TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
Department of Materials and Environmental Technology

THESIS TITLE

ENERGY SOLUTION FOR THE REMOTE AREAS OF BANGLADESH
ENERGIALAHENDUS BANGLADESHI KAUGETELE PIIRKONDADELE

MASTER THESIS

Üliõpilane: Enam Hossain

Üliõpilaskood: 194389KAYM

Juhendaja: Eduard Latõšov
Associate Professor
Department of Energy Technology

Tallinn 2021

(*On the reverse side of title page*)

AUTHOR'S DECLARATION

Hereby I declare, that I have written this thesis independently.
No academic degree has been applied for based on this material. All works, major viewpoints and data of the other authors used in this thesis have been referenced.

20.05.2021

Author: Enam Hossain

Thesis is in accordance with terms and requirements

20.05.2021

Supervisor: Eduard Latõšov
/signature/

Accepted for defence

"......."...................20… .

Chairman of theses defence commission: ....
/name and signature/

Non-exclusive licence for reproduction and publication of a graduation thesis[1]

I Enam Hossain,

1. grant Tallinn University of Technology free licence (non-exclusive licence) for my thesis Energy Solution for The Remote Areas of Bangladesh,

supervised by Eduard Latõšov,

1.1 to be reproduced for the purposes of preservation and electronic publication of the graduation thesis, incl. to be entered in the digital collection of the library of Tallinn University of Technology until expiry of the term of copyright;

1.2 to be published via the web of Tallinn University of Technology, incl. to be entered in the digital collection of the library of Tallinn University of Technology until expiry of the term of copyright.

2. I am aware that the author also retains the rights specified in clause 1 of the non-exclusive licence.

3. I confirm that granting the non-exclusive licence does not infringe other persons' intellectual property rights, the rights arising from the Personal Data Protection Act or rights arising from other legislation.

20.05.2021 (date)

[1] *The non-exclusive licence is not valid during the validity of access restriction indicated in the student's application for restriction on access to the graduation thesis that has been signed by the school's dean, except in case of the university's right to reproduce the thesis for preservation purposes only. If a graduation thesis is based on the joint creative activity of two or more persons and the co-author(s) has/have not granted, by the set deadline, the student defending his/her graduation thesis consent to reproduce and publish the graduation thesis in compliance with clauses 1.1 and 1.2 of the non-exclusive licence, the non-exclusive license shall not be valid for the period.*

Department of Materials and Environmental Technology

THESIS TASK

Student: Enam Hossain, 194389KAYM (name, student code)
Study programme: KAYM, Materials and Processes for Sustainable Energetics (code and title)
main speciality: Processes for Sustainable Energetics
Supervisor(s): Associate Professor, Eduard Latõšov, +3726203908 (position, name, phone)

Thesis topic:
(in English) Energy solution for the remote areas of Bangladesh.
(in Estonian) Energialahendus Bangladeshi kaugetele piirkondadele.

Thesis main objectives:

1. Finding the electricity supply problems in remote areas.
2. Finding out alternative solutions for grid electricity.
3. Calculating for the CSP and PV system and find out a better solution.

Thesis tasks and time schedule:

No	Task description	Deadline
1.	Finding out problems of electricity supply in remote areas.	11.10.2020
2.	Finding out the possibilities to implement different technologies (PV & CSP).	06.02.2021
3.	Calculating and writing the thesis.	21.05.2021

Language: English **Deadline for submission of thesis:** 21.05.202

Student: Enam Hossain .... "......."...............................2021
/signature/

Supervisor: Eduard Latõšov .... "......."......................201….a
/signature/

Consultant: .... "......."......................201….a
/signature/

Head of study programme: Sergei Bereznev "......."......................201.a
/signature/

Terms of thesis closed defence and/or restricted access conditions to be formulated on the reverse side

TABLE OF CONTENTS

PREFACE 7
List of figures 8
List of abbreviations and symbols 9
1. Introduction 10
1.1 Background and Problem 11
1.2 Importance of Renewable Energy 12
1.3 Thesis Structure 12
2. Electricity Supply and Production 13
2.1 Problems in Rural Areas 13
2.2 Electricity Price 14
2.3 Plans for Rural Areas 14
2.4 Conclusion 15
3. Solar Resources in Bangladesh 16
3.1 Solar Radiation 16
3.2 Geological Location of Bangladesh 17
3.3 Solar Irradiation Data 18
3.4 Temperature Effect on Solar Cell 20
3.5 Conclusion 21
4. Technology 22
4.1 Concentrated Solar Power (CSP) Technologies 22
4.1.1 Parabolic Trough 22
4.1.2 Solar Power Tower 23
4.1.3 Enclosed Trough 24
4.1.4 Parabolic Dish Stirling 24
4.2 Photovoltaic Cell Technology 25
4.2.1 Monocrystalline Silicon Cell 25
4.2.2 Polycrystalline Silicon Cell 25
4.2.3 Thin Film Solar Cell 26

4.3 Solar Tracking Technology 26
4.4 Possible Schemes 27
4.5 Comparison Between PV and CSP 27
4.6 Investment Cost 29
4.6.1 Cost of Photovoltaic Cell System 29
4.6.2 Cost of Concentrated Solar Power System 30
4.6 Conclusion 30
5. Electricity Generation 31
5.1 Electricity Generation by PV System 31
5.2 Electricity Generation by Parabolic Trough CSP System 32
6. Feasibility Analysis 34
6.1 Methodology 34
6.2 Main Economic and Technical Assumption 35
6.2.1 Discount Rate 35
6.2.2 Operation and Maintenance Expenditures 35
6.2.3 Financial Lifetime of The Calculation 36
6.2.4 Investment Expenditure In The Year 36
6.3 Levelized Cost of Electricity 36
6.4 Sensitivity Analysis 37
6.4.1 Sensitivity Analysis for PV System 37
6.4.2 Sensitivity Analysis for CSP System 39
7. Result & Conclusions 40
SUMMARY 41
LIST OF REFERENCES 42
APPENDIX 1 46
APPENDIX 2 48

PREFACE

Firstly, I would like to thank my supervisor, Eduard Latõšov, for his full guidance and support, even in this pandemic situation throughout this research. I have enjoyed myself a lot working with him.

Secondly, I am forever grateful to my parents, who have always supported me throughout my life. I am thankful to my Siidisaba friends, who had helped me a lot when I was in difficult situations. Finally, I would like to thank Umme Sayma Bushra and Momin Reja for being my guardian in this foreign land and giving me continuous support.

In this study, we tried to determine the main problems in remote areas for which they are deprived of electricity. After finding out the major problem, we tried to find alternative technologies to install to provide electricity supply to remote areas. PV and CSP systems were chosen for this research project. Different technologies of these two systems were discussed, and two of these techniques were selected for further calculation. As CSP technology is built for large capacity and small consumer groups in remote areas, it would not be a feasible idea to implement. But still, we showed the calculation for the CSP system; if in the near future there is proper infrastructure and grid line to provide electricity to those remote areas, we can use this calculation.

List of figures

Figure 1.1: Chart of installed power by plant and fuel type
Figure3.1: Influence of atmosphere in solar radiation
Figure 3.2: Solar map of Bangladesh
Figure 3.3: Hourly and Daily Irradiation Data
Figure 3.4: Daily temperature data of the selected area of Bandarban
Figure 3.5: Available temperature in a year of the selected area of Bandarban
Figure 4.1: Parabolic Trough type CSP design
Figure 4.2: The Planta Solar 10 (PS10) is the world's first commercial utility-scale solar power tower in Sanlucar la Mayor, Spain
Figure 4.3: Monocrystalline vs. Polycrystalline silicon solar cell
Figure 4.4: Thin-film solar cell
Figure 4.5: Single-axis solar tracking system
Figure 4.6: Dual-axis solar tracking system
Figure 5.1: Sunpower solar panels
Figure 5.2: Comparison between Sunpower solar panels and conventional solar panels
Figure 5.3: Relation between annual full load hours, storage capacity, and Direct normal irradiance
Figure 5.4:Relation between FLH and DNI
Figure 6.1: LCOE calculation of PV system
Figure 6.2: LCOE calculation for CSP system
Figure 6.3: Sensitivity analysis in respect of lifetime
Figure 6.4: Sensitivity analysis in respect of investment cost
Figure 6.5: Sensitivity analysis in respect of efficiency
Figure 6.6: Sensitivity analysis in respect of lifetime
Figure 6.7: Sensitivity analysis in respect of investment cost

List of abbreviations and symbols

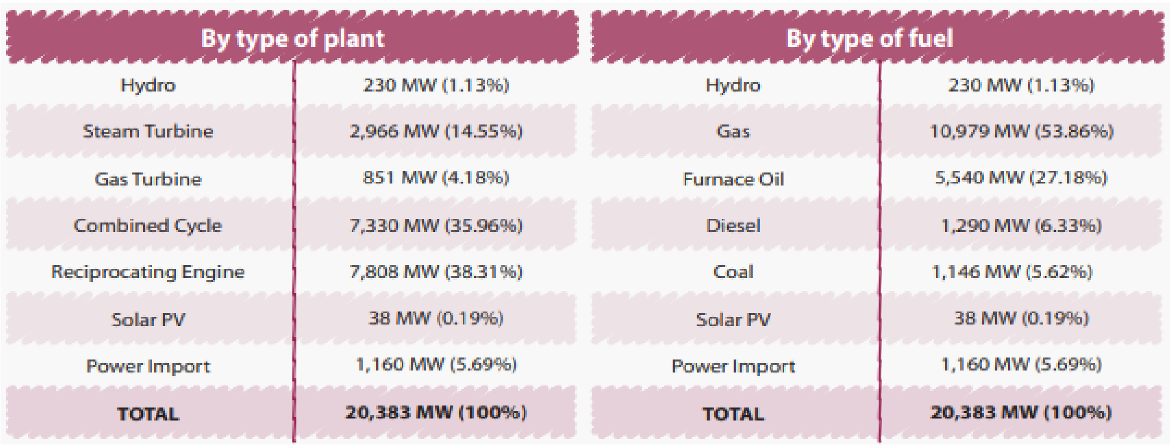
SHS	Solar Home System
PV	Photovoltaic
O&M	Operations & Maintenance
LCOE	Levelized Cost Of Electricity
kWh/m^2	KiloWatt-hour per meter square
IRENA	International Renewable Energy Agency
GHI	Global Horizontal Irradiance
DNI	Direct Normal Irradiance
DHI	Diffuse Horizontal Irradiance
CSP	Concentrated Solar Power
CAPEX	Capital Expenditures

1. Introduction

In the past few decades, renewable energy has seen a boom as an eco-friendly alternative to fossil fuels and nearly inexhaustible. In several countries, renewable energy sources, such as wind power systems, hydraulic systems, solar thermal systems, photovoltaic systems, and biomass plants, are now actively contributing to a large proportion of the total grid. The limited fossil fuel supplies are being strained every hour due to the exponential rise in power demand around the world. Regardless of how abundant they are, these resources will inevitably run out. We are now shifting towards power generation methods that can satisfy our demand while still protecting natural Resources. Two of these approaches are photovoltaics and concentrated solar power (CSP). Scientists are working every day to improve these methods to harvest more energy from the sun. We are going to find out the capacity of electricity production in Bangladesh, how much electricity demand they can fulfill, and what is the actual electricity demand. After that, we are going to discuss the possibilities of Photovoltaics and Concentrated Solar Power (CSP) in Bangladesh, what will be the power outcome of the two methods, how much it will cost to implement these methods, what will be the unit cost of generated electricity from these two methods. Finally, we will offer a better solution for the electricity sector in Bangladesh, which will serve the extra energy demand of the country. As it is renewable energy, it will also become environmentally friendly.

1.1 Background and Problem

Bangladesh has always struggled to meet the demand for electricity in a timely and effective manner. As the population increases in the country, so does the demand for electricity, which is outpacing population growth proportionally. In the fiscal year 2019-2020, the power sector made substantial improvements in terms of power production. The total generation capacity increased to 20,383 MW this fiscal year, and the maximum peak generation was 12,738 MW [1]. While this is a significant achievement for the nation, it is inadequate to meet the rising demand for electricity of the country's population, and there are still shortfalls due to weak distribution infrastructure. Electricity demand has increased by about 10% and is expected to continue to grow in the coming years, mentioned in the 2019 annual report of BPDB (Bangladesh Power Development Board) [1].



By type of plant		By type of fuel	
Hydro	230 MW (1.13%)	Hydro	230 MW (1.13%)
Steam Turbine	2,966 MW (14.55%)	Gas	10,979 MW (53.86%)
Gas Turbine	851 MW (4.18%)	Furnace Oil	5,540 MW (27.18%)
Combined Cycle	7,330 MW (35.96%)	Diesel	1,290 MW (6.33%)
Reciprocating Engine	7,808 MW (38.31%)	Coal	1,146 MW (5.62%)
Solar PV	38 MW (0.19%)	Solar PV	38 MW (0.19%)
Power Import	1,160 MW (5.69%)	Power Import	1,160 MW (5.69%)
TOTAL	**20,383 MW (100%)**	**TOTAL**	**20,383 MW (100%)**

Figure 1.1: Chart of installed power by plant and fuel type [1].

The table above is an abstract representation of Bangladesh's power production and import capabilities. Apart from power plants, Bangladesh generates electricity through a variety of fuel sources, including natural gas, coal, and others. In another market, renewable energy sources such as wind turbines, hydropower plants, and rooftop photovoltaic modules are used to generate electricity. Numerous areas in Bangladesh remain without access to electricity produced by power plants. Solar radiation has been one way they have been able to fulfill their needs in any way. Solar energy generation may be a fantastic project. With proper planning and execution, power can be provided on a broad scale, alleviating pressure on conventional power generation methods.

1.2 Importance of Renewable Energy

We are advancing towards digitalization in every aspect of our life, and for this, we need more and more energy. To acquire this extra energy, we are burning more fossil fuels. Currently, we have the luxury of using these fossil fuels. Unfortunately, in a few centuries, the abundance of fossil fuel will be in undoubted question, and in the eventual time frame, there will be none left on the earth to be obtained. That is why we have to look for innovative ideas to reduce the use of fossil fuels now. Also, using more fossil fuels release more CO_2 and other harmful gases, which is deficient for the environment and our health. It is also one of the primary reasons behind global warming, and as a result, ice caps are melting in two poles. Scientists predict that by the year 2050, many low-lying countries will go underwater. Hence, it is high time we should start emphasizing sustainable energy like solar power. There is no other source of energy for the earth is as copious as the sun. Solar energy falls at a rate of 120 petawatts on the earth's surface. It means that 20 years' worth of world energy demand can be satisfied by the energy received in just one day from the sun [2]. If we properly extract this enormous amount of energy, then our future will be viably sustainable.

1.3 Thesis Structure

The thesis is organized as follows.

In chapter 2, an overview of the electricity supply, production problem, electricity generation price, and local electricity production plan in Bangladesh is given.

After that, the availability of solar resources in Bangladesh, solar irradiation, best tilt angle, and maximum solar hour length are discussed in chapter 3.

In chapter 4, different solar power harvesting technologies are explained in detail, and energy production graphs and simulations of these different types of solar power harvesting technologies are presented in chapter 5.

Chapter 6 is based on an economic evaluation of these technologies, investment cost, and operational cost.

Finally, environmental impact, results, and conclusion are discussed in chapter 7.

2. Electricity Supply and Production

Bangladesh is a densely populated developing country where even rural places lack electricity access. Solar photovoltaic (PV) technology for rural electrification holds promise and is gaining popularity. Solar Home Systems are highly localized, making them suitable for remote and inaccessible locations; thus, both governmental and non-governmental organizations have promoted solar power systems. Solar power systems, especially in Bangladesh's rural areas, contribute significantly to energy and are changing current energy needs. In Bangladesh, there are currently 30 companies operating in the solar energy sector [3]. "Grameen Shakti first introduced low-cost solar systems to the rural people in 1996 and 1997, BangladeshRural Advancement Committee, BRAC, an NGO, launched Solar Energy Program for sustainable development" [3]. In terms of access to energy, Bangladesh lags behind the rest of the country.

Consequently, the government has set a lofty aim of providing equal access to power by 2025. Although oil, gas, and coal-derived energy will be necessary to meet rising demand, the realization that fossil fuels are finite has ignited interest in renewable energy sources. Both developed and emerging countries have shown a strong interest in renewable energy usage during the past two decades.

2.1 Problems in Rural Areas

Grid access is mostly economically prohibitive for rural and isolated regions of developed nations or a distant potential prospect. Grids and sub-stations are far away from the remote areas. As a result, transmission cost is high, and sometimes there is no proper structure to start building the transmission system. Also, fewer people are staying in remote areas. So, the lack of end user's electricity providers is unwilling to spend a vast amount of money on the sub-station, grids, and transmission line. Transportation is also a problem in Bangladesh's rural areas as there is no proper road to go to these places, bring the appropriate equipment, and make an infrastructure. Cost becomes so high when any kit comes from a city or urban area. In our case, we're going to take the hilly region of Bandarban. The district is in the southeastern part of Bangladesh and part of the Chittagong division. All the people living in the remote areas of Bandarban are almost cut off from digital technology because of the lack of electricity. There is no proper way to go to these areas because the roads are not being constructed yet due to no electricity transmission line. After the sun goes down, the whole area plunged into darkness. School-going kids are affected the most because of lack of electricity. They can not study properly for lack of light at night. They are using kerosene mostly to do their necessary household work, which costs a lot of money. The irrigation system is also dependent on natural fountain water. If there is no water in the fountain, they can grow crops because they can not use the pump to use the underground water, which is another obstacle to not having electricity. They are lagging far behind the people of the urban area.

2.2 Electricity Price

The remote areas of Bandarban are located deep in the hilly regions. No proper infrastructure and roads are available in those areas. Most of the people are living on the house made of bamboo. As they mostly use kerosene for their necessary household work and few places have a solar home system, it isn't easy to measure their daily electricity needs. Also, there has been no research done before collecting the data and comparing it with our experimental data. So, we will take electricity price data of the city region of Bandarban for comparison. From September 2020, the price of energy in all of Bangladesh is 0.067 US dollars per kilowatt-hour (kWh) for households and 0.107 US dollars per kilowatt-hour (kWh) for companies, including all components of the electricity bill, such as the expense of fuel, delivery, and taxes [4]. So this price is also valid in the Bandarban region.

2.3 Plans for Rural Areas

Renewable resources accounted for less than 1% of total electricity production, and the energy market confronted several problems, including an unprecedented lack of electricity to satisfy demand, a strong dependence on natural gas for power generation, which is also in short supply, and insufficient expenditures in power generation and tariffs to cover costs. Power was prioritized for urban regions with heavy manufacturing loads, leaving rural areas with a disproportionate share of power outages. Grid electrification in many areas of Bangladesh is challenging and costly due to the fragmented existence of rural communities and the various rivers that crisscross the region. As a result, off-grid renewable energy was the only near-to-medium-term choice for millions of people living in rural areas worldwide.

In remote rural areas where grid electricity is not yet commercially feasible, the Second Rural Electrification and Clean Energy Development (RERED II) Project promotes renewable energy solutions, such as solar home systems (SHS). Solar mini-grids in remote regions, solar irrigation pumps, and better cookstoves that use half the amount of firewood used by conventional stoves, as well as biogas digesters, are all part of the initiative. Via micro-credit programs, sixty-one non-governmental organizations (NGOs) known as “partner organizations” are assisting in the installation of renewable energy goods in rural households.

2.4 Conclusion

This chapter provides an overview of the electricity production and supply in Bangladesh. Different problems and limitations of electricity supply in remote areas and what issues are happening due to lack of electricity were discussed. In this chapter, the readers will find the reason for choosing a specific location for this thesis, the electricity price of that region, and the plans for electrification in rural areas in Bangladesh.

3.Solar Resources in Bangladesh

The equator line is so near to Bangladesh, and as a result, Bangladesh gets a massive amount of sunlight and high temperature. This extra solar radiation and heat is essential for Photovoltaic Cell and Concentrated Solar Power (CSP).

3.1 Solar Radiation

The amount of solar radiation that hits the earth's surface is a complex feature of both the extraterrestrial spectrum and the earth's atmospheric structure, plays a significant role in a photovoltaic, photochemical process, thermal solar, etc.

The solar energy obtained per unit time on a surface of $1m^2$ perpendicular to the path of radiation propagation and positioned outside of the atmosphere at a middle distance between the Sun and Earth is classified as extraterrestrial radiation (solar constant). 1367 W/m2 is the figure used.

Surface radiation demonstrates the atmosphere's effect(Fig:3.1). The properties of solar radiation in the environment are changed by two processes:

- Diffusion: due to the interaction of light with air molecules, as well as suspended water and dust.
- Absorption: by O_3 in the UV and H_2O and CO_2 in the band of IR.

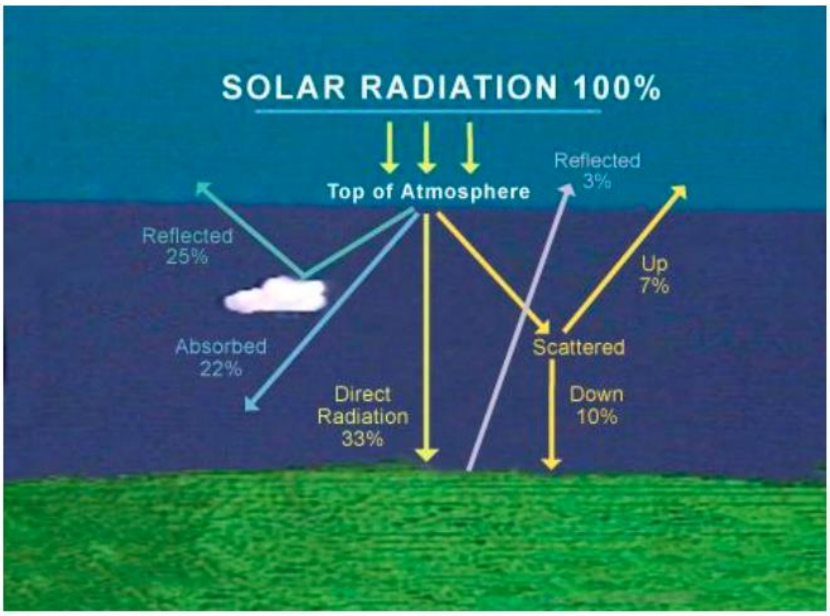


Figure3.1: Influence of atmosphere in solar radiation [5].

The amount consumed by all human actions in a year is equivalent to the solar radiation that hits the earth's surface in one hour [6]. Additionally, the solar radiation flux that hits the earth's surface is the main source of energy for nearly all recognized sources of energy. Solar energy is responsible for the circulation of the atmosphere and seas, as well as the life of plants and fossil fuels.

It is essential to consider the amount of solar energy that enters the earth's surface and its connection to spatial and climatological parameters from the viewpoint of solar energy applications.

The sum of energy emitted by the sun per time unit can be determined by multiplying the solar constant by the surface area of a sphere of the same radio frequency as the Sun-Earth size. The solar energy event on the terrestrial surface is therefore equivalent to $1.743*10^{14}$ kW. The annual incident energy to the ground is approximately 5.23*1013 kW if we believe that the seas intercept about 70% of this energy., which is already a significant amount sufficient to meet the world's energy needs.

3.2 Geological Location of Bangladesh

"Bangladesh is located in the northeastern part of South Asia and splits its longest three geographical borders with the nearest country India. The positional view of Bangladesh in the perspective of solar radiation is 24° 0′ 0″ N latitude in the north (N) and 90° 0′ 0″ E longitude to the east (E)" [7]. With a total area of 147,570 square kilometers, Bangladesh is covered by low-lying lands and rivers. With 1,252 inhabitants per square kilometer, Bangladesh is the most densely populated country on the planet. Bangladesh experiences six distinct seasons due to its subtropical monsoon climate. Three of which are more common: winter, summer, and monsoon season. The winter season extends from November to February. The weather varies from a low of 7° to 13° C to a mean of 24°C to 31°C in the season. During the summer months, the highest temperature reported is 37°C, but it can regularly reach 41°C (105°F or more) in some areas [8]. As summer is longer in Bangladesh, it gets more sunlight hour, but Bangladesh uses a small amount of this energy to fill up its energy demand. However, Bangladesh's gross solar energy generation is 500 MW, accounting for 39.5 percent of its overall renewable energy. IDCOL, Bangladesh's state-owned infrastructure development company, has already installed 3 million solar-powered home systems, supplying renewable electricity to over 13 million rural residents (SHS) [9].

3.3 Solar Irradiation Data

Bangladesh receives around 4-5 kWh/m2 of solar radiation regularly, and its yearly global horizontal irradiation average is 1746 kWh/m^2, and best tilt angle for setting up a PV cell is 23° south, and annual direct normal irradiation average for CSP is 999 kWh/m^2 [10].

Figure 3.2: Solar map of Bangladesh [10].

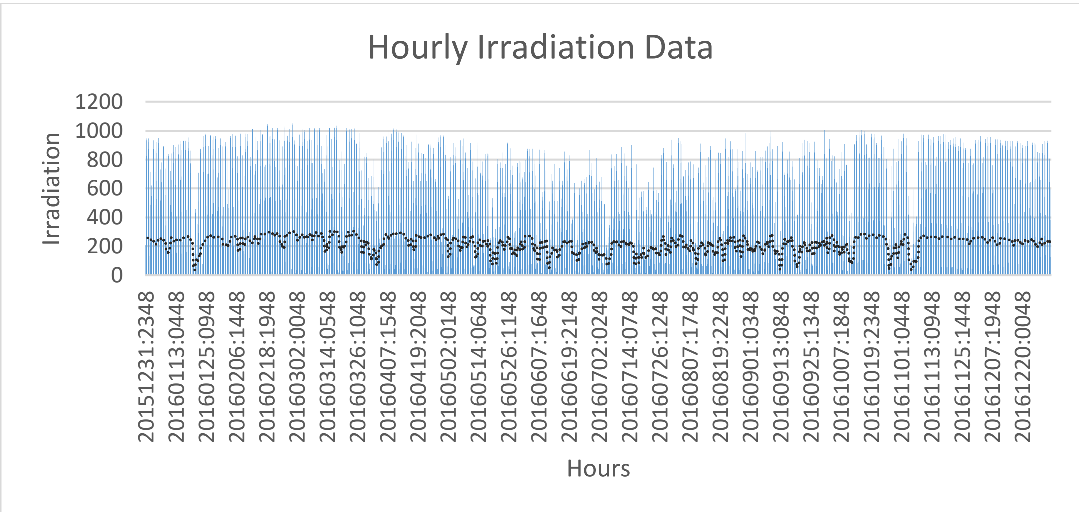


Figure 3.3: Hourly and Daily Irradiation Data [11].

The hourly and daily irradiation of Dhaka, Bangladesh, in 2016 is shown in the figuure 3.3. Daily average irradiation, which includes Global Horizontal Irradiance (GHI), Direct Normal Irradiance (DNI), and Diffuse Horizontal Irradiance (DHI) data for each month of 2016, is taken individually in appendix 1.

The daily irradiance graph of each month shows that Bangladesh gets the most irradiance at 12 PM local time from November to April, which is more than 800 W/m^2. Other months are not that far behind, and the high irradiance point fluctuates between 600-750 W/m^2. The daily average irradiance is measured as 4.496 kWh/m^2 per day [10].

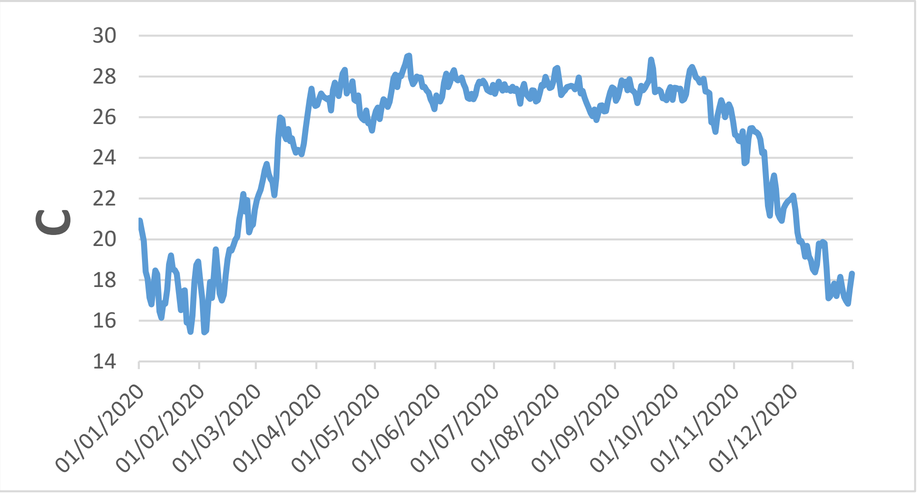


Figure 3.4: Daily temperature data of the selected area of Bandarban [12].

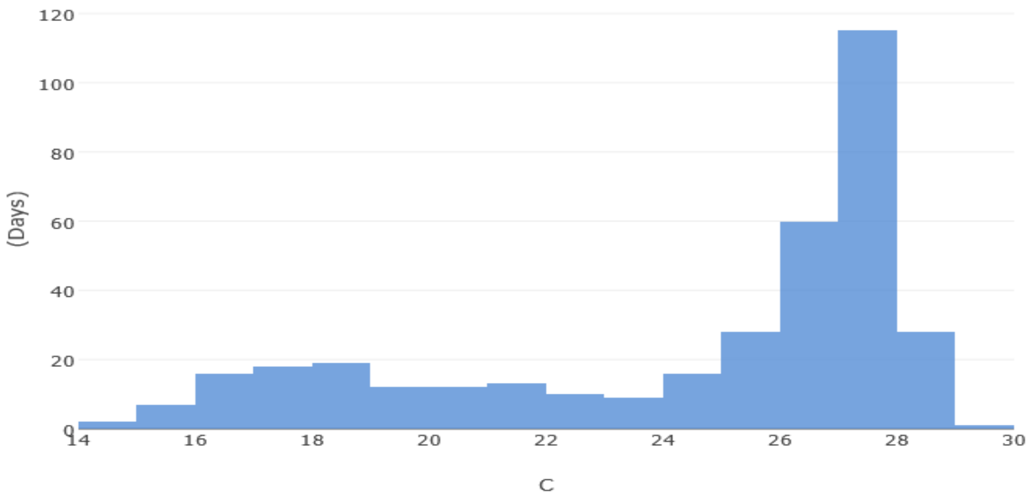


Figure 3.5: Available temperature in a year of the selected area of Bandarban [12].

Above mentioned graphs are collected from the NASA website, and these graphs, we can get the daily temperature data of the selected area of Bandarban. We can also see almost 210 days in a year; the temperature stays between 25-28 °C which we use to calculate CSP power generation.

3.4 Temperature Effect on Solar Cell

In the case of energy harvesting, ambient temperature is just as essential as irradiance. "The standard test condition (STC) for the performance of the solar cell is a solar cell spectrum irradiance called the Air Mass of 1.5, an irradiance of 1000 W/m^2, and a cell temperature defined as 25 °C" [13]. An increase in ambient temperature more than 25 °C will decrease the solar panel efficiency, and a decrease in ambient temperature less than 25 °C will increase the solar panel efficiency. With the temperature coefficient's help, We will calculate how much power a solar panel would lose if the temperature rises by 1 degree above 25 degrees Celsius and how much power it can receive if the temperature drops by 1 degree below 25 degrees Celsius. For temperature correction, we need the temperature of the solar module. We can calculate the module temperature from the below equation,

$$T_{module} = T_{ambient} + \frac{G}{h} \quad (3.1) \qquad [14]$$

In which:

$T_{ambient}$: Ambient temperature [°C]

G: Irradiance [W/m^2]

h: Heat transfer coefficient [$W/m^2 \cdot K$]

For this equation, the heat transfer value will be,

$$h = 20\ W/m^2 \cdot K \ [14]$$

For temperature correction, we need temperature coefficient and vary from material to material used in solar modules. For Silicon modules temperature coefficient is

$$\gamma_{si} = 0.44\%/°C \ [14]$$

and for the Thin Film modules,

$$\gamma_{si} = 0.38\%/°C \ [14]$$

To calculate the temperature correction following equation has been used.

$$k_T = 1 - (T_{module} - T_{ambien}) \frac{\gamma_T}{100} \quad (3.2)$$

In which:

K_T: Temperature coefficient correction

T_{module}: Temperature of the solar module [°C]

$T_{ambient}$: Ambient temperature [°C]

γ_T: Temperature coefficient [%/°C]

In Bangladesh’s perspective, in summer, when the temperature is around 33-38 °C, solar panels lose their efficiency. On the other hand, in winter, the temperature stays under 25 °C and gets a lot of sunlight. Theoretically, it is possible to harvest the most energy in winter than in summer in Bangladesh.

3.5 Conclusion

In this chapter, different types of solar radiation have been explained. The geological location of Bangladesh and what benefits it gets have been discussed. Readers can get the idea of temperature in Bangladesh, hourly and daily solar irradiation result of whole Bangladesh, and the selected remote area of Bangladesh. Also, how temperature affects the solar cell was mentioned in the chapter.

4. Technology

Fossil fuel is decreasing day by day. To find an alternative source of energy, scientists were experimenting with different ways to extract energy from renewable sources. The sun is the most prolific green energy source, and as a result, various technologies have been invented over the years to harness the sun's energy. Concentrated Solar power systems and Photovoltaic cells are two of them, and these two leading technologies have other sub-technology. Parabolic Trough, Solar Power Tower, Fresnel Reflector, Enclosed Trough, Stellio Heliostat, Dish Stirling are some technologies for harnessing solar through the concentrated solar power systems. Monocrystalline silicon, polycrystalline silicon, and thin film are the three types of photovoltaic cell technologies that currently dominate the global market.

4.1 Concentrated Solar Power (CSP) Technologies

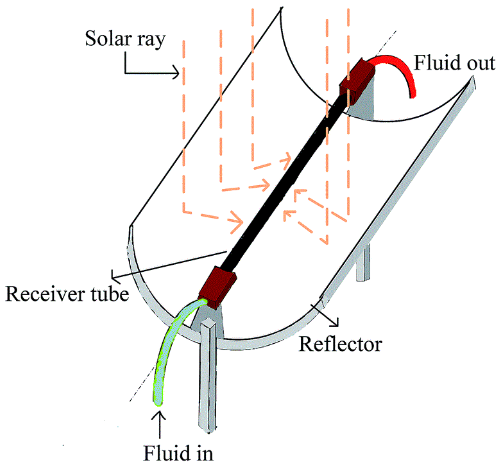
4.1.1 Parabolic Trough

Among all the CSP technology, this is the most mature technology. Almost 90% of the current CSP system is based on 'Parabolic Trough' technology. This system consists of a wide area covered in long rows of rectangular mirrors with parabolic surfaces called collectors. "The collectors have a reflective surface that reflects the sun's heat onto a pipe (generally called receiver tubes) running along the length of the collectors. The collector mirrors can rotate to follow the sun from east to west. The receiver tubes absorb the reflected thermal heat by a type of fluid running through the tubes. The tubes, as well as the fluid, heats up to almost 550 degrees Celsius. This heated-up fluid is used to produce steam and energy as well" [15].

Therminol is used for heat transfer which is a unique form of a fatty fluid (oil). However, nowadays, the use of molten salt is becoming more popular. "The salt mixture contains 40% Potassium Nitrate (aka Saltpeter) and 60% of Sodium Nitrate. This mixture has higher heat sustainability and absorption limit than Therminol". To remain liquid, the molten salt solution needs a temperature of at least 290 degrees. Lack of temperature will make the solution lumpy with solidified crystals. Its heat sustainability is a plus point where its liquid state threshold point is low. Before cooling down, molten salt will retain heat for up to six hours. This means the device is operational at all times of the day and night. "It must be noted that the receiver tubes are usually housed inside another non-reflective tube and a vacuum between the two tubes" [15]. Traditional turbine modules used in power plants are very consistent with this CSP process. Changing cloud cover and other environmental disturbances can be compensated for by the storage capacity.

The average efficiency in converting sunlight into electricity for 'Parabolic Trough' is 20% [15].

Figure 4.1: Parabolic Trough type CSP design [16].



4.1.2 Solar Power Tower

"This system solely depends on three core components. They are ground heliostats, a central receiver at the top of a tower, and the tower itself". The sun's rays are absorbed by heliostats and reflected into the tower's central receiver. [15].

Dual-axis rotation is normally possible for heliostats. This ensures optimum heat capture and reflection during the day. "The heliostats' main components are reflective mirrors, a supporting columnlike structure, and control mechanisms. The number of heliostats can be as many as 600 or more" [15].

At the top of the stack is a central receiver of the 'cavity' kind. Four vertical surfaces make up the frame. Each has an 18-foot width and a vertical length of 39 feet. "The panels are arranged in a semi-circle and enclosed within a square housing with a 36-foot-by-36-foot opening" [15]. The sun's thermal radiation is absorbed by the central receiver, which heats the molten salt mixture flowing inside.

Figure 4.2: The Planta Solar 10 (PS10) is the world's first commercial utility-scale solar power tower in Sanlucar la Mayor, Spain [16].

The molten salt mixture is either retained or transferred for use in other energy generation processes, such as operating steam turbines [15].

4.1.3 Enclosed Trough

"The Solar thermal system is encapsulated inside a housing." In the case of an open system, this offers much greater reflector security and allows for the use of fewer components. This form saves money. To get the best sunshine during the day, a single-axis sensor is used [17].

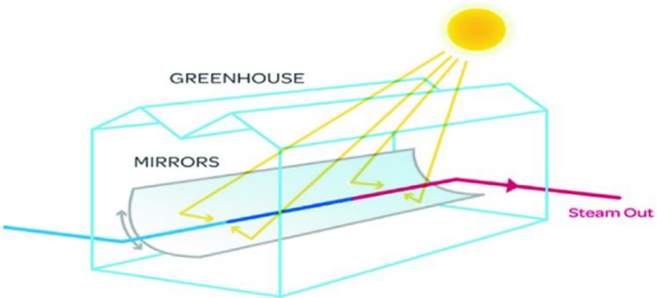


Figure 4.3: Inside view of Enclosed Trough System [18].

4.1.4 Parabolic Dish Stirling

In a dish Stirling or dish motor device, an embedded parabolic reflector focuses light onto a recipient situated at the reflector's point of view. Along two axes, the reflector follows the sun. The receiver's working liquid is heated to between 250 and 700 °C (482– 1,292 °F) before being driven by a Stirling motor. "Parabolic dish frameworks give high sun-powered to-electric effectiveness (near 31% and 32%), and their secluded nature gives adaptability". With a productivity rate of 31.25 percent, a new world record for solar-powered electric energy was set [15].

4.2 Photovoltaic Cell Technology

4.2.1 Monocrystalline Silicon Cell

"These cells are made from pure monocrystalline silicon. There are almost no defects or impurities in these cells, and the silicon has a single continuous crystal lattice structure." This cell has a high efficiency which is around 15%, but the manufacturing process is complicated. As a result, for producing monocrystalline silicon cells, the cost is slightly higher and other technologies [19].

4.2.2 Polycrystalline Silicon Cell

Numerous grains of monocrystalline silicon are used to make multi-crystalline or polycrystalline silicon cells. The manufacturing process begins with the casting of molten polycrystalline silicon into ingots, cut into thin wafers, and molded into full cells. Polycrystalline cells are less expensive to produce than monocrystalline cells due to the streamlined manufacturing process. On the other hand, they are marginally less effective, with average efficiencies of about 12% [19].

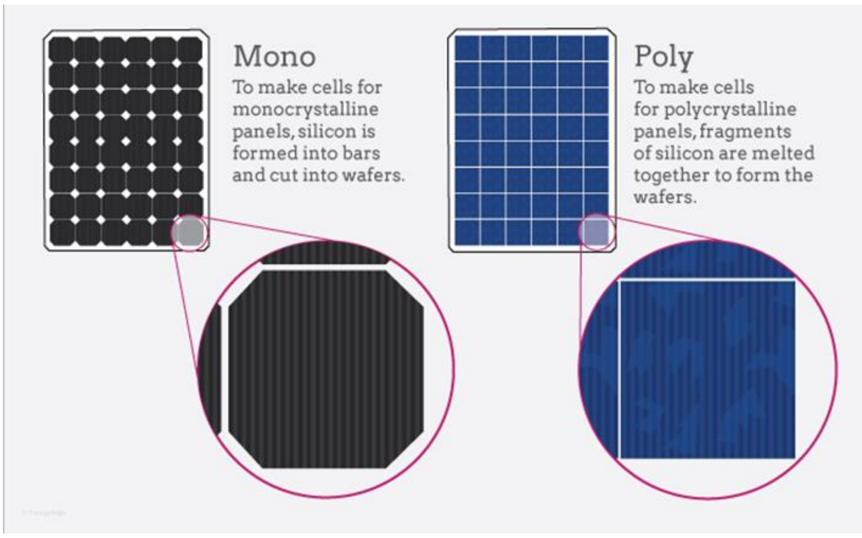


Figure 4.3: Monocrystalline vs. Polycrystalline silicon solar cell [20].

4.2.3 Thin Film Solar Cell

“A thin-film solar panel is made of thin-films of semiconductors deposited on glass, plastic, or metal. The films are ultra-thin, sometimes up to 20 times thinner than c-Si wafers”. Solar panels made of thin-film materials are lightweight and flexible. If the thin-film cells are encased in plastic, the resulting structure can be light enough to be molded into the form of a roof. Thin-film panels become more rigid and less flexible if the glass usage. [21].

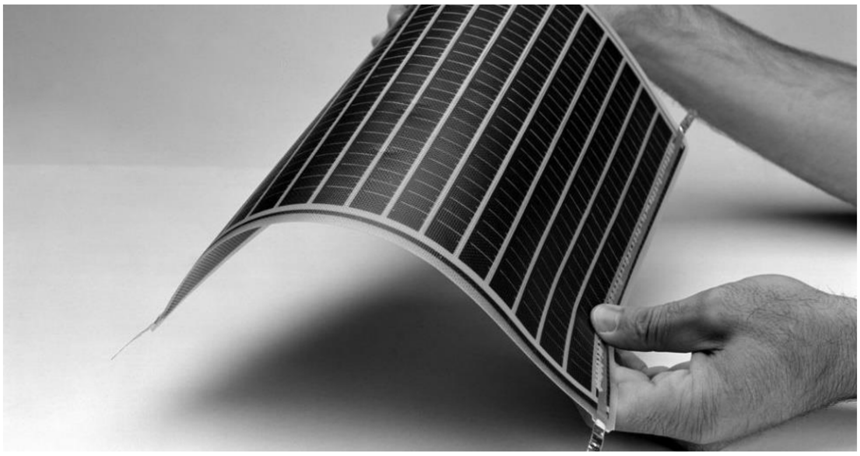


Figure 4.4: Thin-film solar cell [21].

4.3 Solar Tracking Technology

“A solar tracker is a device that orients a payload towards the sun. Payloads are usually solar panels, parabolic troughs, Fresnel reflectors, lenses or the mirrors of a heliostat” [22]. The solar panels or collectors must be oriented in the right direction to absorb the most amount of energy from the sun rays to produce from the solar modules.

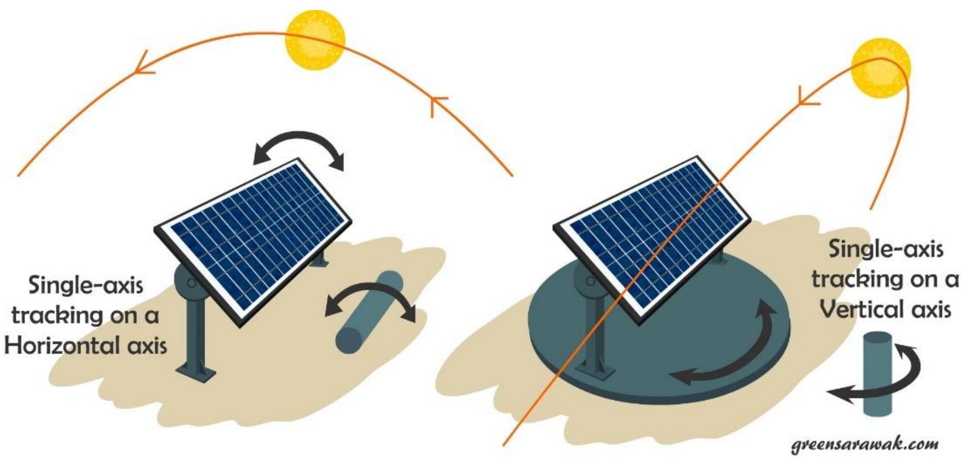


Figure 4.5: Single-axis solar tracking system [23].

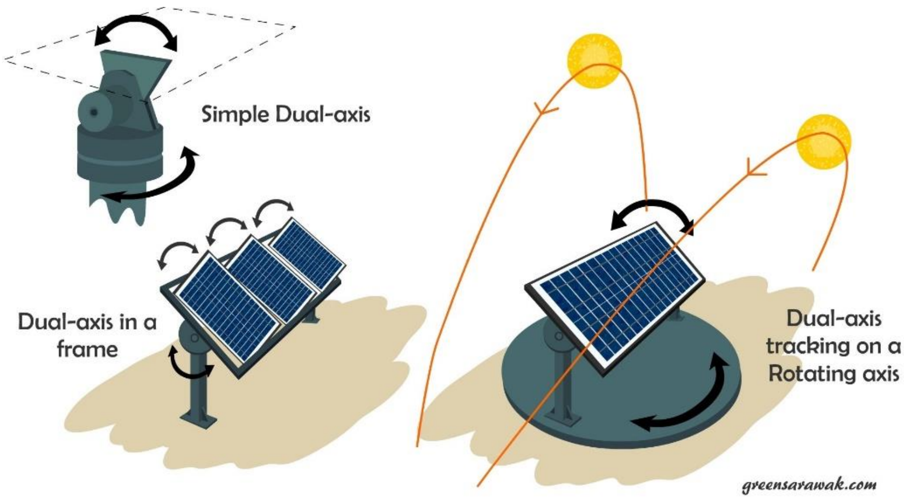


Figure 4.6: Dual-axis solar tracking system [23].

4.4 Possible Schemes

In the perspective of remote areas of Bangladesh, some solar harvesting technologies like solar power tower, parabolic trough, enclosed trough, and thin-film solar cell are not feasible. The Parabolic Dish system and monocrystalline solar cell system can be viable and cost-effective for a small area. Although the Parabolic Dish system is the most potent CSP system, it is also being improved to make it more cost-effective. Much useful for remote areas and farms but may also be included in properties. The monocrystalline solar cell system is also more efficient than other PV cell technology, and it is possible to install in a small area. It is also possible to merge dual-axis solar tracking technology with the Parabolic Dish system and PV cell to get the most output from the sun.

4.5 Comparison Between PV and CSP

Photovoltaic cells (PV) are unquestionably the most commonly accepted conventional form of green energy production. However, the CSP has a lot of potential in the power production and distribution market. However, controversies about CSP vs. conventional PV have raged for decades. Two of the inventions have their own set of criteria for recognition and approval. However, all mechanisms have specific characteristics that are opposed. One of them is the system’s price. PV is somewhat less expensive, but it also falls short of CSP in terms of certain technological advantages. A contrast of the two schemes is presented in tabular form in the following.

Table 4.1: Comparison between PV and CSP technology [24], [25], [26].

Criteria	**Photo-Voltaic (PV)**	**Concentrated Solar Power (CSP)**
System type according to distribution	Distributed	Centralizied
Cost	Less	More
Ease of use	More	Less (due to construction complexity)
Required maintenance	Low	High
Installation	Easier	More complicated
Operation continuity (power generation)	Not possible typically (for lack of storage capability)	Possible (throughout the day and night)
Storage capability	Optional (can be done by sacrificing simplicity and low cost)	Yes
Efficiency	Less	More and improved.
Source dependency	Daytime only	None. Due to storage capability.
Source utilization	Indirect (Photovoltaic effect)	Direct (Sun's thermal irradiance)
Electrical grid compatibility	Poor (generated DC power must first be transformed to AC power)	Better (generated direct distribution of AC power is possible)
Required land space	Less	More (Because of thermal collectors)

When it comes to the advantages and disadvantages of the two technologies, table 1 will help one understand a few things. The following is a list of the causes.

1. While a photovoltaic device is inexpensive, its delivery contributes to the expense and difficulty.
2. CSP creates a smooth link between a system's generation and storage modules. This will further offset the expense of more advanced architecture.
3. CSP is preferred by investors searching for a large-scale implementation because of its smooth energy integration for distributing and improved power production consistency.
4. The CSP system will need more maintenance by default. However, if the photovoltaic device is to be made storage capable and sufficiently large, it will require additional maintenance, complexity, and staggering costs.
5. Despite its numerous advantages in industrial/large-scale applications, CSP needs a significant amount of property. This consideration is critical for our increasing community, which is causing land shrinkage.

4.6 Investment Cost

4.6.1 Cost of Photovoltaic Cell System

Depending on the size and type of device, a single solar panel will cost between $450 and $700. A 4kW solar panel device, which costs about $7500 and covers around 29 square meters of your roof, is one of the most popular domestic sizes [27]. Solar panels have been significantly less expensive in recent years due to advances in solar energy technologies. In general, the more the initial construction costs, the more energy your device can produce. In the long term, though, the gains would be more significant. A 3kW machine, for example, would be less expensive to build, but it would not be willing to gain as much over 25 years as you will for a 6kW device. On the other hand, commercial solar panels have large upfront costs and higher returns on investment.

4.6.2 Cost of Concentrated Solar Power System

The expense of constructing new CSP plants has dramatically decreased. The average total capital expenditure (CAPEX) per kilowatt was found to be $3,910 to $6,355 for recent projects in CSP, according to the latest analysis done by New Energy Update, which has been following the field since 2016. The capacity of energy storage ranges from six to sixteen hours. In a survey by the International Renewable Energy Agency (IRENA), the CAPEX of plants was between $6,050/kW to $12,600/kW, which was built between the years 2013 and 2015 with storage of four to eight hours. From the research of IRENA, it has been found out that it costs between $7,300 and 11,300 per kW for plants which has storage of more than 8 hours. In contrast, plants without storage cost less [28]. After 2016, 16 schemes have been settled upon, including 12 in China with capacities ranging from 50 to 100 MW and four outside China with capacities ranging from 150 to 700 MW. It combines technologies such as towers, parabolic troughs, and linear fresnels. As is now standard, any project includes energy storage, which can last anywhere from six to sixteen hours. Typically molten salt is used for energy storage in parabolic trough CSP system.

4.6 Conclusion

In this chapter, different Photovoltaic Cell (PV) and Concentrated Solar Power (CSP) technology were discussed, and which techniques we can implement in remote areas were mentioned. Comparing PV and CSP, investment costs to implement these technologies, and how to compare investment costs were also discussed in this chapter.

5. Electricity Generation

To compare PV and CSP technologies, it is necessary to calculate the electricity production from these two technologies.

5.1 Electricity Generation by PV System

For calculating the electricity generation, hourly irradiation and temperature data have been taken, which is mentioned in chapter 3. The hourly temperature of the module have been calculated using equation (3.1),

$$T_{module} = T_{ambient} + \frac{G}{h}$$

For calculating the hourly efficiency of the PV module, the following equation has been used, and the approximate efficiency value is 16%.

$$Y = 15.96 - 0.058X \quad (5.1) \qquad [29]$$

Where,

Y= efficiency of the PV module

X= irradiation (W/m^2)

After that, the hourly efficiency is multiplied by the hourly irradiation to get the annual energy production, which is 0.220 MWh/m^2. The total area of the PV module is assumed 312.5 m^2. So, the total electricity generation will be the multiplication of total area and annual energy production per meter square, and the calculated value is 68.76 MWh annually. All the calculation is given in appendix 2.

Solar panels from the Sunpower company have been chosen for this calculation. They are the first to sell 400W solar panels in the world [30].

Figure 5.1: Sunpower solar panels [30].

SunPower® Complete Confidence Warranty	vs	Conventional Solar Panel Warranty*
✓	Complete System	✗
✓	Removal of Defective Part	✗
✓	Installation of New Part	✗
✓	Shipping	✗*
90%	Peak System AC Power	✗
25 years	Product warranty term*	10 years
8%	25 year DC power decline	19.3%

Figure 5.2: Comparison between Sunpower solar panels and conventional solar panels [30].

5.2 Electricity Generation by Parabolic Trough CSP System

For calculating the approximate annual energy generation of the Parabolic trough CSP system, the annual full load hours method has been used. The following graph is taken

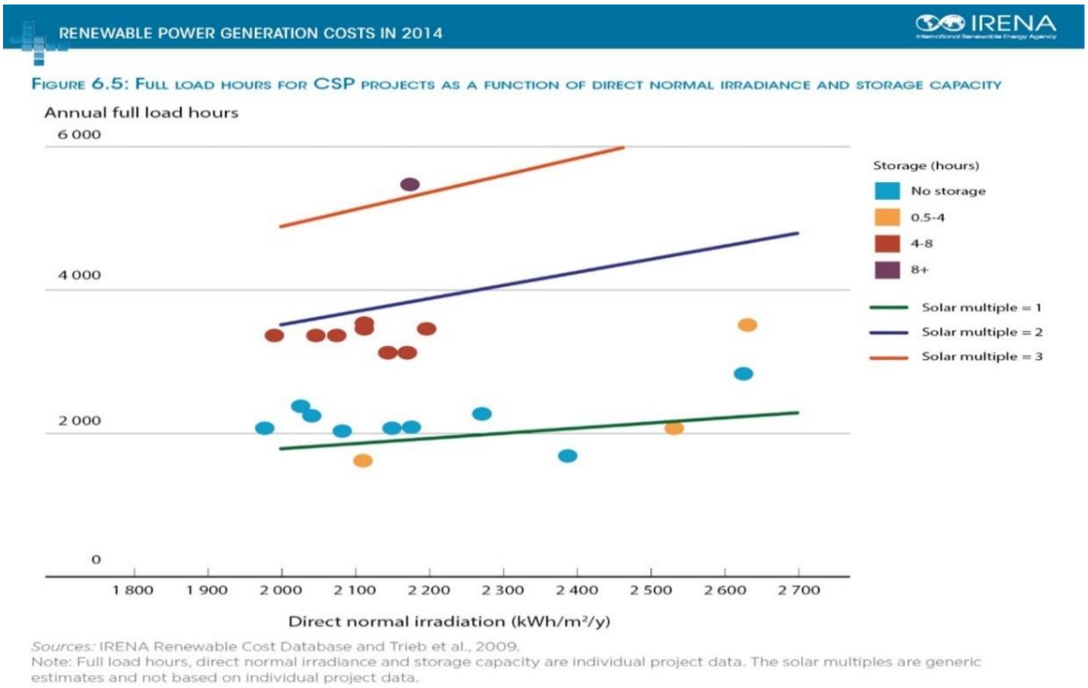


Figure 5.3: Relation between annual full load hours, storage capacity, and Direct normal irradiance [31].

from IRENA. This graph shows the relationship between the system’s storage capacity, full load hour, and Direct Normal Irradiance (DNI). For the selected area, DNI is 1356 kWh/year [10]. We assume that we use 4-8 hour storage capacity. In this graph, the relation between irradiance and full load hour is linear. So, equation (5.2) can be estimated from the graph to calculate the full load hour for 1356 kWh/year DNI.

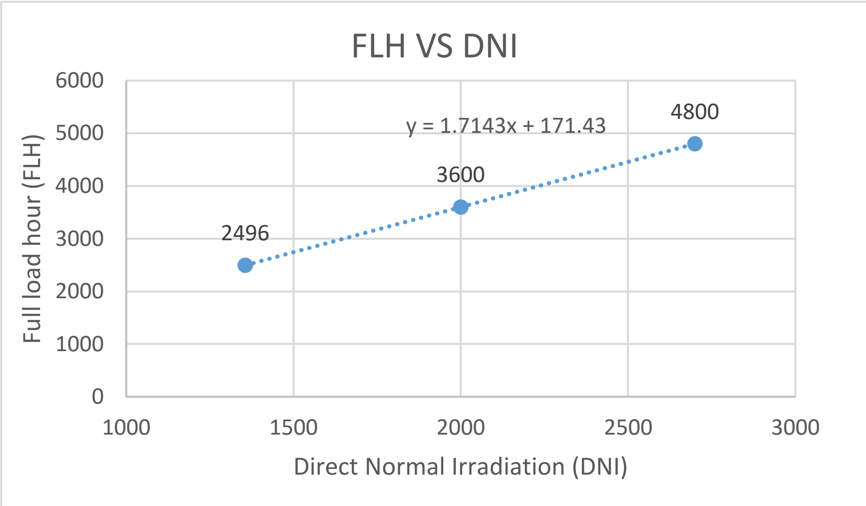


Figure 5.4:Relation between FLH and DNI.

$$Y = 1.7143X + 171.43 \quad (5.2)$$

using equation (5.2), we can find 2496 full load working hours for 1356 kWh/year DNI. After multiplying 2496 with an approximate plant capacity of 50 MW, we will get 1,24,800 MWh annual electricity production. Detail calculation file is given in appendix 2.

6. Feasibility Analysis

6.1 Methodology

The LCOE concept is a widely used metric for comparing the costs of different power generation technologies. "The Levelized cost of energy (LCOE) is the price at which electricity must be produced from a specific source in order to break even over the project's lifespan. [32]" It's a study of the cost of the energy-generating system from a financial standpoint over its lifespan, taking into account all costs: initial expenditure, activities, and repairs, including land rent if necessary, end-of-life management, fuel, and capital cost. LCOE can be calculated as:

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \qquad (6.1)$$

Where:

LCOE = average lifetime Levelized electricity generation cost
I_t = investment expenditures in the year t
M_t = operational and maintenance expenditures in the year t
F_t = fuel expenditures in the year t, which is zero for PV and CSP systems
E_t = electricity generation in the year t
r = discount rate
n = financial lifetime of the calculation

With this LCOE calculation, we will compare the electricity unit price produced by PV and CSP systems.

6.2 Main Economic and Technical Assumption

6.2.1 Discount Rate

According to Bangladesh Infrastructure Finance Fund Limited (BIFFL), the minimum standard interest rate for small infrastructure is 4%. "The maximum amount for a single project loan application is BDT 1 billion. The minimum amount for a single project loan application is temporarily set at BDT 5 million". This loan would be given out on a first-come, first-served basis, based on the validity of each situation. Concerning the quality of the programs, BIFFL can offer a grace period for the loan [33].

6.2.2 Operation and Maintenance Expenditures

Every year it cost some money for the operation and maintenance of the whole PV system. Scheduled maintenance and cleaning, inverter replacement reserve, insurance, property tax are some of these costs. This O&M cost is represented as $/kW/year. Over time, the total cost of operation and maintenance has decreased. For example, O&M costs for utility-scale systems have significantly reduced in Lawrence Berkeley National Laboratory (LBNL) from an average of $30/KW per year from 2011 to 2015, before jumping back to $18 per kW year in 2017. A more recent survey of LBNL revealed that there is an increase in project lifetime of approximately 21.5 years in 2007, and in 2019 it is 32.5 years. On average, those operating and management expenses have decreased from $35 per kW per year to $17 in 2019 [34]. So, for our calculation, $20/kW/yr O&M cost is considered.

Operational and maintenance expenses (O&M) for CSP plants are comparatively large, ranging from USD 0.02 to USD 0.035 per kWh. There are ways to reduce costs, and when plant designs improve, and more familiarity with running more significant quantities of CSP plants is obtained, savings opportunities will emerge. In the United States, O&M costs for a parabolic trough device are generally calculated to be about USD 0.015/kWh. The expected O&M costs (including insurance) for two planned parabolic trough and solar tower ventures in South Africa range between USD 0.029 and 0.036/kWh [35]. But the cost is decreasing day by day. "A recent study by the International Renewable Energy Agency (IRENA) shows that the operation and maintenance costs of CSP plants range from $20/MWh to $40/MWh" [36]. Operational and maintenance costs are minimal for a small-scale Parabolic Trough Solar system. An analysis is done in a parabolic power plant in Louisiana claims, O&M costs around $0.005 kWh. This price value is taken for the calculation [37].

6.2.3 Financial Lifetime of The Calculation

For this calculation, we assume that the financial lifetime is equal to the technical lifetime of the project. "Operation of the CSP plants is expected to last over an economic life cycle of 25 to 30 years"[38]. Lifelong increase for solar fields and energy blocks, for storage cells for 25 years, in 2025 for 35 years and 30 years, and for 2050 for 40 years and 35 years, respectively[39]. For this project, a lifetime of 33 years is considered for the CSP plant.

Standard solar panels have a life span of around 20 to 35 years [40] [41]. For this project, we considered the average life span for PV plants as 25 years.

6.2.4 Investment Expenditure In The Year

The investment cost of both technologies has already been discussed in chapter 4.6. From that discussion, we can assume that the investment cost of the PV plant is around $1875/kW, and for CSP, the average price is approximately $4500/kW. So to get the investment expenditure per year, we have to divide the total investment cost by the total life span of the project.

6.3 Levelized Cost of Electricity

After calculating PV and CSP system, we found that the LCOE for PV is 72.58 $/MWh and for CSP 74.004 $/MWh. The full calculation can be found in appendix 2.

	PV		
Capacity	0.05	MW	
Specific investment	1875	$/kW	
Investment	93,750	$	
Lifetime	25	years	
Investment expenditures in the year	3,750	$	
Operational and maintenance expenditures	20	$/kW/year	
Operational and maintenance expenditures	1000	$	
Electricity generation	0.220033689	MWh per m2	
Total Area	312.5	m2	
Total Electricity production in a year	68.76052781	MWh	
LCOE	72.58	LCOE, $/MWh	

Figure 6.1: LCOE calculation of PV system.

	CSP	
Capacity	50	MW
Specific investment	4500	$/kW
Investment	225,000,000	$
Lifetime	33	years
Investment expenditures in the year	6,818,182	$
Operational and maintenance expenditures	0.005	$/kWh
Operational and maintenance expenditures	2,190,000	$/kW per year
Electricity generation	124,800	MWh
LCOE	74.004	LCOE, $/MWh

Figure 6.2: LCOE calculation for CSP system.

6.4 Sensitivity Analysis

In Bangladesh, the electricity price from the grid is 0.066 USD per kWh or 66 USD per MWh [4]. Based on this price, we can do a sensitivity analysis of the proposed systems. Sensitivity analysis has been done from different perspectives, such as; lifetime, investment cost, and efficiency.

6.4.1 Sensitivity Analysis for PV System

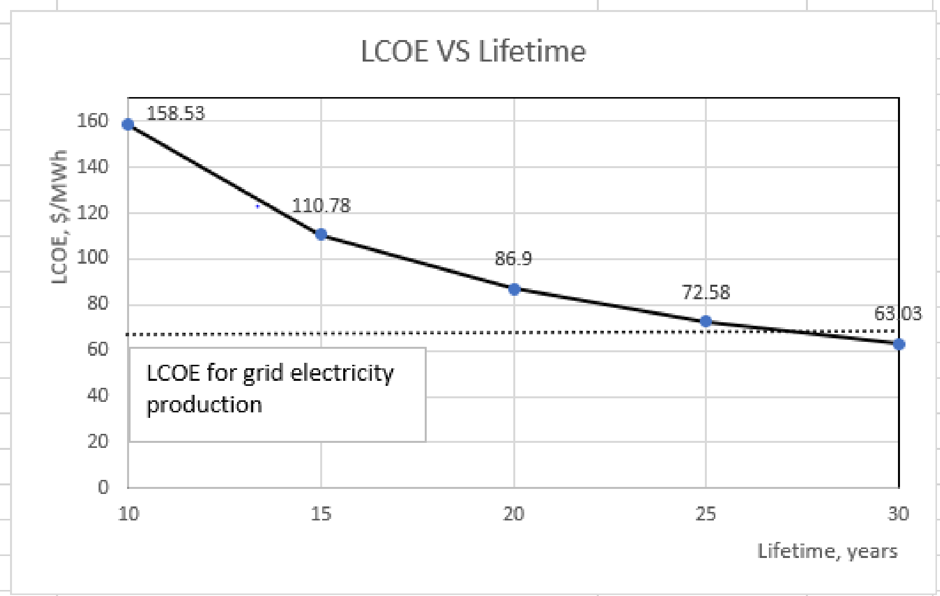


Figure 6.3: Sensitivity analysis in respect of lifetime.

For our calculation, the lifetime is taken 25 years. As the dotted line represents the LCOE for the grid electricity production, we can get that the electricity price would be lower than the grid price if the lifetime were 30 years.

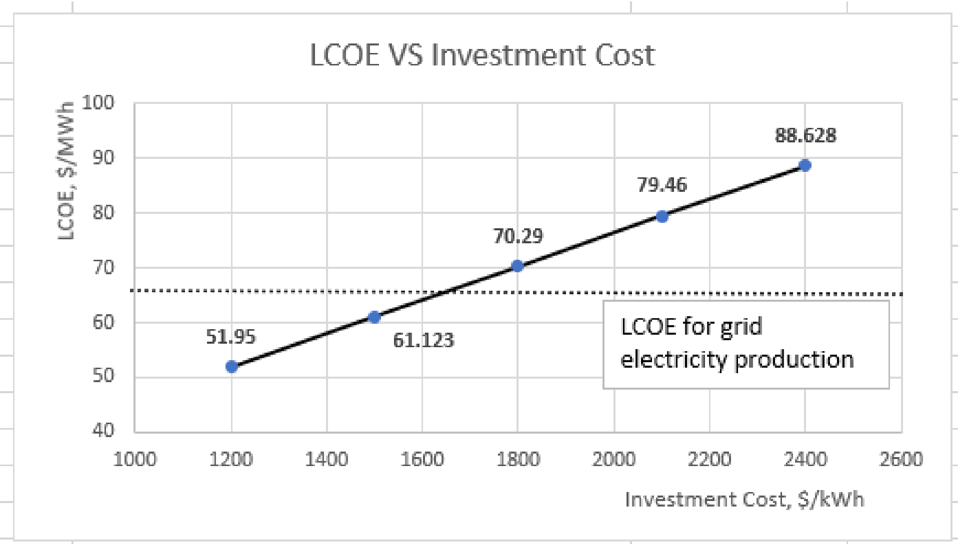


Figure 6.4: Sensitivity analysis in respect of investment cost.

For the PV system, the investment cost is assumed as 1875 $/kW. The graph shows that if the investment cost is less than 1700 $/kW, it is possible to produce energy that will cost less than the grid. Scientists and researchers are trying to create more efficient and cheaper PV modules. Their success will lead to a lower investment cost for the plant. So, it might be possible to provide electricity at a lower price than the grid in the future.

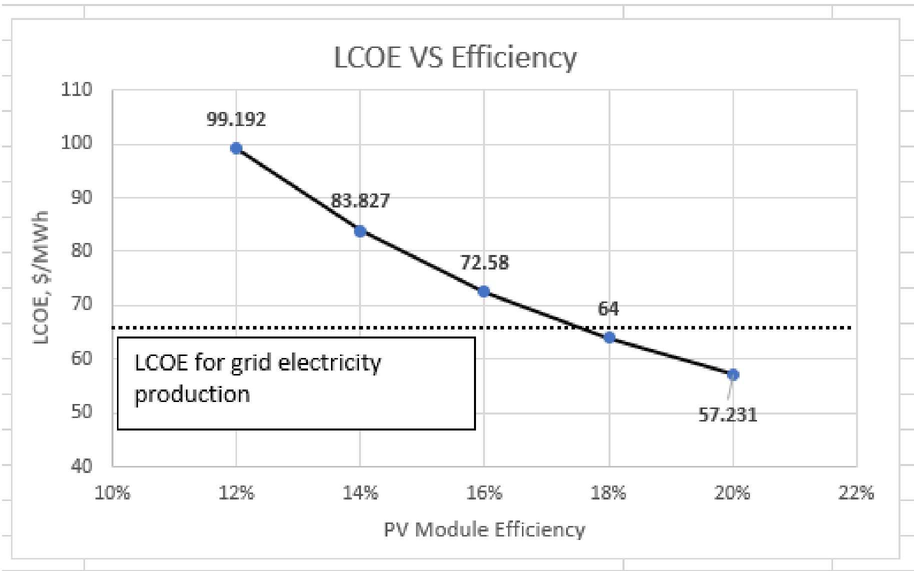


Figure 6.5: Sensitivity analysis in respect of efficiency.

Considering the Direct Normal Irradiance (DNI), the efficiency of the PV module is calculated as 16% for this project. LCOE is slightly higher than the local grid. If the module's efficiency increases to 18%-20%, it is possible to produce at a lower cost.

6.4.2 Sensitivity Analysis for CSP System

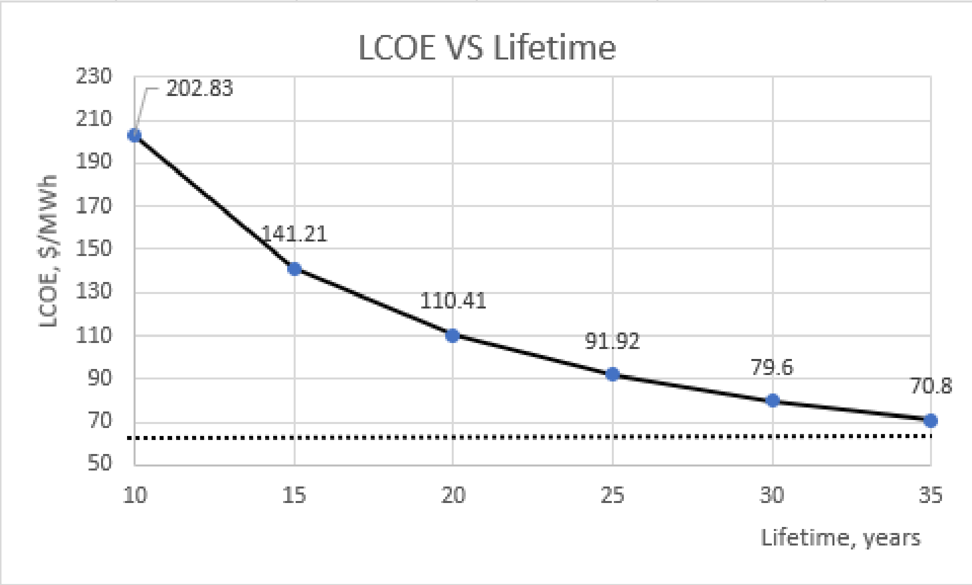


Figure 6.6: Sensitivity analysis in respect of lifetime.

The lifetime of the CSP system is higher than the PV system. But still, the LCOE is more than the PV system as CSP technology is comparatively new, and it costs more money. For our calculation, 33 years of a lifetime is considered, and for that, LCOE is approximately 74 $/MWh.

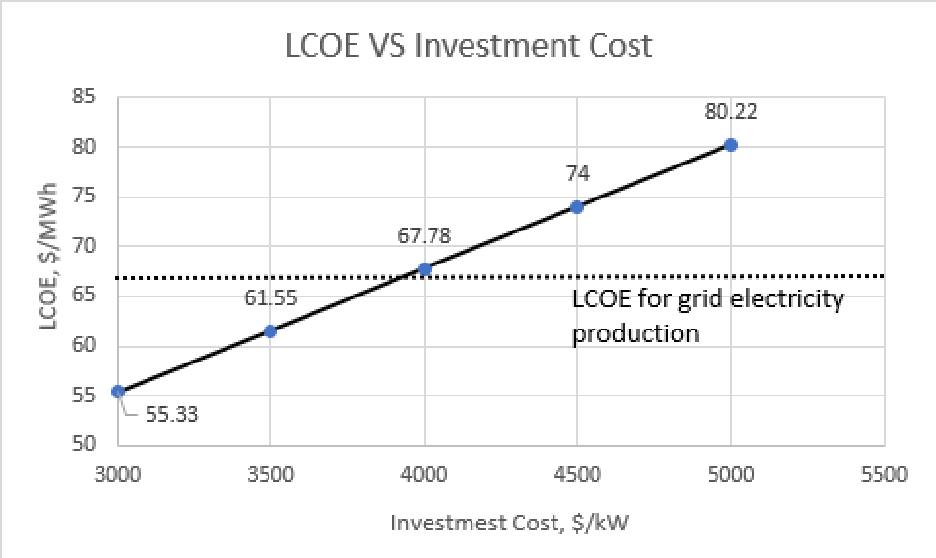


Figure 6.7: Sensitivity analysis in respect of investment cost.

The investment cost is higher for CSP technology than PV and grid systems. For the present situation, if the investment cost is less than 4000 $/kW, then it is possible to produce electricity at a lower price than the grid.

7. Result & Conclusions

This master thesis aimed to find a better energy solution for the remote areas of Bangladesh. The first task was to choose a remote location for this project and why it is impossible for the grid line to supply electricity to that remote. The second task was to find out feasible technology that we can implement in that remote area. PV systems and CSP systems are considered as possible technology. The final task was to calculate the feasibility of these technologies.

After the calculation, we found the levelized (LCOE) cost of electricity for both technologies. As investment cost is higher for CSP technology, LCOE is higher than PV technology. Also, it is not possible to build a lower-capacity CSP plant. The minimum capacity of a CSP plant is 40-50 MW. On the other hand, there are fewer consumers of electricity in remote areas. So, it is not possible to properly utilize the full capacity of the CSP plant in remote areas. But, in the future, when there will be proper infrastructure and distribution lines in those remote areas, the CSP plant can be considered as we can connect the plant with grid line and provide the extra energy in the city areas. As the investment cost and O&M cost of CSP are decreasing day by day, it can be a good option to harvest energy.

For now, PV technology is the possible solution for the electrification of these remote areas. It is easier to install, operations and maintenance cost is lower, and investment cost is also low. LCOE is a little bit higher than the grid production. Still, we can hope that with the advancement of the technology, the efficiency of the PV module will increase, and production costs will decrease, which will eventually reduce the cost of electricity production.

Renewable energy is the future energy resource of the world as fossil fuel is decreasing every day. Also, to produce energy from fossil, we are polluting our environment and causing a greenhouse effect. As a result, ice caps are melting in the north and south poles, and low-lying lands of different countries are going underwater. Renewable energy is environmentally friendly. So if we can utilize renewable resources properly, we can solve the world’s energy problem and save the environment.

SUMMARY

We are living in a world where electricity is a must needed thing for everyone. But people from third-world countries who are living in remote areas are deprived of electricity. There are no proper roads to go to these places, not even a proper infrastructure for grid lines to reach. People of these areas are using woods and kerosine to make fire and do their daily activities. To solve this problem, two of the renewable energy harvesting system were discussed in this study. As fossil fuel is decreasing day by day, renewable energy is the future of this world. Different classifications of PV system and CSP system technology were discussed in this research. From PV technology, monocrystalline solar module, and from CSP technology, a Parabolic trough system was chosen for this research. Different types of costs to implement these systems were mentioned in this thesis, and calculation is shown to understand these technologies' economic aspects. After observing all the possibilities, the PV system is recommended for remote areas, but the CSP system can be a good option in the near future.

Me elame maailmas, kus elekter on kõigile vajalik asi. Kuid kolmandatest riikidest pärit inimesed, kes elavad kaugemates piirkondades, jäävad elektrist ilma. Ei ole õigeid teid, et minna nendesse kohtadesse, isegi mitte korralikku infrastruktuuri, et võrguliinid ulatuksid. Nende alade inimesed kasutavad metsa ja kerosiini, et teha tuld ja teha oma igapäevaseid tegevusi. Selle probleemi lahendamiseks arutati selles uuringus kahte taastuvenergia koristussüsteemi. Kuna fossiilkütus väheneb päevast päeva, on taastuvenergia selle maailma tulevik. Käesolevas uurimuses arutati fotoelektrilise süsteemi ja CSP süsteemitehnoloogia erinevaid klassifikatsioone. FOTOELEKTRILISEST tehnoloogiast, monokristallsest päikesemoodulist ja CSP tehnoloogiast valiti selle uuringu jaoks välja Paraboolne tainasüsteem. Selles väitekirjas mainiti eri liiki kulusid nende süsteemide rakendamiseks ning on näidatud, et arvutus mõistab nende tehnoloogiate majanduslikke aspekte. Pärast kõigi võimaluste vaatlemist on fotoelektriline süsteem soovitatav kaugete alade jaoks, kuid CSP-süsteem võib lähitulevikus olla hea valik.

LIST OF REFERENCES

[1] Bangladesh power Development Board, "Annual Report 2019-2020 of BPDB," p. 114, 2020.

[2] J. Khan and M. H. Arsalan, "Solar power technologies for sustainable electricity generation - A review," *Renew. Sustain. Energy Rev.*, vol. 55, pp. 414–425, 2016, doi: 10.1016/j.rser.2015.10.135.

[3] M. F. Hossain, S. Hossain, and M. J. Uddin, "Renewable energy: Prospects and trends in Bangladesh," *Renew. Sustain. Energy Rev.*, vol. 70, no. November 2016, pp. 44–49, 2017, doi: 10.1016/j.rser.2016.11.197.

[4] "Bangladesh electricity prices, September 2020 | GlobalPetrolPrices.com." https://www.globalpetrolprices.com/Bangladesh/electricity_prices/ (accessed Apr. 11, 2021).

[5] "Solar cell/Panle-EVERREDtronics Ltd." http://www.everredtronics.com/Solar.Download.html (accessed Apr. 07, 2021).

[6] F. Diner, "The analysis on photovoltaic electricity generation status, potential and policies of the leading countries in solar energy," *Renewable and Sustainable Energy Reviews*, vol. 15, no. 1. Elsevier Ltd, pp. 713–720, Jan. 01, 2011, doi: 10.1016/j.rser.2010.09.026.

[7] F. Ahmed, A. Q. Al Amin, M. Hasanuzzaman, and R. Saidur, "Alternative energy resources in Bangladesh and future prospect," *Renew. Sustain. Energy Rev.*, vol. 25, pp. 698–707, 2013, doi: 10.1016/j.rser.2013.05.008.

[8] M. Taheruzzaman and P. Janik, "Electric Energy Access in Bangladesh," *Trans. Environ. Electr. Eng.*, vol. 1, no. 2, 2016, doi: 10.22149/teee.v1i2.13.

[9] M. N. Uddin, M. A. Rahman, M. Mofijur, J. Taweekun, K. Techato, and M. G. Rasul, "Renewable energy in Bangladesh: Status and prospects," *Energy Procedia*, vol. 160, pp. 655–661, 2019, doi: 10.1016/j.egypro.2019.02.218.

[10] "Global Solar Atlas." .

[11] "JRC Photovoltaic Geographical Information System (PVGIS) - European Commission." https://re.jrc.ec.europa.eu/pvg_tools/en/#HR (accessed Mar. 07, 2021).

[12] "POWER Data Access Viewer." https://power.larc.nasa.gov/data-access-viewer/ (accessed Apr. 16, 2021).

[13] N. H. Zaini, M. Z. Ab Kadir, M. Izadi, N. I. Ahmad, M. A. M. Radzi, and N. Azis, "The effect of temperature on a monocrystalline solar PV panel," *2015 IEEE Conf. Energy Conversion, CENCON 2015*, pp. 249–253, 2015, doi: 10.1109/CENCON.2015.7409548.

[14] I. Lopez Ramirez, "Operating correction factor of PV system: Effect of

temperature, angle of incidence and invertor in PV system performance," no. January, p. 97, 2017.

[15] "Concentrated Solar Power." .

[16] "Diagram of a parabolic trough collector | Download Scientific Diagram." .

[17] B. Bierman, J. O'Donnell, R. Burke, M. McCormick, and W. Lindsay, "Construction of an Enclosed Trough EOR system in South Oman," in *Energy Procedia*, 2014, vol. 49, pp. 1756–1765, doi: 10.1016/j.egypro.2014.03.186.

[18] V. K. Ramesh, V. Chintala, and S. Kumar, "Direct Steam Generation by an Enclosed Solar Parabolic Trough for Enhanced Oil Recovery," Springer, Singapore, 2020, pp. 189–198.

[19] R. D. Prasad and R. C. Bansal, "Photovoltaic systems," *Handb. Renew. Energy Technol.*, pp. 205–224, 2011, doi: 10.1142/9789814289078_0009.

[20] "Monocrystalline Cells vs. Polycrystalline Cells: What's the Difference? | CED Greentech." .

[21] "What is thin-film solar?" .

[22] M. Munsell, "Global Solar Tracker Shipments Grow 32% in 2017, NEXTracker Leads the Market," *www.greentechmedia.com*, Feb. 2018, Accessed: Mar. 13, 2021. [Online]. Available: https://www.greentechmedia.com/articles/read/global-solar-tracker-shipments-grow-32-in-2017-nextracker-leads-the-market.

[23] "What Is a Solar Tracker and Is It Worth the Investment?" https://www.solarreviews.com/blog/are-solar-axis-trackers-worth-the-additional-investment (accessed Mar. 13, 2021).

[24] "Concentrated Solar Power (CSP) Vs Photovoltaic (PV): An In-depth Comparison | SF Magazine." https://mag.solarfeeds.com/csp-and-pv-differences-comparison/ (accessed Apr. 15, 2021).

[25] "The future of solar energy: concentrated solar power vs. photovoltaic power plants." https://blogs.dnvgl.com/energy/the-future-of-solar-energy-concentrated-solar-power-vs-photovoltaic-power-plants (accessed Apr. 15, 2021).

[26] "CSP vs PV – Understanding the current situation and future outlook | UCL UCL Institute for Sustainable Resources Blog." https://blogs.ucl.ac.uk/sustainable-resources/2015/11/30/csp-vs-pv-understanding-the-current-situation-and-future-outlook/ (accessed Apr. 15, 2021).

[27] "Installation Cost of Solar Panels 2021 | GreenMatch." https://www.greenmatch.co.uk/blog/2014/08/what-is-the-installation-cost-for-solar-panels (accessed Apr. 17, 2021).

[28] "Concentrated Solar Power capex costs fall by almost half – HELIOSCSP."

https://helioscsp.com/concentrated-solar-power-capex-costs-fall-by-almost-half/ (accessed Apr. 17, 2021).

[29] W. C. L. Kamuyu, J. R. Lim, C. S. Won, and H. K. Ahn, "Prediction model of photovoltaic module temperature for power performance of floating PVs," *Energies*, vol. 11, no. 2, 2018, doi: 10.3390/en11020447.

[30] "Solar Panels Based on Maxeon Solar Cell Technology | SunPower." https://us.sunpower.com/why-sunpower/maxeon-solar-cells (accessed May 06, 2021).

[31] "CSP." https://www.irena.org/costs/Charts/CSP (accessed May 12, 2021).

[32] A. Jäger-Waldau, *PV Status Report 2019*. 2019.

[33] "EEC LOAN - Bangladesh Infrastructure Finance Fund Limited (BIFFL) | BIFFL | Government owned non banking financial institution in Bangladesh | Project Finance in Bangladesh." https://biffl.org.bd/eecloan/ (accessed Apr. 27, 2021).

[34] A. Walker *et al.*, "Model of Operation-and-Maintenance Costs for Photovoltaic Systems, Technical Report NREL/TP-5C00-74840," *Nrel*, no. June, 2020.

[35] J. J. C. S. Santos, J. C. E. Palacio, A. M. M. Reyes, M. Carvalho, A. J. R. Freire, and M. A. Barone, "Concentrating Solar Power," *Adv. Renew. Energies Power Technol.*, vol. 1, no. 2, pp. 373–402, 2018, doi: 10.1016/B978-0-12-812959-3.00012-5.

[36] "New CSP research shows how O&M cost savings begin in planning phase | Reuters Events | Renewables." https://www.reutersevents.com/renewables/csp-today/new-csp-research-shows-how-om-cost-savings-begin-planning-phase (accessed Apr. 29, 2021).

[37] K. A. Ritter III, M. J. Prilliman, T. L. Chambers, and J. R. Raush, "Maintenance of a Small-Scale Parabolic Trough Concentrating Solar Power Plant in Louisiana," *Int. J. Sustain. Green Energy*, vol. 6, no. 6, pp. 104–111, 2018, doi: 10.11648/j.ijrse.20170606.12.

[38] "CONCENTRATING SOLAR POWER NOW CLEAN ENERGY FOR SUSTAINABLE DEVELOPMENT." Accessed: Apr. 28, 2021. [Online]. Available: http://www.bmu.de.

[39] P. Viebahn, Y. Lechon, and F. Trieb, "The potential role of concentrated solar power (CSP) in Africa and Europe-A dynamic assessment of technology development, cost development and life cycle inventories until 2050," *Energy Policy*, vol. 39, no. 8, pp. 4420–4430, Aug. 2011, doi: 10.1016/j.enpol.2010.09.026.

[40] "What will happen to solar panels after their useful lives are over? | Greenbiz." https://www.greenbiz.com/article/what-will-happen-solar-panels-after-their-useful-lives-are-over (accessed Apr. 28, 2021).

[41] "Useful Life | Energy Analysis | NREL." https://www.nrel.gov/analysis/tech-footprint.html (accessed Apr. 28, 2021).

APPENDIX 1

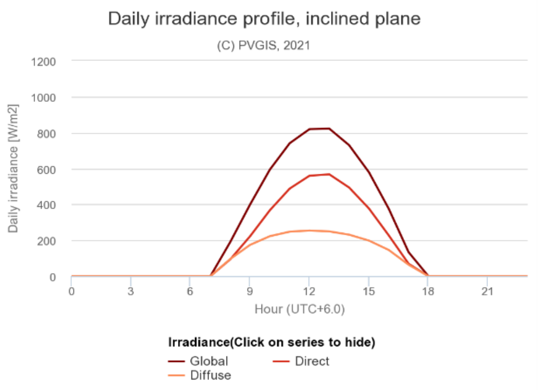


Figure: Daily irradiance January 2016

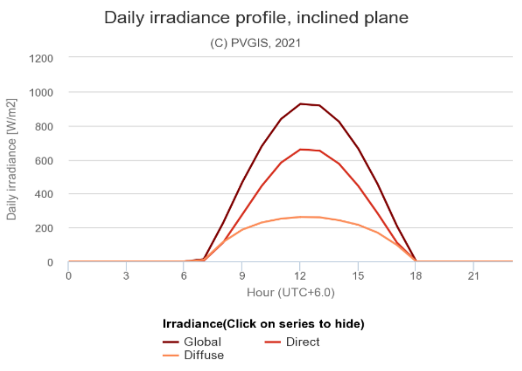


Figure: Daily irradiance February 2016

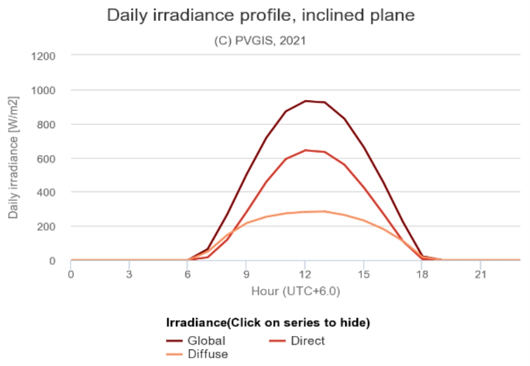


Figure: Daily irradiance March 2016

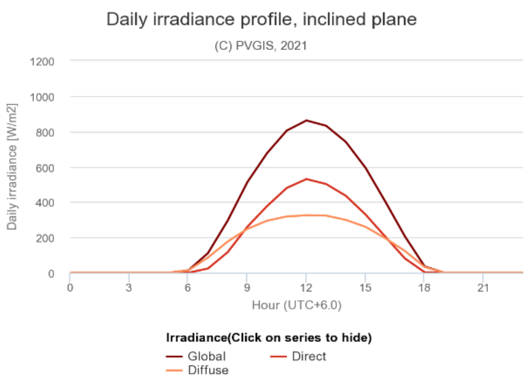


Figure: Daily irradiance April 2016

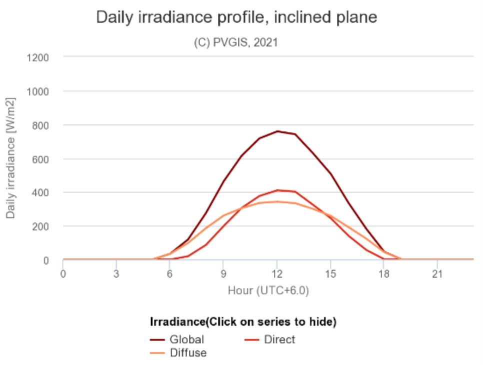


Figure: Daily irradiance May 2016

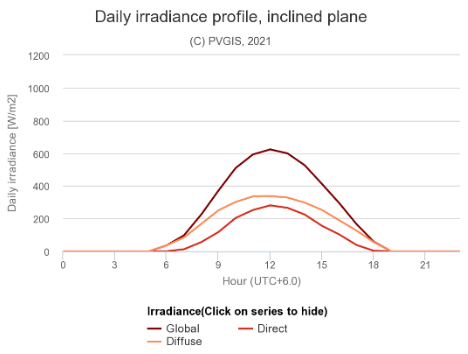


Figure: Daily irradiance June 2016

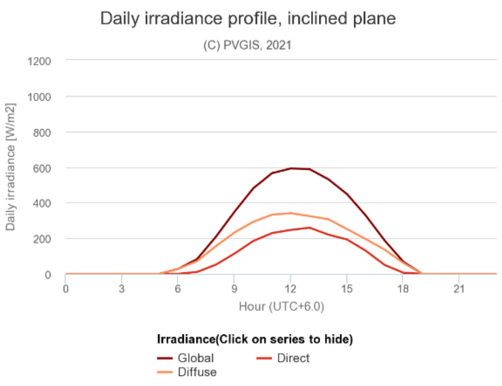


Figure: Daily irradiance July 2016

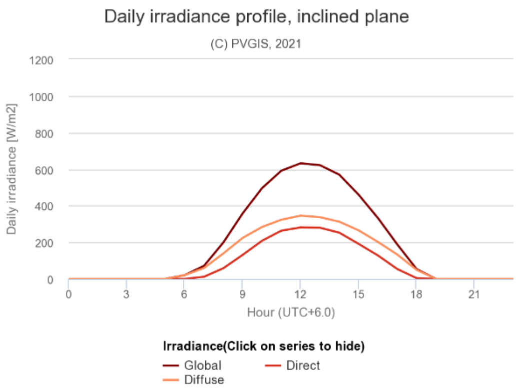


Figure: Daily irradiance August 2016

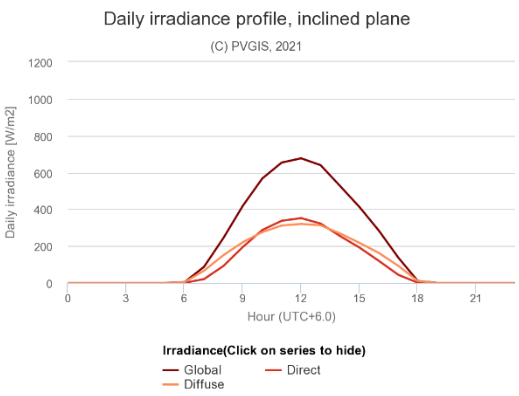


Figure: Daily irradiance September 2016

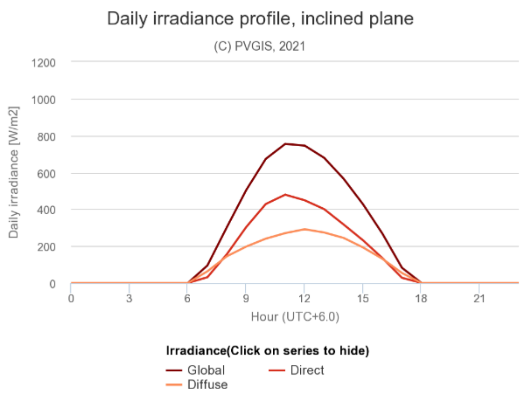


Figure: Daily irradiance October 2016

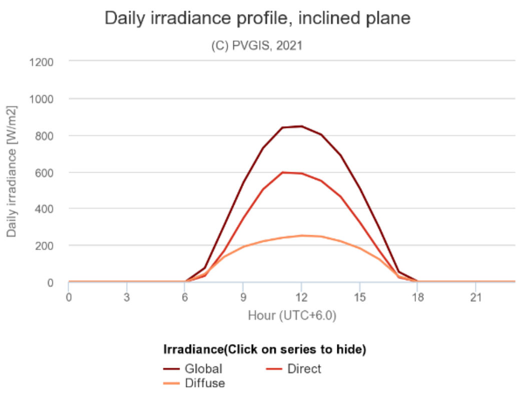


Figure: Daily irradiance November 2016

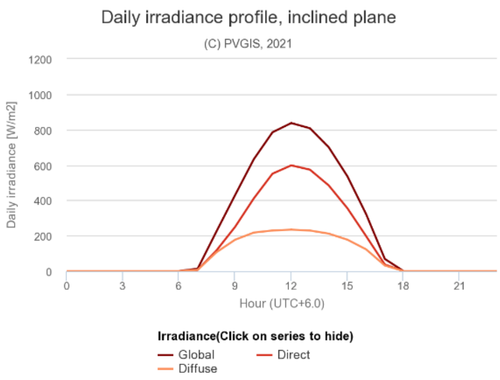


Figure: Daily irradiance December 2016

APPENDIX 2

The calculation can be found in the given link:
https://drive.google.com/file/d/1e-
hglc3ppcxvNzn_PNxKo75FAdSiBbe7/view?usp=sharing