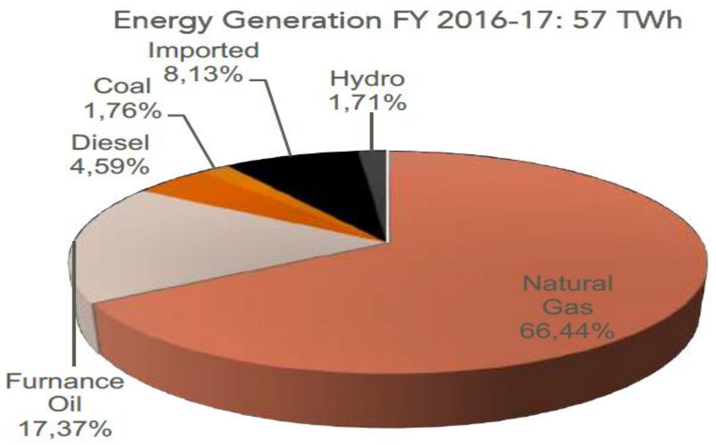


Figure 2: Bangladesh's Total Energy Generation by Source 2016-2017 (Suntrace, 2018)

1.1.7 Renewable Energy Scenario in Bangladesh

Table 4:Bangladesh's Total Renewable Energy Capacity 2009-2018[22]

Year	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Capacity (MW)	251	266	267	291	330	358	382	393	438	439

Table 5: Bangladesh's Generated Capacity from Renewable Resources 1965-2017[14]

Year	**1965**	**1975**	**1985**	**1995**	**2000**	**2005**	**2010**	**2015**	**2016**	**2017**
Generated Capacity (Twh)	0	0	0	0	0	< 0.1	0.1	0.2	0.3	0.3

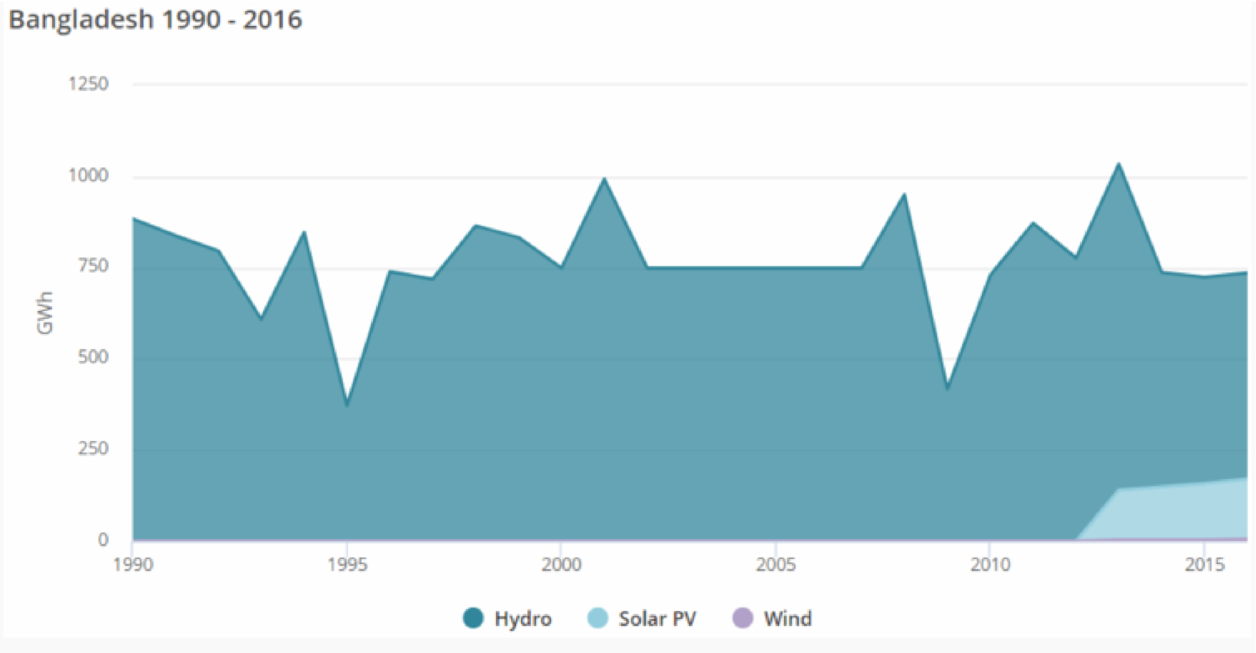


Figure 3: Bangladesh's Renewable Energy Generation by Source 1990-2016 (IEA, 2018)

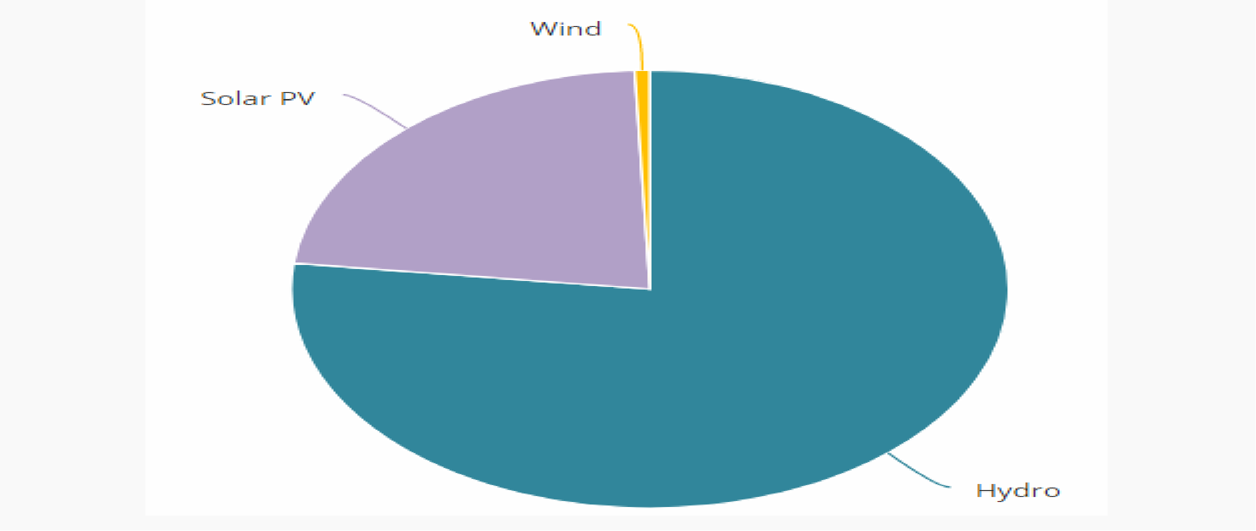


Figure 4: Bangladesh's Different Renewable Sources' Shares in Electricity Generation in 2016 (IEA, 2018)

Table 6: Bangladesh's Renewables' Consumption 1965-2017										
Year	**1965**	**1975**	**1985**	**1995**	**2000**	**2005**	**2010**	**2015**	**2016**	**2017**
Consumed Capacity (Mtoe)	0	0	0	0	< 0.1	< 0.1	< 0.1	0.1	0.1	0.1

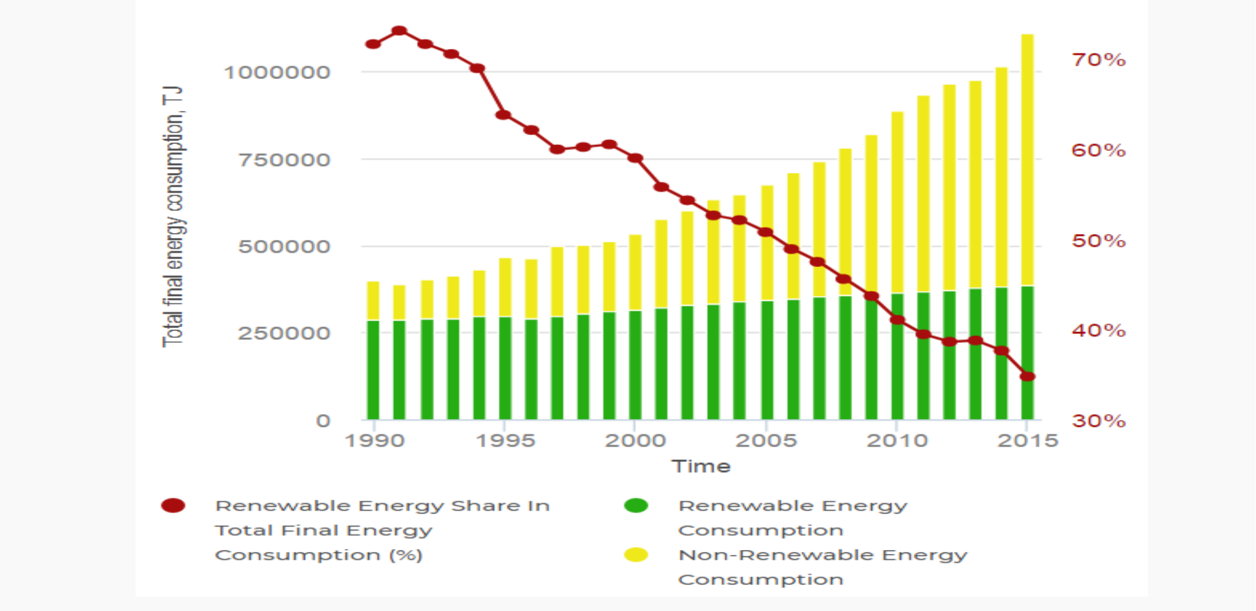


Figure 5: Renewable Energy Share in Total Final Bangladeshi Energy Consumption 1990-2015 (Tracking SDG7, 2018)

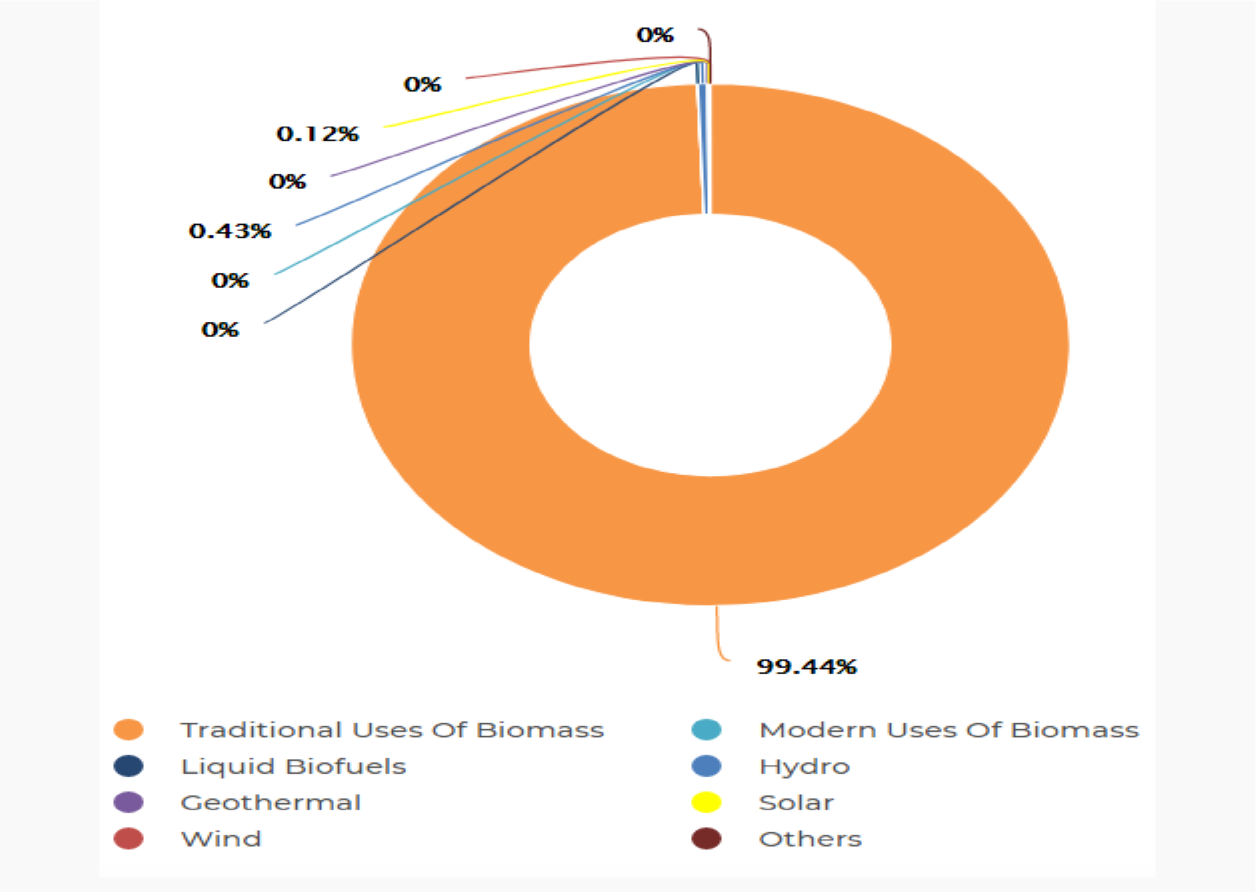


Figure 6: Bangladesh's Renewable Energy Consumption by Source (Tracking SDG7, 2018)

1.2 Solar Energy

1.2.1 Why Solar Energy

- Solar is a safe alternative which can replace current fossil fuels like coal and gas for generation of electricity that produce air, water, and land pollution.
- Pristine forests are destroyed for mining raw materials like fossil or nuclear fuels. Trees constantly remove and use carbon dioxide from the air to make their food, and this carbon is then stored in them. When forests are cut for mining raw materials for conventional

energy, this major carbon sink disappears and also increases climate change. Switching to solar power is important to keep these habitats intact for the animals who live there as well as continue to keep the air clean.

- Emissions are blamed for the rise in global temperatures, and changes in weather patterns leading to a cascade of effects. Heat waves, and increase in disease-spreading insects cause health problems especially for children and the elderly. Climate change has lead to an increase in flooding and hurricanes due to disturbed weather patterns. Higher carbon dioxide concentration is making oceans acidic and killing marine life, like corals. Climate change causes extinct of species from Sub-Arctic Boreal forests to tropical Amazon forests. Higher temperatures result melting of polar ice caps, reducing habitats for wildlife and also increase sea level. This results in submersion and loss of land along the coast, displacing people. Irregular rainfall or increasing droughts affects agriculture and livelihoods of the weaker sections of society globally. Solar power can restrict climate change as it produces no carbon emissions. The carbon footprint of solar panels can be offset in as quickly as four years' time

- Solar energy's greatest attraction is that it can be produced on a small scale directly by the end consumers in contrast to large centralized conventional energy sources controlled by large corporations.

Figure 7: Solar Panels on rooftop

1.2.2 Solar Energy Potential in Bangladesh

Solar is the most common source of renewable energy in Bangladesh, and it is used in a variety of ways, including PV, SHS, nano-grids, and mini-grids. Biomass is thought to have a considerable amount of potential for integration in the region. These small-scale renewable energy solutions (such as solar home systems, SHS, and biogas plants) have developed and are proving to be a viable option for supplying electricity to remote communities. Bangladesh's off-grid solutions are dominated by SHS technology, which accounts for 80% of the market. The country possesses great potential for solar energy, with average solar energy incident about 4-6.5 kWh/m^2/day, and averaging 10.5 hours of sun per day, of which 4-4.5 are peak sunlight hours and 300 clear sunny days per year. Currently, the country is considered a market leader when it comes to SHS, and standalone PV systems.

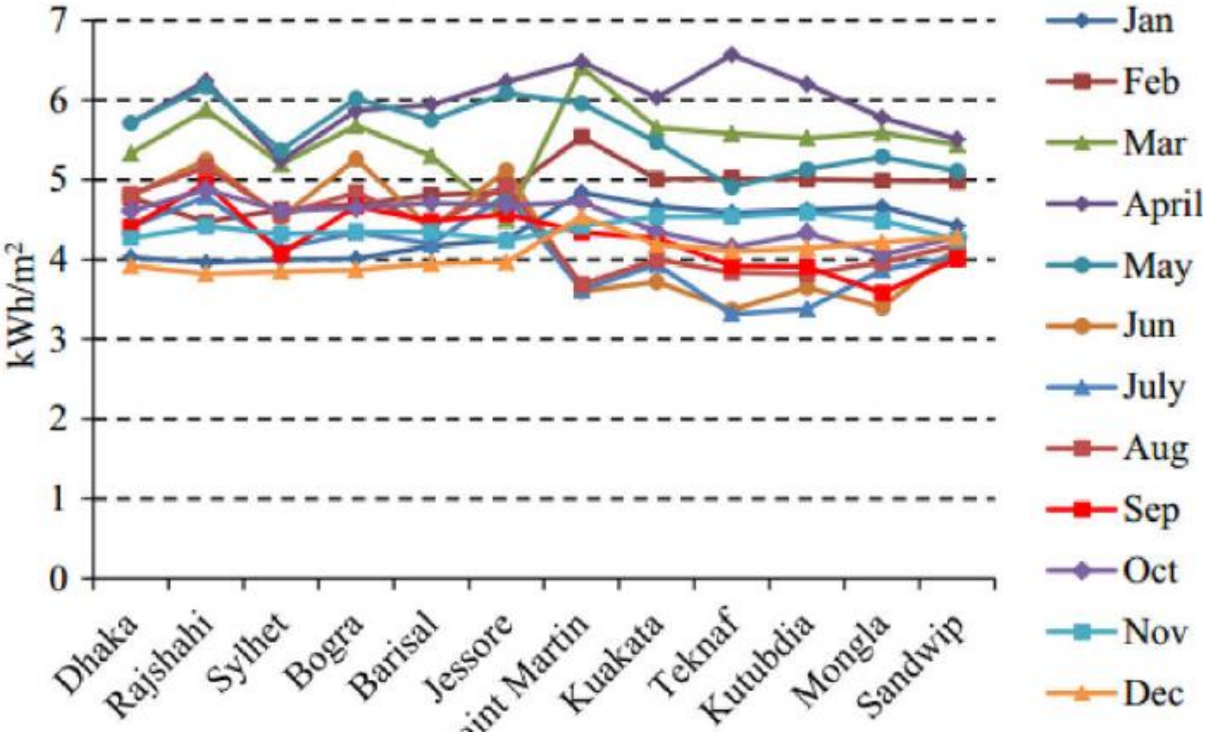


Figure 8: Solar Irradiation of Different Areas in Bangladesh through the Year (Taheruzzaman & Janik, 2016)

Despite the country's vast solar potential, the majority of proposed solar projects have been repeatedly postponed in recent years. This is due to the fact that Bangladesh is predominantly an agricultural society, making securing non-agricultural, suitable land for solar projects a challenge. Nonetheless, in the last five years, Bangladesh has successfully commissioned two solar plants: a 20 MW plant in Cox's Bazar and a 3 MW plant in Sarishabari, Jamaplur.

Table 7: Bangladesh's Solar Energy Capacity 2009-2018

Year	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Capacity (MW)	18	32	43	66	95	122	145	155	200	201

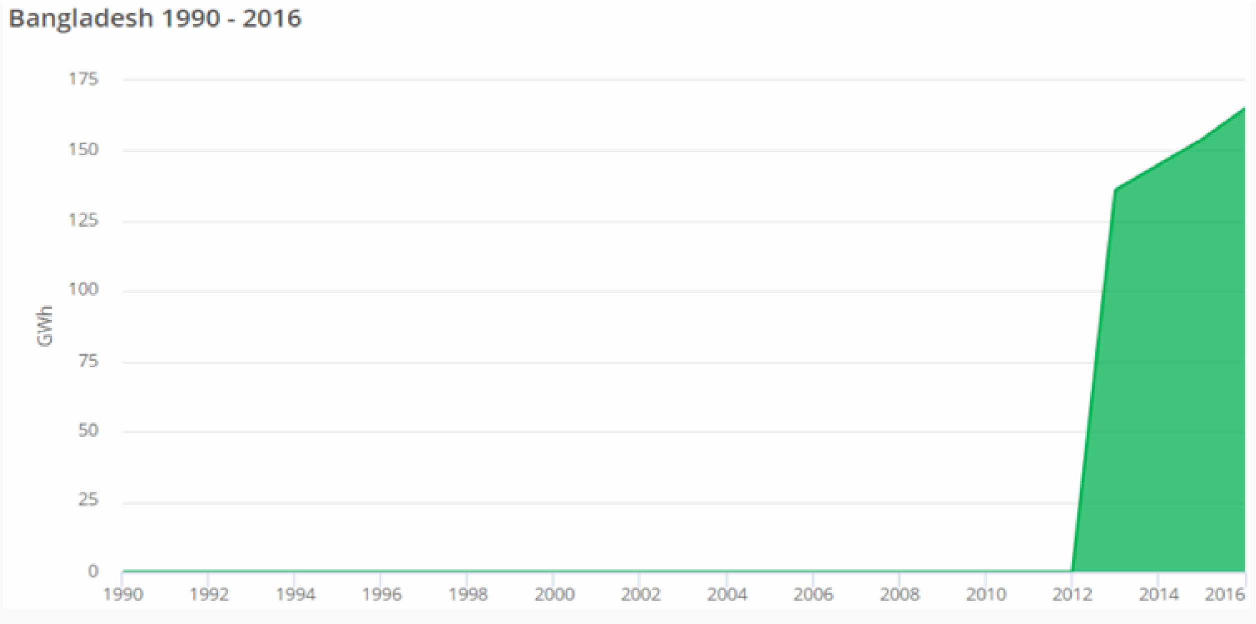


Figure 9: Bangladesh's Electricity Generation by Solar PV 1990-2016 (IEA, 2018)

Over 2.9 million household-level solar photovoltaic (PV) installations with a capacity of 122.2 MW are in use across the world (April 2014). Infrastructure is being used to scale up solar PV systems with the support of construction partners, Development Company Limited

(IDCOL), Rural Electrification Board (REB), Local Government Engineering Department (LGED), Bangladesh Power Development Board (BPDB), NGOs and Private Organizations implementing solar energy program. There is a strong potential for solar energy within the country. Dissemination of solar home systems (SHSs) is being promoted mainly by IDCOL, private sector companies and NGOs based on the direct-sale approach and provision of refinancing funds for micro-financing of SHSs to participating organizations (mostly NGOs) through IDCOL.

1.3 Literature Review

Jamal et al. [4] used GIS mapping to show the potential rooftop distribution for solar installation in the Dhanmondi region. Mahmud et al. developed a bifacial module-based solar installation for use on some of Bangladesh's main highways [5]. Shuvho et al. used fuzzy logic to forecast solar irradiation and test the efficiency of an 80 kWp on-grid solar plant in Dhaka. A case study on the techno-economic viability of a 1 MW on-grid linked photovoltaic device in Adam, Oman was conducted by Kazem et al. [7]. Dondariya et al. used several PV simulations tools to simulate the efficiency of an on-grid solar panel system for small households in Ujjain, India [8]. As a result, it has been discovered that the limitations of accessible land for PV installation can be overcome by using open highways and available rooftop areas in urban areas. Different researchers, on the other hand, have created and studied various renewable energy models, as well as explored their implications for power generation and distribution. Khan et al. suggested a hybrid off-grid energy system that could be used on Bangladesh's Sandwip Island [9]. Kabir et al. also contributed to the modeling of a hybrid power plant using photovoltaic and wind energy as renewable energy sources and diesel as a non-renewable standby energy source [10]. For the Coxes-Bazar field, Islam et al. investigated wind characteristics and assessed wind energy potential [11].

1.4 Thesis Objective

The main objective of the thesis can be concluded as to find out the Solar Energy aspects of Bangladesh. Nevertheless, it could be quantized as:

- To create a positive impression about the huge Solar Energy resources of Bangladesh.
- To look through the suitable Bifacial Solar Energy conversion method.
- To design and Simulate Solar photovoltaic system using the bifacial panel in different location.
- To design and operate a prototype to predict the outcome.
- To examine the prototype outcome and propose a real-life model.

Section-2

Methodology

2.1 Bifacial Solar Panel

Traditional solar panels have a number of disadvantages that bifacial solar modules do not. A bifacial module can generate power from both sides, increasing total energy production. They're also more resilient because both sides are UV resistant, and when the bifacial module is frameless, the risk of potential-induced deterioration (PID) is minimized. Balance of system (BOS) costs are also reduced when more power can be generated from bifacial modules in a smaller array footprint.

LG, LONGi, Lumos Solar, Prism Solar, Silfab, Sunpreme, Trina Solar, and Yingli Solar are some of the companies that currently have bifacial modules on the market. Bifacial modules appear to be a niche product that is becoming mainstream as more manufacturers begin production.

Solar power is produced from both sides of the panel in bifacial modules. Bifacial modules display both the front and backside of the solar cells, whereas conventional opaque-back sheeted panels are monofacial. When bifacial modules are mounted on a highly reflective surface (such as a white TPO roof or the ground with light-colored stones), some bifacial module manufacturers say that the extra power produced from the rear will result in a 30 percent increase in output.

Bifacial modules are available in a variety of styles. Some of them are framed, while others are not. Some have dual-glass back sheets, while others have flat back sheets. The majority of the time, monocrystalline cells are used, but polycrystalline designs are also available. One thing remains constant: power is generated from both sides. Frameless, dual-glass modules that expose the backside of cells but are not bifacial are available. Contacts/busbars are present on both the front and back sides of true bifacial modules' cells.

The form of bifacial module determines how it is assembled. Since conventional mounting and racking systems are already adapted to framed models, a framed bifacial module might be easier to install than a frameless model. Most bifacial module manufacturers have clamps for mounting their particular brand, removing any installation concerns.

For frameless bifacial modules, the module clamps will often feature rubber guards to protect the glass, and special care must be taken to prevent overtightening bolts and damaging the glass.

The more power a bifacial module receives from its bifacial properties, the higher it is tilted. Any reflected light is blocked from accessing the backside of the cells by bifacial modules fixed flush to a rooftop. Since there is more space for tilt and bouncing reflected light to the rear of the modules, bifacial modules work better on flat commercial rooftops and ground-mounted arrays.

The efficiency of the bifacial modules can be influenced by the mounting system. Back rows of bifacial cells will be shaded by racking systems with support rails that are normally protected by the back sheet of a monofacial module. To avoid shading, bifacial panel junction boxes have shrunk or been split into multiple units located along the panel's edge. Mounting and racking systems specially formatted for bifacial installations take out the question of backside shading [12].

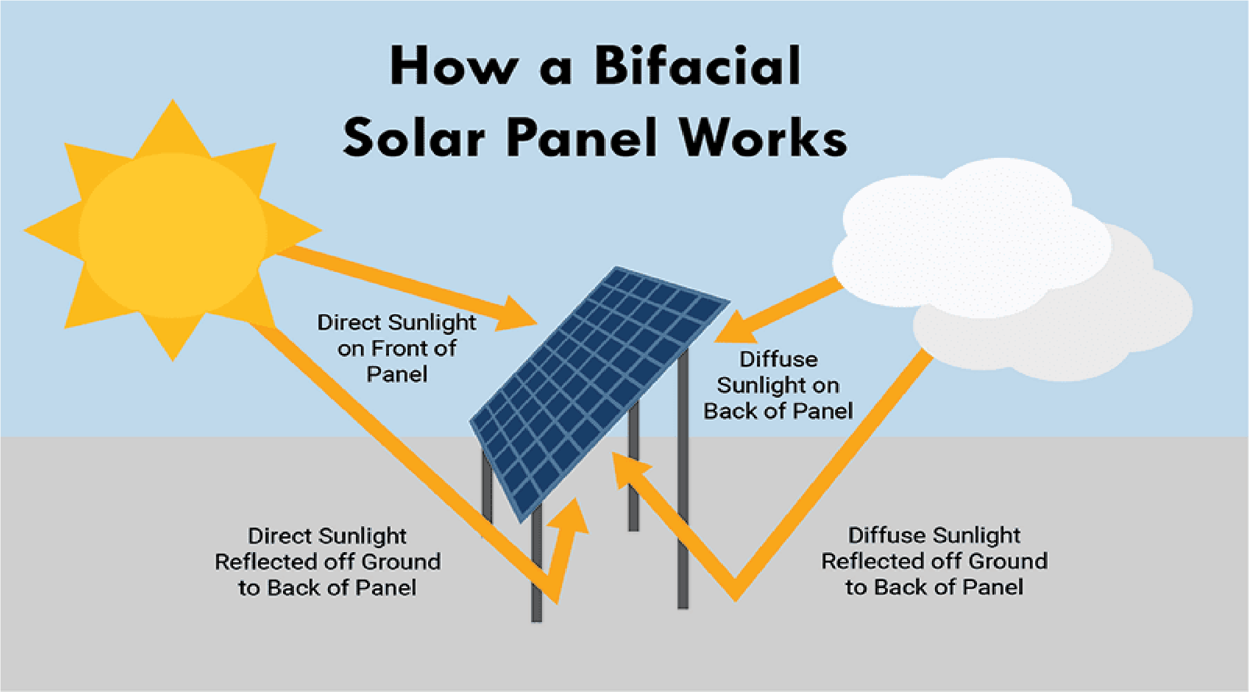


Figure 10: How Bifacial Solar Panels work

2.1.1 Theoretical Model

<u>Front side irradiation model:</u>

The Hay and Davies diffuse model divides the sky diffuse irradiance into isotropic and circumsolar components. Horizon brightening is not included. An anisotropy index, A_i , is defined as:

$$A_i = \frac{DNI}{E_a} ,$$

where DNI is the direct normal irradiance and E_a is the extraterrestrial radiation.
The Hay and Davies model formulation for sky diffuse radiation is:

,

where DHI is the diffuse horizontal irradiance, $R_b = \cos(AOI) / \cos(Z)$, AOI is the angle of incidence, Z is the solar zenith, and θ_T is the tilt angle of the array.[13,14]

Rear side Irradiation model:

A prevalent model used for the rear side irradiation is the view factor model. View factors are known as the shape and configuration factors, which help to calculate the

fraction of the irradiance reflected from one surface to the receiving surface. According to the view factor models the component E_2, which contributes to the total rear irradiance is given by

$E_2 = G_1$ X VF

where,

$G_1 = G$ is the total irradiance (W/m2) on the reflecting area

VF = the view factor from the reflecting area to the rear surface

View factors can be computed by numerical integration, which is also known as the cell level view factor model (Analysis of Irradiance Models for Bifacial PV Modules). The view factor from a general surface A_1 to another general surface A_2 can be represented as,

$$F_{1\to 2} = \frac{1}{A_1} \int_{A_1} \int_{A_2} \frac{\cos\theta_1 \cos\theta_2}{\pi s^2} dA_2 dA_1$$

where θ_1 and θ_2 are the angles between the surface normal and a ray between the two differential areas. [15, 16, 17]

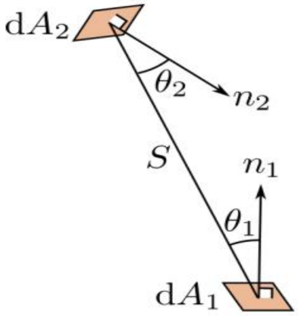


Figure 11: Rear side irradiance model

2.1.2 Performance Parameters

Annual PV Energy

The total energy output from a PV array on an annual basis is known as the annual PV Energy. Its unit is kWh. The annual PV energy, E_{Array} is given by,

$E_{Array} = I*V*t$

Where,

I = DC current (A)

V = DC voltage (V)

t = Time (h)

Specific Yield

Specific yield is defined by the amount of energy (kWh), generated per unit of module capacity (kWp) over a period of one year. [18] Its unit is kWh/kWp.

Specific yield, $Y_s = E_{gen} / Cap_{module}$

Where,

$E_{gen =}$ Amount of energy generated (kWh)

Cap_{module} = Module capacity (kWp)

Final Yield:

The net AC energy output of the system, when divided by the peak power of the installed PV array gives us the final yield. It is measured under standard test conditions (STC) at solar irradiance of

1000 W/m_2 and cell temperature of 25 °C. It can be measured on a daily, monthly or annual basis. Its units are kWh/kWp. The final yield, Y_F is given by the formula,

$Y_F = E_{AC}/P_{peak}$

Where,
E_{AC} = AC energy output of the system (kWh)
P_{peak} = Peak power of PV array (kWp)

Performance ratio:

To judge the performance of PV Plants performance Ratio (PR) is a globally accepted indicator which is an indication of the overall effect of losses on the PV system's rated output due to array temperature, incomplete utilization of the irradiation, and system component inefficiencies or failures. [19]

Shading loss:

Shading occurs when in sort of shadow partially or fully covers a solar panel thus preventing the sunlight radiation to reach the cells and reducing power output. Little shading can cause significant amount of power loss. In the book by Stanford University's Gil Masters, it was demonstrated that if only 1 out 36 cells are shaded the power loss can lead up to 75%. In-addition Photovoltaic plants are affected by shadows projected between PV arrays mainly at sunrise and sunset. [20,21]

2.2 Software Description

To carry out feasibility analysis, 3 prominent solar simulation software has been used. They are PVSOL, PVsyst, SAM (System Advisory Model).

2.2.1 PVSOL

PVSOL premium, developed by Valentin Software is a PV simulation program with facilities of 3D visualization and detailed shading analysis for the calculation of photovoltaic systems in combination with electrical equipment, battery systems, and electric vehicles. The main steps of simulation by PVSOL are given below [22]

- This was used for 3-D designing. The format of the exported 3-D model from Google earth was changed and later imported into PVSOl.
- Location of the site was chosen from a software integrated map that downloaded weather data.
- Different parameters such as albedo, mismatch loss, diode loss, soiling loss were set according to our system.
- During the 3D design module model was chose from the MODULE MOUNTING tab, we could also configure row spacing, tilt angle, orientation, the gap between module, the height of the module to match our desired orientation.
- The panel was placed on the roof using either the cover mounting surface option or manually putting panels on desired places.
- Inverter was configured from MODULE CONFIGURATION. The program automatically matches the number of inverter and string connections from the selected inverter model.
- The data was adopted, and shading simulation was done.
- Load profile was implemented from the Load tab.
- The data was adopted, and shading simulation was done.

After simulation, the software generated a detailed simulation result.

2.2.2 PVsyst

PVsyst is an energy modeling tool that helps in analyzing how much solar energy can be harvested and then converted into electrical energy from a particular site or location. It was developed by PVsyst SA. The main steps of simulation by PVsyst are given below [23].

•At first, the location was chosen, a synthetic simulation of the climate was generated based on the available meteorological data of the site.

•At the ORIENTATION tab, preferred system orientation was chosen.

•In the SYSTEM tab, all the detailed configuration of the system were set.

•Module model, Inverter model, number of MPPT, number of inverters, number of modules in parallel, or series had to be set here manually.

•Loss settings were set under the tab DETAILED LOSS.

After the simulation, a detailed report was obtained.

2.2.3 SAM (System Advisory Model)

The System Advisor Model (SAM), developed by NREL, is a techno-economic software model that facilitates system designing decision-making for people involved with renewables. The main steps of simulation by SAM are given below [24].

• At first, the location was chosen, and the meteorological file was downloaded from the LOCATION AND RESOURCE tab. Albedo was also set here.

• Under the MODULE tab- module number, mounting height above the ground were set.

• Inverter model was chosen from the INVERTER tab.

- In SYSTEM AND SIZING tab AC configuration, such as the number of inverters, DC to AC ratio, the desired array size was chosen. Electrical configuration such as modules per string in subarray, strings in parallel sub-array was set. Tilt, orientation, ground coverage ratio were also set from here.

- Losses were set from the LOSS tab.

2.2.4 Brief Description of the System.

Figure below summarizes the main work flow diagram of each software.

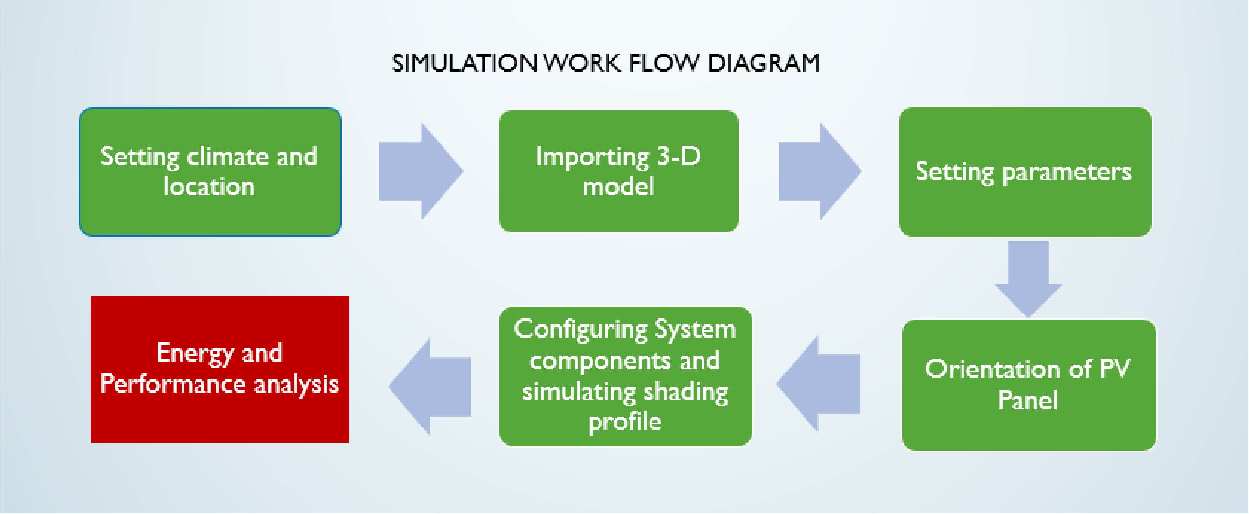


Figure 12: Work flow diagram

With the obtained result from 3 software mean value is calculated to obtain accurate result.

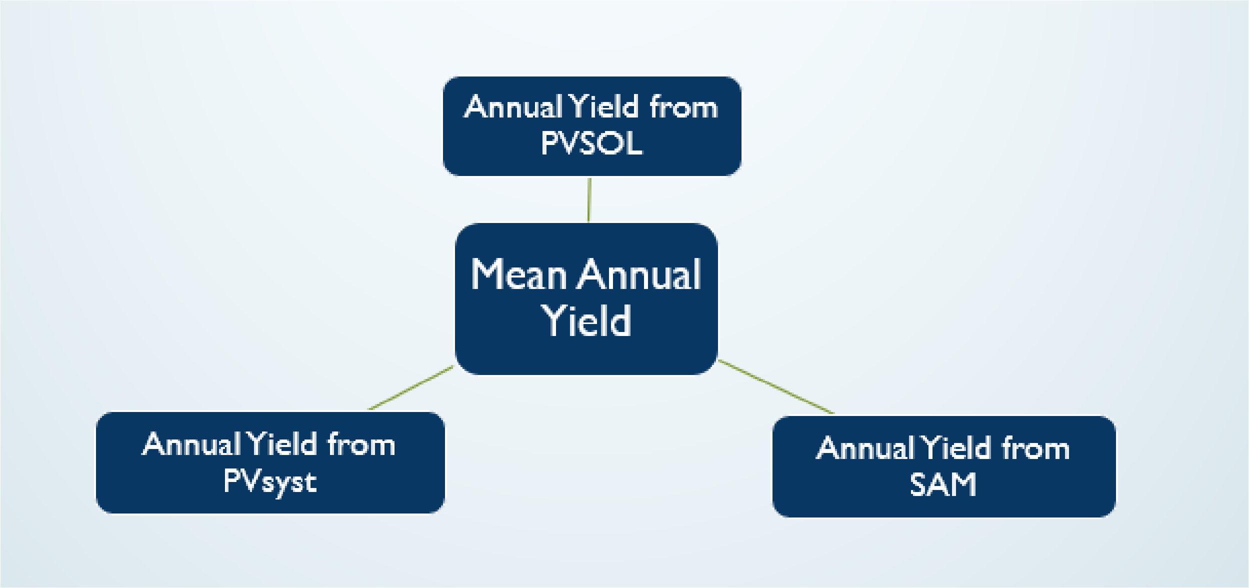


Figure 13: Mean Annual Yield obtained from 3 software

With the result obtained from 3 software, 2 detailed model have been simulated using the Bifacial Solar panels at different location. For the first part a design and simulation has been carried out in load shedding prone industrial area for a University residential hall. For the second part design and simulation for marine drive road Cox's Bazar Has been simulated.

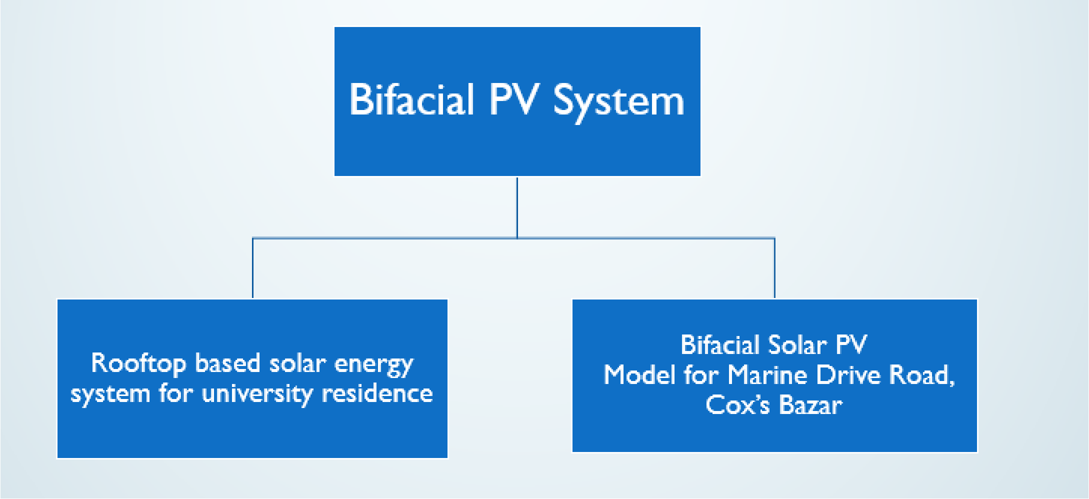


Figure 14: Bifacial solar model in 2 different location

Section-3

Rooftop Based Solar Energy System for University Residence

In this article, we simulated the rooftop of the IUT campus residential hall. Bifacial modules have been used for our research here. A lot of careful calculations are needed to physically implement such a system and there are also many maintenance problems. For this reason, in three different orientations, we have demonstrated rigorous machine modeling and simulation and evaluated the feasibility of each and finally provided a comparative study between the three setups.

3.1 Site Information

For our site, residential hall of Islamic University of Technology (IUT) is chosen. IUT is located at Board-Bazar Gazipur an industrial prone area where load-shedding is a common occurrence. Thus, to maintain a healthy academic and personal life style constant and uninterrupted supply of electricity is much needed. Although, IUT has existing generator to provide backup power supply, this is not a sustainable way to provide alternative sources of energy. Hence, solar energy potential is analyzed for providing an eco-friendly solution to the prevailing energy crisis.

In total, 3 orientation has been setup for optimum harvesting of solar energy using the bifacial panel. On the other hand, a Monofacial based setup has been built to find the bifacial energy gain.

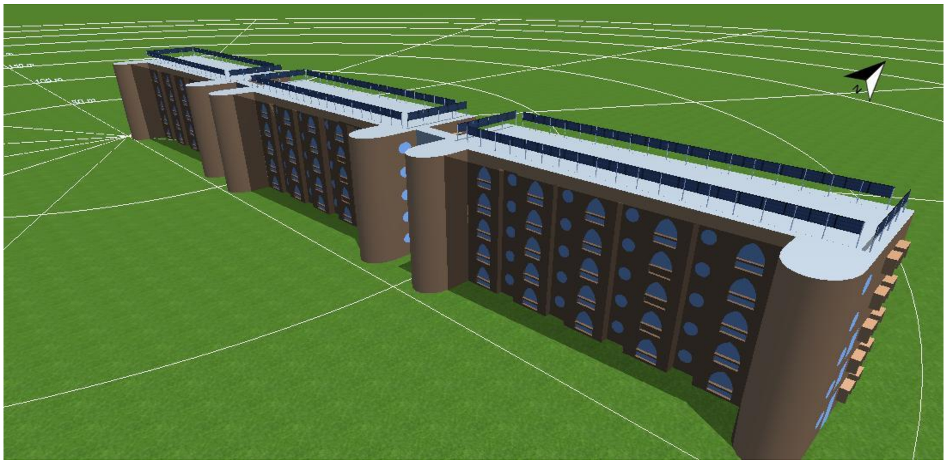


Figure 15: Residential hall of IUT

3.2 Meteorological Information

The annual temperature is mild in Gazipur. The graph below shows the variation in temperature difference throughout the year. January and February have the lowest temperature of 16-18 degree. Highest temperature is obtained during the month of May, June, July and August.

Direct and Diffuse irradiance has been shown on another graph. Here the variation is because of weather factor. In general, diffuse radiation is high during March, April and May and falls afterwards due to the cloudy sky. A low value is maintained during the winter season. On the other hand, diffuse irradiance suffers less during monsoon thus, it doesn't show a dramatic fall during that time.

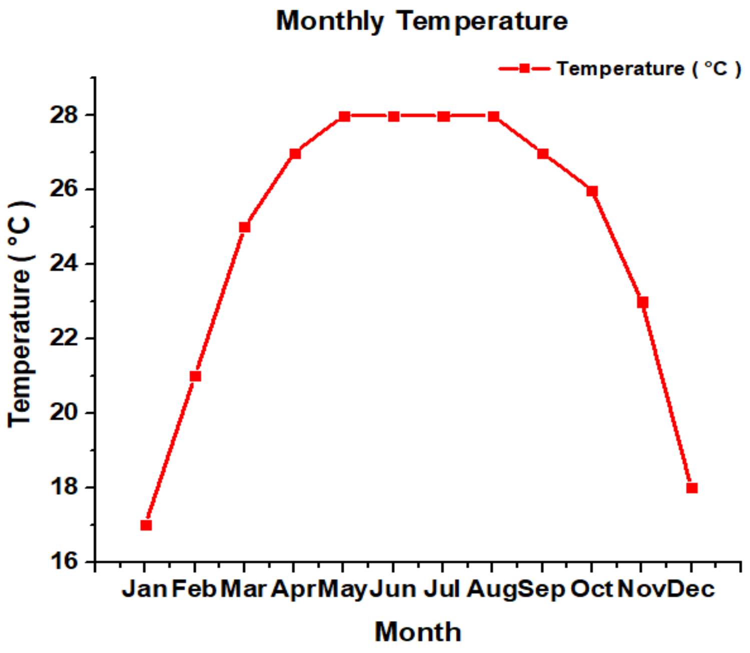


Figure 16: Monthly Temperature variation throughout the year

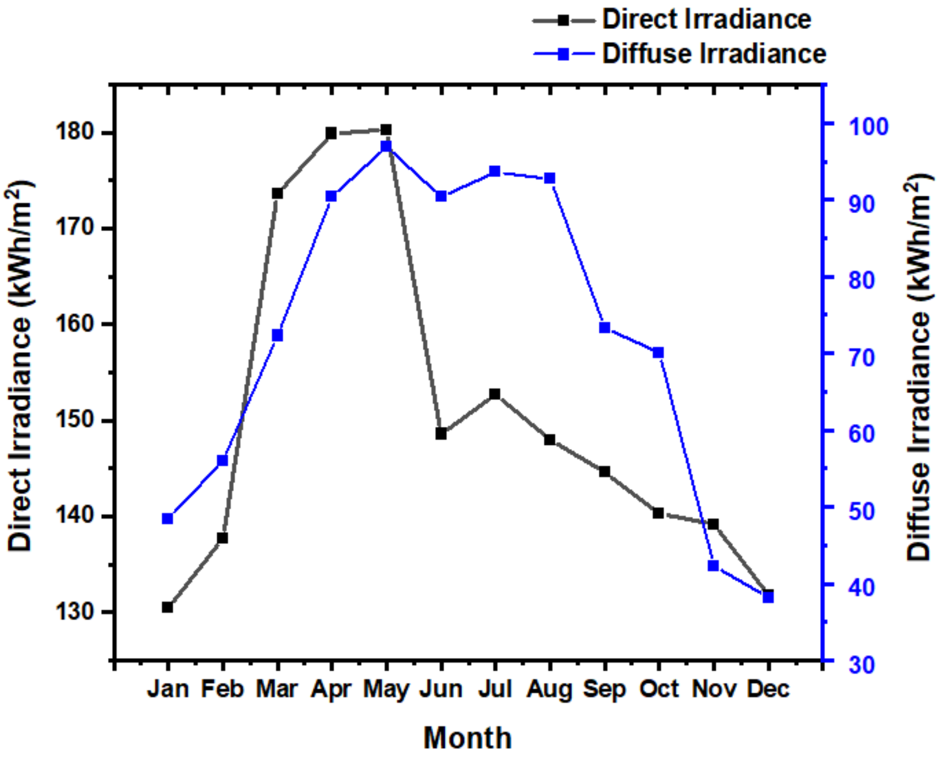


Figure 17: Monthly variation in irradiance throughout the year.

The table below summarizes the meteorological information.

Table 8: Meteorological information

Site name	Islamic University of Technology
Coordinates	23.9481° N, 90.3793° E
Annual global irradiance	1793 kWh/m^2
Annual horizontal diffuse irradiance	864 kWh/m^2
Average temperature	24.9 °C

3.3 Orientation-1

In case of orientation-1 only bifacial modules are used. Here, in total 174 modules are placed at the edge of the rooftop at 90-degree tilt angle. Azimuth was respectively 90 degree and 180 degree. A total of 174 modules were placed on 3 different blocks to cover the whole rooftop.

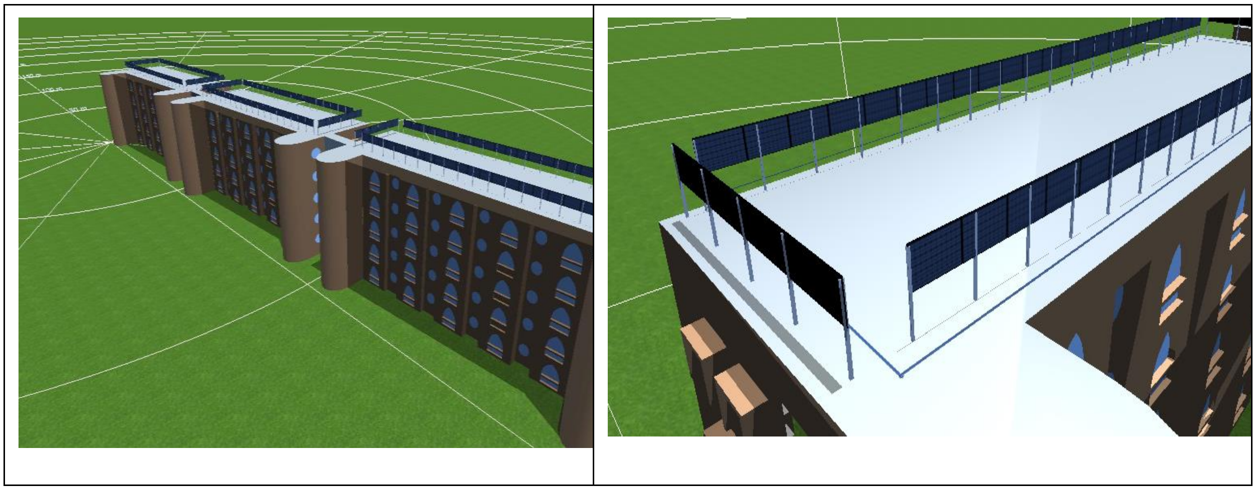


Figure 18: Vertically mounted modules at the edge of roof top

From this setup the result obtained showed mean annual PV energy of 92,508.62 kWh, performance ratio of 71%, shading loss of 1.3 %.

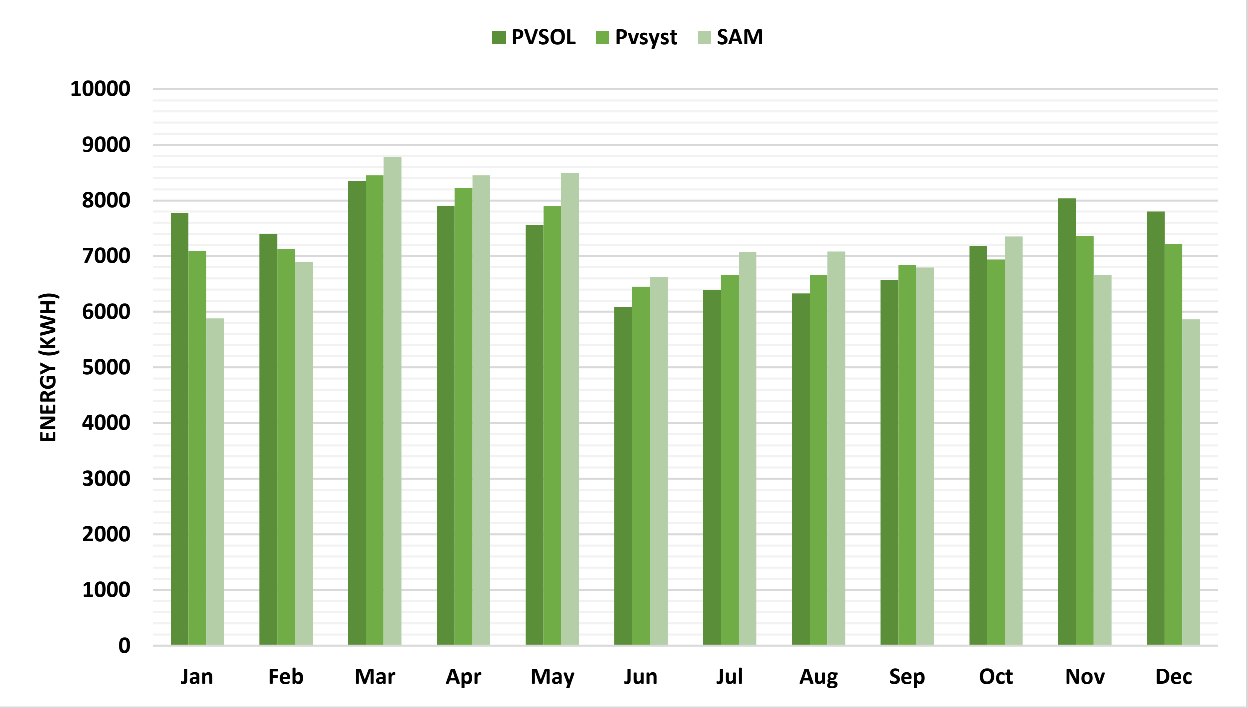


Figure 19: Monthly Energy profile for Orientation-1

3.4 Orientation-2

Same number of modules were used for orientation-2 but this time the modules were facing East-West direction with azimuth of 90 degree. Tilt angle was 90 degree as well.

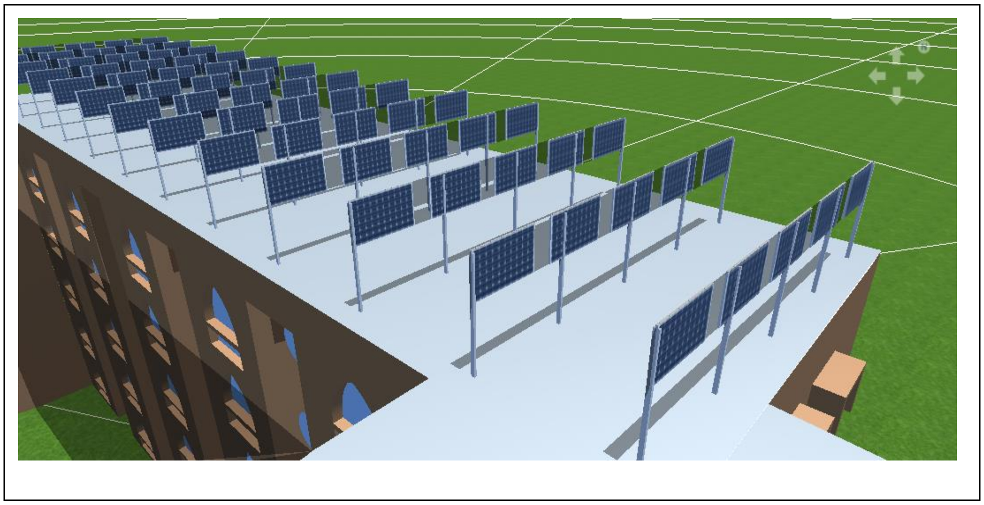


Figure 20: Bifacial modules facing East-West direction

From this setup the result obtained showed mean annual PV energy of 94,643.48 kWh, performance ratio of 66.4 %, shading loss of 5.7 %.

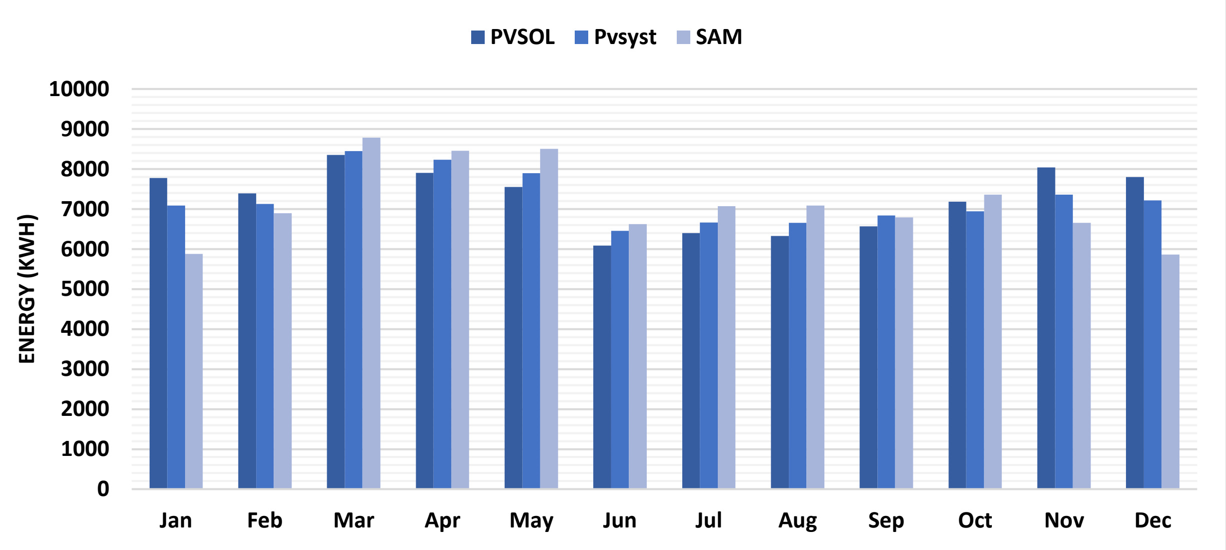


Figure 21: Monthly Energy Profile for Orientation-2

3.5 Orientation-3

Same number of modules were used for orientation-3 but this time the modules were facing south with azimuth of 180 degree. Tilt angle was 24 degree which is the optimum tilt angle for Bangladesh considering the location.

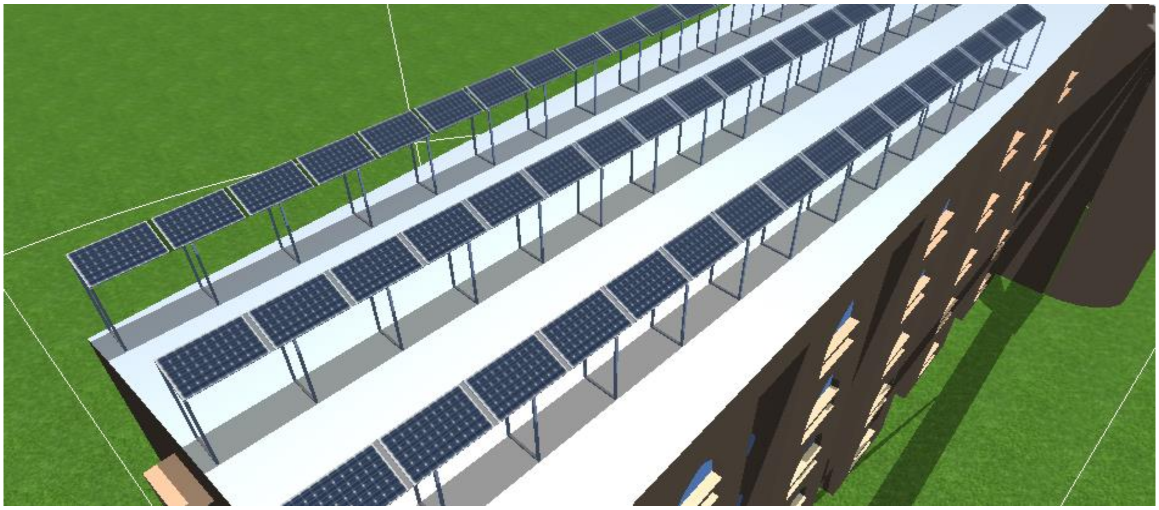


Figure 22: Bifacial modules tilted 24 degree

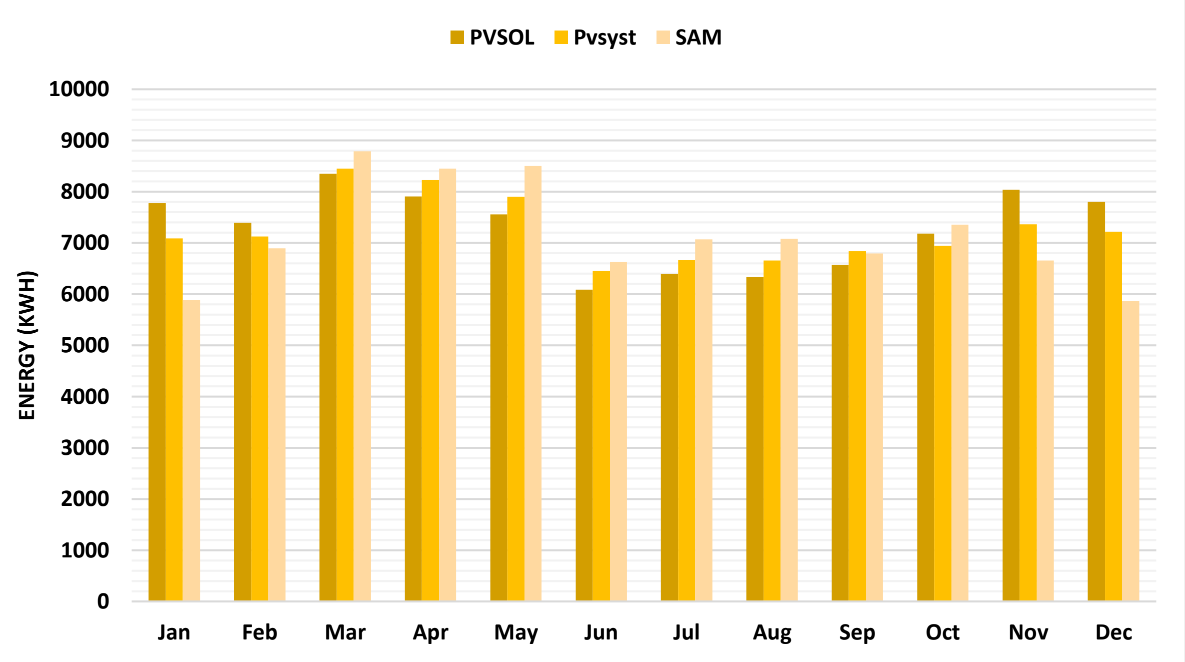


Figure 23: Monthly Energy profile for Orientation-3

From this setup the result obtained showed mean annual PV energy of 96,758.94 kWh, performance ratio of 72 %, shading loss of 0.4 %.

3.6 Orientation-4

Same number of modules were used for orientation-4 but this time the monofacial modules were facing south with azimuth of 180 degree. Tilt angle was 24 degree which is the optimum tilt angle for Bangladesh considering the location. Monofacial panels were used as a reference for finding out the bifacial gain of the system.

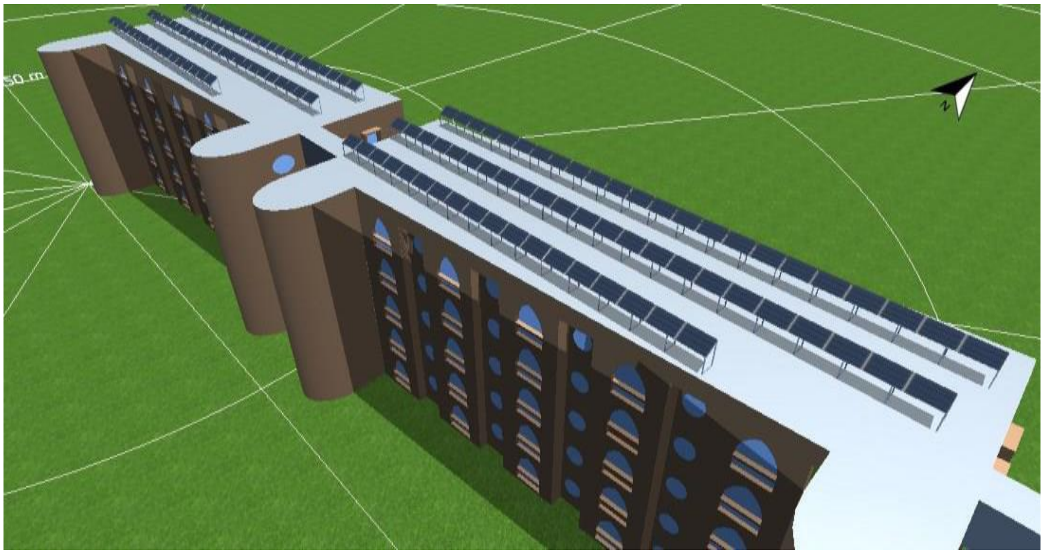


Figure 24: Monofacial modules tilted 24 degree

From this setup the result obtained showed mean annual PV energy of 81,838.48 kWh, performance ratio of 73.3 %, shading loss of 0.4 %.

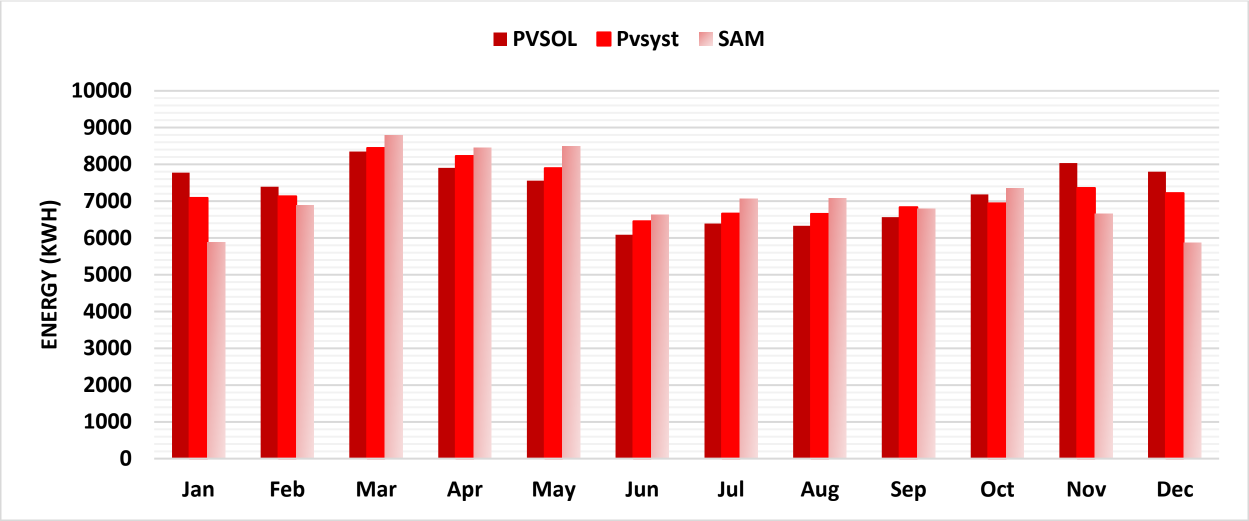


Figure 25: Monthly Energy profile for Orientation-4

3.7 Bifacial Energy Gain

To find out the annual performance gain of the bifacial panel compared to monofacial one. For orientation-1 the annual gain is 13% for orientation-2 it is 15.6%, for orientation-3 gain is 6%.The graph below shows the bifacial gain throughout the year.

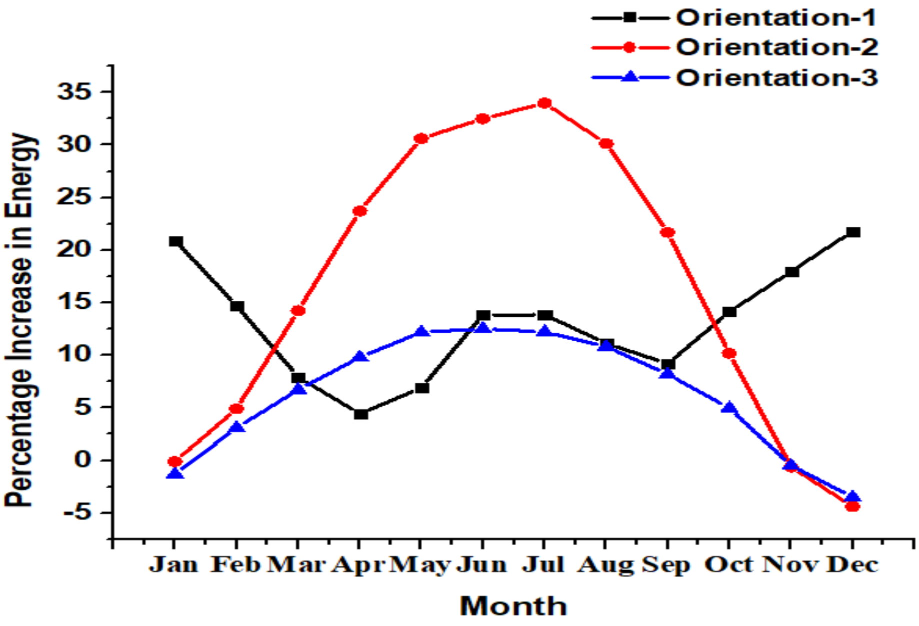


Figure 26: Monthly bifacial gain of each orientation throughout the year.

3.8 Prospect and Conclusion

In this research a simulation-based approach is taken to carry out a feasibility analysis of bifacial mounted system for University residence. Vertical mounted bifacial system seems to have more upper hand in terms of producing energy compared to traditional single sided monofacial based panels. Thus, we can conclude that bifacial panels have huge prospect in Bangladesh. In future this type of setup can be utilized too.

Section-4

Bifacial Solar PV Model for Marine Drive Road, Cox’s Bazar

4.1 Objective

Here a Design and Simulation of grid connected PV system is done by utilizing vertically mounted bifacial panel in the marine drive road Cox’s Bazar. This is achieved by using 3 of the prominent software namely PVSOL, PVsyst, SAM. The hardware installation of the solar panels is quite a challenge, especially in a marine environment like Cox’s Bazar. Hence, software-based investigation with bifacial PV panels opens a new window to attain knowledge and ideas so that constructive decisions can be made before hardware implementation of this type of project. The software-based analysis will be able to contribute to speculating the feasibility and applicability of the system. This will help in solving the problem of the energy crisis in Bangladesh.

4.2 Site Information

4.2.1 Cox’s Bazar

Situated around 150 km south of Chittagong Metropolitan city, Cox's Bazar is linked both via air and street with the capital of Bangladesh, Dhaka and the main port city Chittagong. It is a city, fishing port, the travel industry focus and area base camp in southeastern Bangladesh. It is renowned generally for its long sandy sea shore.

Geography and Climate:

Cox's Bazar town has a region of 6.85 km2 (2.64 sq mi), and is limited by Bakkhali Stream on the north and East, Straight of Bengal in the West, and Jhilwanj Association in the south.

The sea shore in Cox's Bazar has a delicate incline and with a whole length of 155 km (96 mi) it is regularly named the "longest natural unbroken sea beach" on the planet.

Cox's Bazar lies on a beach front plain in the southeastern corner of Bangladesh. From over, the plain seems to swell out into the Inlet of Bengal. Along the shore is a broad zone of sea shore and rises. The greater part of the city is based on a floodplain that is lower in height than the ridges, making it more powerless to flooding because of twisters and tempest floods. The Cox's Bazar coastal plain was framed after the ocean arrived at its current level around 6,500 years prior, with the region of the ebb and flow floodplain initially shaping a dreg sink that has since been progressively filled in by the Bakkhali waterway just as more modest streams descending from the hills.

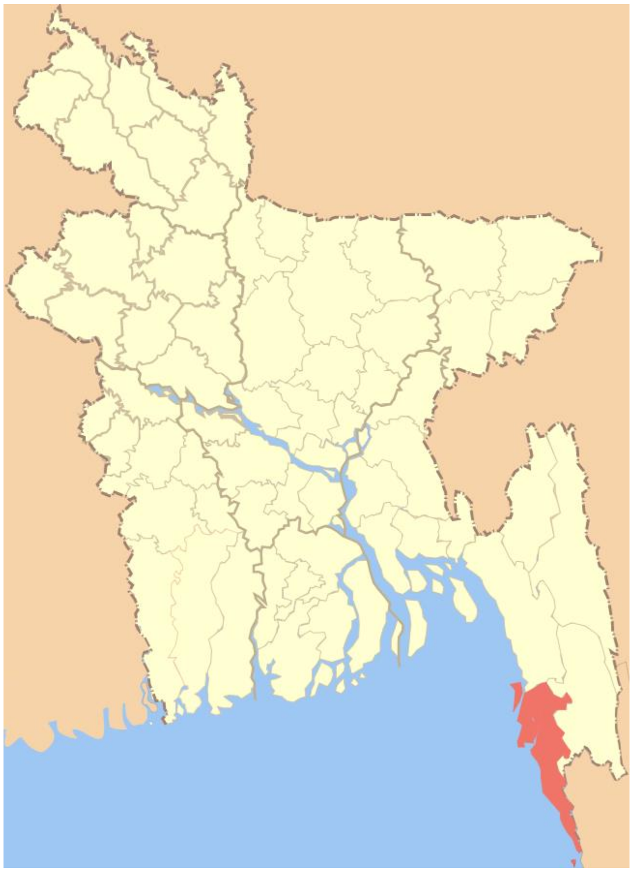
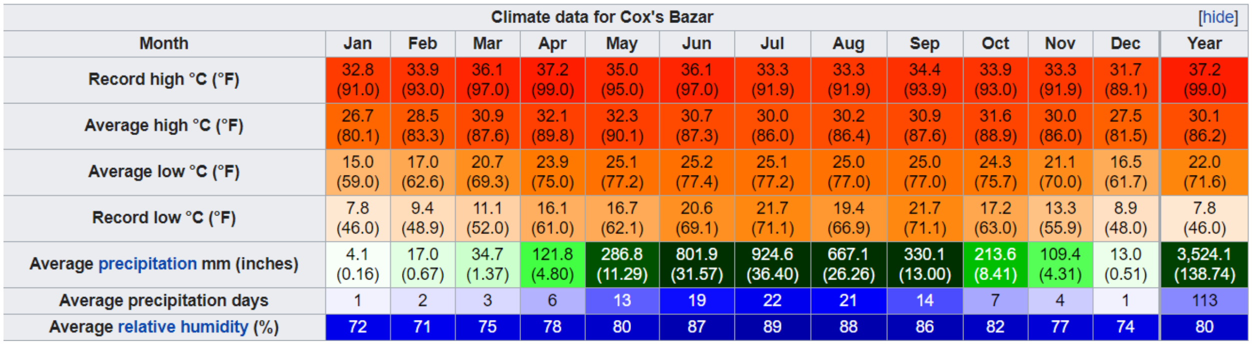


Figure 27: Location of Chittagong

Figure 28: Location of Cox’s Bazar

The environment of Bangladesh is for the most part controlled by its area in the tropical rainstorm district: high temperature, substantial precipitation, and by and large inordinate moistness, with particular occasional variations. The environment of Cox's Bazar is generally like the remainder of the country. It is additionally described by the area in the seaside region. The yearly normal temperature in Cox's Bazar is a limit of 34.8 °C (94.6 °F) and at least 16.1 °C (61.0 °F). The normal measure of precipitation is 3,524 mm (138.7 in).



Climate data for Cox's Bazar [hide]

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °C (°F)	32.8 (91.0)	33.9 (93.0)	36.1 (97.0)	37.2 (99.0)	35.0 (95.0)	36.1 (97.0)	33.3 (91.9)	33.3 (91.9)	34.4 (93.9)	33.9 (93.0)	33.3 (91.9)	31.7 (89.1)	37.2 (99.0)
Average high °C (°F)	26.7 (80.1)	28.5 (83.3)	30.9 (87.6)	32.1 (89.8)	32.3 (90.1)	30.7 (87.3)	30.0 (86.0)	30.2 (86.4)	30.9 (87.6)	31.6 (88.9)	30.0 (86.0)	27.5 (81.5)	30.1 (86.2)
Average low °C (°F)	15.0 (59.0)	17.0 (62.6)	20.7 (69.3)	23.9 (75.0)	25.1 (77.2)	25.2 (77.4)	25.1 (77.2)	25.0 (77.0)	25.0 (77.0)	24.3 (75.7)	21.1 (70.0)	16.5 (61.7)	22.0 (71.6)
Record low °C (°F)	7.8 (46.0)	9.4 (48.9)	11.1 (52.0)	16.1 (61.0)	16.7 (62.1)	20.6 (69.1)	21.7 (71.1)	19.4 (66.9)	21.7 (71.1)	17.2 (63.0)	13.3 (55.9)	8.9 (48.0)	7.8 (46.0)
Average precipitation mm (inches)	4.1 (0.16)	17.0 (0.67)	34.7 (1.37)	121.8 (4.80)	286.8 (11.29)	801.9 (31.57)	924.6 (36.40)	667.1 (26.26)	330.1 (13.00)	213.6 (8.41)	109.4 (4.31)	13.0 (0.51)	3,524.1 (138.74)
Average precipitation days	1	2	3	6	13	19	22	21	14	7	4	1	113
Average relative humidity (%)	72	71	75	78	80	87	89	88	86	82	77	74	80

Figure 29: Climate data for Cox’s Bazar

Most of Cox's Bazar locale depend on the travel industry. A huge number of unfamiliar and Bangladeshi locals visit this waterfront city consistently. Various hotels, guest houses, and inns have been underlying the city and waterfront district and the hospitality industry is a major employer in the area.

Various individuals are engaged with the fishing and assortment of shellfishes and ocean items. Shellfish, snails, pearls and adornments produced using shells are mainstream with the vacationers in the ocean side and city stores. Various individuals are likewise associated with the transportation business for sightseers. Numerous individuals of the area are ranchers.

4.2.2 Marine Drive Road

The second phase of the project is based on the longest marine drive in the world - Cox's Bazar – Teknaf Marine Drive. It is an 80 km long road screeched from Cox's Bazar's Kalatali (latitude 21° 24' 20.9″ N, longitude 91° 29' 24.6″ E) to Teknaf (latitude 20°52′N, longitude 92°18′E).

The road construction work was done by 16th Engineer Construction Battalion of Bangladesh Army. Bangladesh Roads and Highways Department supervises the construction. The whole construction required around BDT 1050 crore (US$120 million).[25]

At first, the Cox's Bazar Marine-Drive Road Project was affirmed to develop an 80 km long Cox's Bazar-Teknaf Marine Road in 1993. However, because of inaccessibility of asset, the undertaking was eliminated. The road is constructed in three phases. The first phase is a 24 km road from Kalatoli to Inani (latitude 21 09' 00" N, longitude 92 04' 00' E), another 24 km under second phase is from Inani to Shilkhali (latitude 21°49'33.5"N longitude 92°00'32.9"E), and the third phase is extended from Shilkhali to Teknaf. [26]

It is trusted that Cox's Bazaar will eventually want to pull in more tourist with this road. It has been already working as an attractive tourist spot with its beautiful miles of golden sands, surfing waves, rare conch shells, towering cliffs, pleasant seafood, tribes, colorful pagodas, and temples. This tourist friendly environment also contributes to economic growth of sounding area of marine road, especially the Cox's Bazar where new hotel, cottage, and resorts are being constructed. [27]

The geographical location of the road has made it a suitable place for utilization of solar energy. The coastline receives around 4.77 KWh/m2/day average annual solar radiation. For a country like Bangladesh where land price is very high, this kind of project will make efficient usage of space of the road.

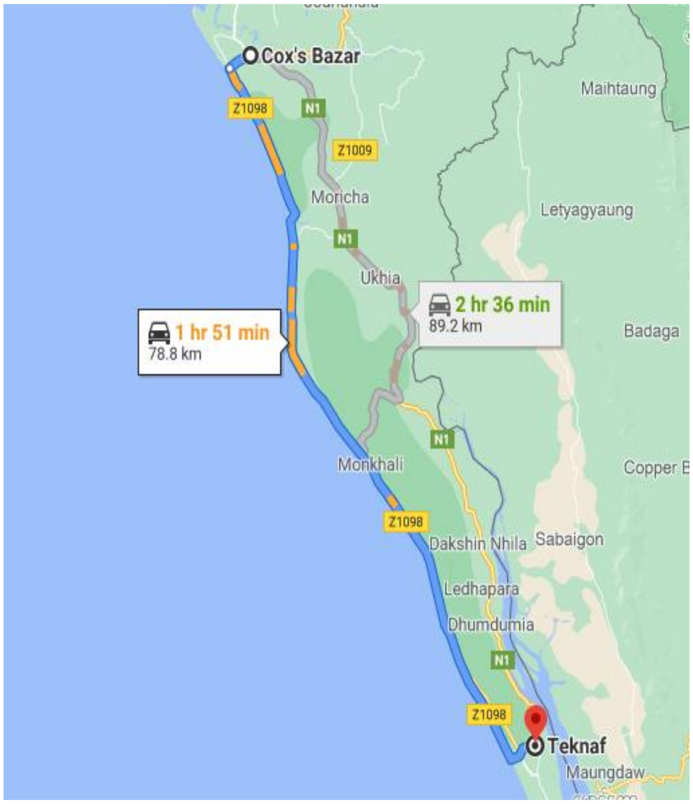


Figure 30: Marine drive road

4.3 Design of the system

A 3D design was created in PVSOL to find the annual yield. Later PVsyst and SAM were used to model the same system and verify the result. A length of 200 meters is taken into consideration for primary simulation and analysis. Hence, a total number of 117 modules were placed within the specified length.

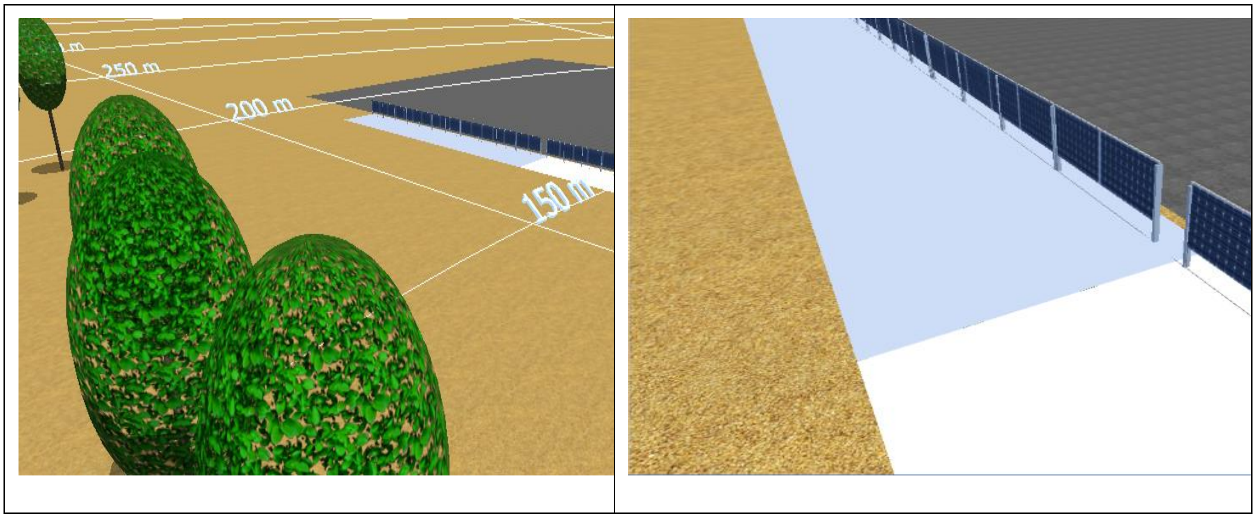


Figure 31: Design of the system created using PVSOL

For this design tilt angle was considered as 90 degree and azimuth 240 degree. To ensure maximum reflection off the ground a white painted surface can be implemented around the standing bifacial panels. Here, a descent albedo of 0.65 is considered. Since the weather is near costal area, the panels will be exposed to lots of humid air and salty water. Thus, overall soiling loss is considered 5% keeping in mind the low soiling loss experienced by vertically mounted bifacial panels. Mounting height is 2m above ground to ensure maximum absorption of light from reflected surface. In this case a 200-meter model road is used for simulation which is later extrapolated for entire length of the road.

A similar work flow has been followed for designing and simulating this model just like the one for University residence.

4.4 Result

4.4.1 Simulation Result

The annual yield was 72185.4 kWh, 69867 kWh, 69426.31 kWh in PVSOL, PVsyst, SAM respectively. Hence the total average yield was 70492.9 kWh. The highest yield was obtained during March when both direct and diffuse irradiation was high. Although April had the highest direct and diffuse irradiation value, the temperature was quite high causing it to lose efficiency. The lowest yield was obtained in July due to rain and cloudy weather.

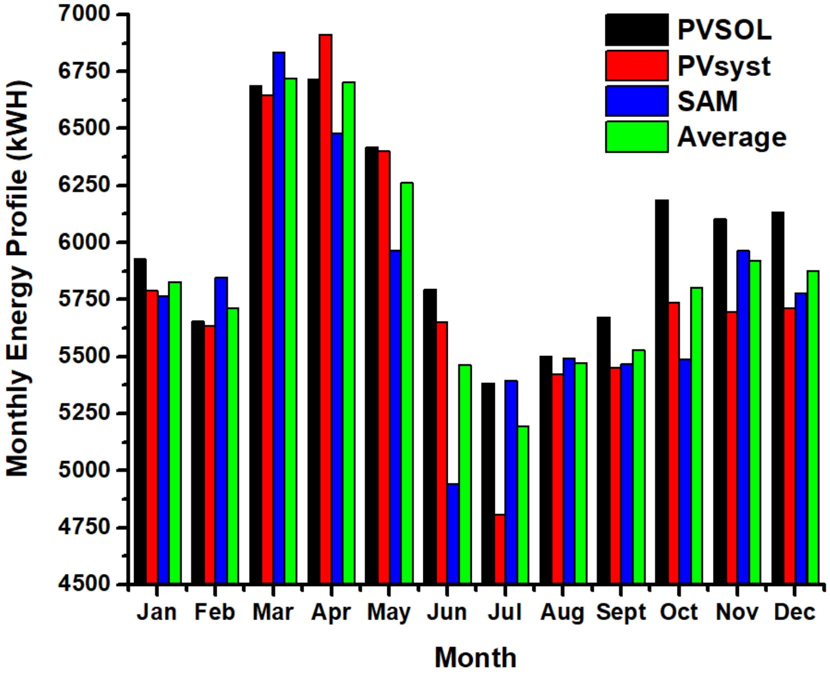


Figure 32: Annual energy profile obtained from 3 software

4.4.2 Bifacial Gain

To analyze the prospect of bifacial system compared with traditional monofacial panel, a comparison analysis has been done to find the bifacial gain of the system. The necessary simulations were performed for monofacial system where the mean annual energy was obtained 62.8 MWh while for bifacial it was 70.5 MWh. Thus, annual bifacial gain is found to be 12.26%.

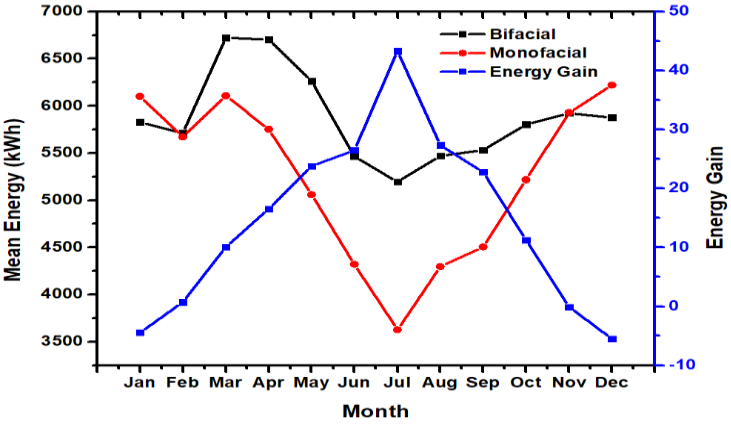


Figure 33: Monthly bifacial gain

4.5 Prospect in Future

If the model is extrapolated for the entire road (almost 80 Km), the annual generated yield will be almost 28.2 GWh (approximately). Hence, this software approach of clean energy project will prevent carbon emission which will be released in a conventional fossil fuel-based power plant. So, this promising source of green energy can be implemented in a popular tourist destination like Cox’s Bazar with a view to turning it into an eco-friendly city.

Section-5

Conclusion

Design, simulation and analysis of Bifacial based PV system on the roof top of North-hall of residence of Islamic University of Technology and vertical mounted bifacial modules along the marine drive road Cox's Bazar have been presented here. A detailed 3D design was created and analyzed using three different software and mean annual yield was obtained from the data of 3 software. In case of rooftop-based energy system the mean annual yield for orientation-1 was 92,508.62 kWh, for orientation-2 the obtained value was 94,643.48 kWh, in case of orientation-3 86,758.94 kWh and for the reference purpose monofacial panel-based energy system was simulated which showed annual yield of 81,838.48 kWh. All the bifacial panel-based energy system showed a significant performance increase compared to monofacial setup. For marine drive road Cox's Bazar, a 200-meter model road was created in PVSOL and annual energy production was calculated from 3 software. Mean annual energy obtained was 70492.9 kWh. If the model is extrapolated for the entire length of the road (80 KM) total annual yield will be 28.2 GWh.

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