COMPREHENSIVE MODELLING ON VARIOUS SOLAR PHOTOVOLTAIC TECHNOLOGIES BASED ON LOCAL CLIMATE CONDITIONS: THE POTENTIAL, LIMITATIONS AND ECONOMIC IMPACT

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A project report submitted in partial fulfilment of the requirements for the award of Master of Engineering (Electrical)

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Jan 2022

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"COMPREHENSIVE MODELLING ON VARIOUS SOLAR PHOTOVOLTAIC TECHNOLOGIES BASED ON LOCAL CLIMATE CONDITIONS: THE POTENTIAL, LIMITATION AND ECONOMIC IMPACT"** was prepared by **EDBERT HUAM JUN PING** has met the required standard for submission in partial fulfilment of the requirements for the award of Master of Engineering (Electrical) at Universiti Tunku Abdul Rahman.

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ABSTRACT

Solar Photovoltaic is a type of renewable energy technology that converts solar energy into electrical energy. This type of electricity generation does not produce any carbon dioxide (CO2) towards the surroundings as compared to burning of fossil fuels. Hence, this technology is a clean and environmentally friendly. However, not all solar power plant project is successful as it may prone to lack of planning, design, estimation and financial that will lead to failure operation of solar power plants. Since Malaysia is a county situated at the equator, where abundant of solar is available. In order to fully utilize the solar energy, it is recommended to install the solar panel with tilted angle to obtain the maximum solar irradiation, while able to generate income and electricity.

The aim and objective in this project consist of computation modelling of python programming using the metrological data of the local climate, where the annual average solar irradiation, optimum tilt angle, orientation of solar panel and the maximum solar irradiation received in a year. Next, in a specific area of land, the amount of carbon dioxide emission due to deforestation will be compared with the carbon dioxide avoidance due to installation of solar panel. This is to estimate whether the area of land is suitable for solar panel installation in order to introduce more renewable energy than fossil fuels. If the carbon dioxide emission is more than carbon dioxide avoidance, that area of land is not recommended for installation and should be left untouched. Lastly, the investment cost and annual income generated by the solar farm is estimated, while calculating the estimated payback period of the project.

For the accuracy of simulation in estimating the tilt angle and orientation angle, the simulated results are compared with the literature review results and found out the overall accuracy is 66.67%, which is above average and acceptable. In addition, the percentage error obtained between the solar irradiation received is within the range of 1-2% error, which is acceptable. Next, the carbon dioxide presence and carbon dioxide avoidance are highly dependent on the area of clearance, local climate and electricity generated. The overall solar sites are able to avoid the carbon dioxide when it is operating. Lastly, the investment cost, annual income and payback period for specific solar sites are estimated as it will depends on the local interest rate and inflation rate.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

LIST OF SYMBOLS / ABBREVIATIONS

CO2	Carbon Dioxide
Solar PV	Solar PhotoVoltaic
DC	Direct Current
AC	Alternating Current
DNI	Direct Normal Irradiance (W/m2)
DHI	Diffuse Horizontal Irradiance (W/m2)
GHI	Global Horizontal Irradiance (W/m2)
TNB	Tenaga National Berhad
UTC	Universal Time Coordiante
GMT	Greenwich Mean Time
A_s	Solar Azimuth from North
A_{PV}	Panel Azimuth from North
$\mathrm{I_N}$	Solar Irradiation on Normal Surface of PV Panel
$\mathrm{I_{DNI}}$	Direct Normal Irradiation on Horizontal Surface of PV Panel
$\mathrm{I_{DHI}}$	Diffuse Horizontal Irradiation on Horizontal Surface of PV Panel
$\mathrm{I_T}$	Total Solar Irradiation onto the surface of PV Panel
GFW	Global Forest Watch
Ha	Hectare
tCO2	Tons Carbon Dioxide
kWh	KiloWatt Hour
MWh	MegaWatt Hour
i	Interest Rate
j	Inflation Rate
i'	Real Interest Rate
NEM	Net Metering
3D	Three Dimensional
EOT	Equation of Time
kWh/m2	KiloWatt Hour per Meter Square (Solar Irradiation)

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 General Introduction

Renewable energy is a type of energy that can be obtainable from the nature such as wind, solar, water and others (Zoe, 2021). Renewable energy technology is able to convert this natural energy into another form of energy which are the electrical, mechanical, chemical and others. On the other hand, a non-renewable energy is a type of energy that cannot be reproduce once and will be depleted once it has been used. The example of non-renewable energy are petroleum, natural gas, coal and others (Harrington, 2009). Both renewable and non-renewable energy have similar purposes, which provide energy for human activities; however, renewable energy is able to replenish its resources whereas non-renewable energy does not (NationalGeographic, 2022). Another concern of using non-renewable energy as source is due to its environmental impact. GreenTumble (2017), mentioned that this type of energy produces various greenhouse gases, mainly on carbon dioxide (CO2) is being released towards the surrounding upon burning of fossil fuels. With the increasing level of carbon dioxide, the greenhouse effect increase, which leads to the temperature of the Earth increase due to the heat is being trapped at the atmosphere. Hence, global warming effect activates (BBK, 2022). Mankind discovered the non-regeneration and environmental effect of utilizing the non-renewable energy, they seek to focus in obtaining an alternative solution, which is the usage of renewable energy, where free from environmental effect and reliable energy sources can be achieved (Myisha, 2021).

One of the renewable energy technologies mentioned is the solar photovoltaic technology, also know as solar PV. The basic components that made up of the PV system are numerous solar cells, where it converts the incoming solar energy into electrical energy. These solar cells convert the electricity in a direct current (DC) as an output. Often the solar PV is connected to the grid, which is an AC based. Hence, the solar PV is connected to an inverter before injecting the output electricity towards the grid. The main purpose of inverter is to convert the output DC electricity from the solar cells to AC electricity to connect to the grid (Louis, 2018). The DC power convert by the solar cells is not always constant as the intensity of the incoming sunlight are different from time to time (Deolalkar, 2016). Figure 1.1 shows an example on how solar energy is being converted to AC power towards the grid.

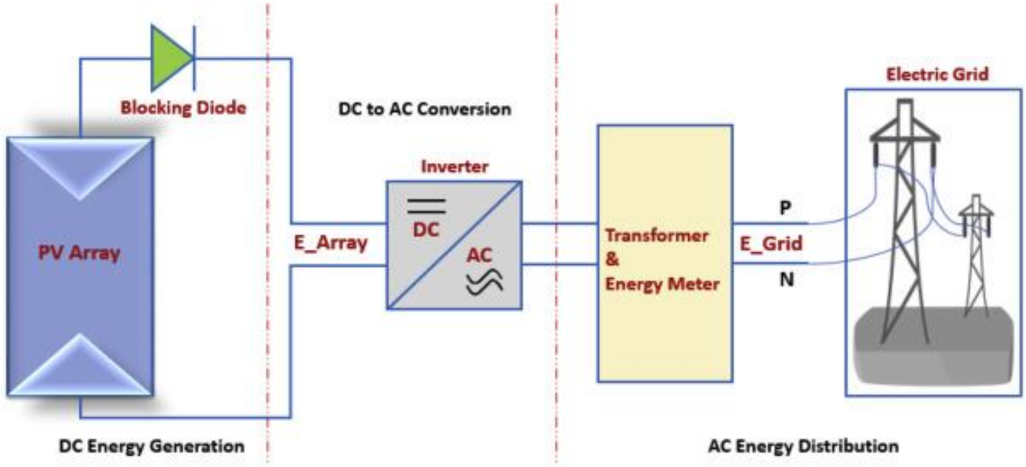


Figure 1.1 Solar PV towards the Grid Connection (Nallapaneni, 2019).

Malaysia is a country with a geographic location situation at the equator, where solar energy is abundant at the equator (Gerardo, 2005). Since solar energy is abundant, it is recommended to explore the advantage and opportunity for the development of solar photovoltaic technology, which is a safer option towards the environment. According to ScienceDirect, a website publisher with various journals, papers and research on large scale of topics, specifically solar energy. Based on the title “Solar Photovoltaic AND Malaysia”, the numbers of paper produces are increased each year (2016 to 2021), meaning that the development and research on solar energy are still in progress and improved each year. Figure 1.2 shows the published paper each year obtained from ScienceDirect.

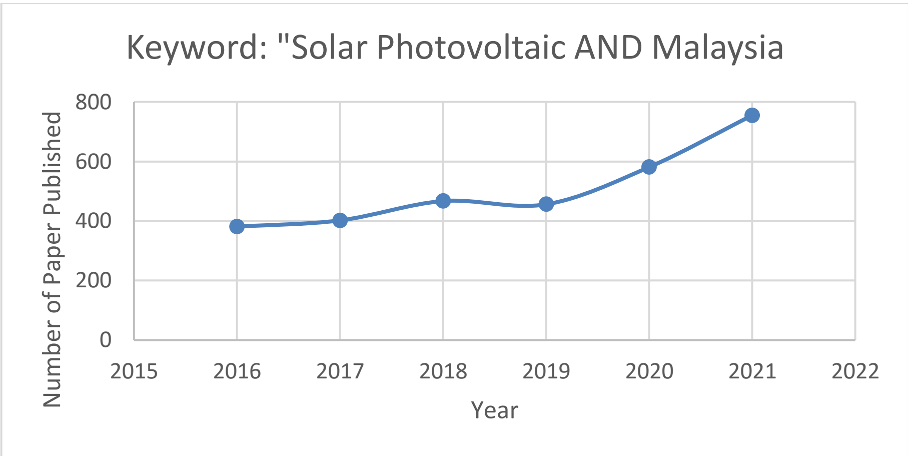


Figure 1.2: Statistic on ScienceDirect Published Paper.

1.2 Importance of the Study

Since solar photovoltaic requires solar energy to operate, which is a clean and renewable energy that can be obtained and convert to electricity during daytime. In terms of economic impact, the implementation of solar panel helps to reduce the cost of electricity bills. According to Dr Ermeey through Bernama (2021), mentioned that UITM successfully install solar panels with a capacity of 1.6 MW, where the electricity bills is able to save up to 20% monthly. Furthermore, he mentioned that the usage of solar energy should be continued to transform the country into a carbon neutral and be able to generate income for the country.

The study is important is because it helps achieving the 4 out of 17 sustainable development goals which is shown in Figure 1.3.

Figure 1.3: 17 Sustainable Development Goals (UN, 2022).

In this study, there are 4 main goals will be achieved which are:

Goals	Remarks
7. Affordable and Clean Energy	The implementation of solar photovoltaic to obtain the maximum solar irradiation based on local climate.
15. Life on Land	To estimate the carbon dioxide reduction by operating solar farm.
8. Decent work and economic growth	To introduce the income generated by operation of solar farm.
4. Quality Education	Able to simulate a model using Python Programming

1.3 Problem Statement

According to Isidoro (2017), mentioned that solar project will experience failure due to 3 main parameters, which are the design, PV module and environmental condition during implementation. For example, different location has different solar irradiation, meaning that without proper survey, even the best solar panel is unable to harvest the solar energy to its maximum potential and may lead to a poor sustainability.

Based on the observations from Solynta (2017), stated one of the main reasons that the solar farm project failed is due to lack of planning, design, estimation and financing. Once the company ignore this step and process in installing, the investment cost upon the project will be dissipated. In terms of environmental impact, trees were cleared to install the solar panels, however, when the performance of the solar plant does not exceed expectation, the project may cease its operation and abandoned. (Casey, 2019).

Hence, the computational modelling in this project is implemented for estimate the optimum tilt and orientation angle to obtain the maximum solar irradiation, environmental impact with carbon dioxide reduction, economic impact with payback period as a pre-estimation value for any individual that interested in setting up a solar farm based on local climate.

1.4 Aims and Objectives

This proposed project aims to perform the case study on various renowned solar farms in Malaysia based on different objectives.

1. To run a computational model by using Python Programming for a year of metrological data from Solcast © for each solar site
2. To estimate the annual average solar irradiation and peak sun hours received on each of the solar sites.
3. To determine among the 17 solar sites, by ranking the solar sites based on the solar irradiation received for a year.
4. To compute the sun position of the solar sites using the formula given in Chapter 3.
5. To model the suitable tilt angle, azimuth of the solar panel based on the maximum total solar irradiation of the year in 3D.
6. To estimate the carbon dioxide presence based on the area of case study due to deforestation.
7. To estimate the carbon dioxide reduction by introducing the solar photovoltaic in the solar sites.
8. To estimate the investment cost, annual income and payback period of the solar site.

1.5 Scope and Limitation of the Study

This project scope is to perform case study on 17 solar sites, for the parameters of annual average solar received, peak sun hours per day, sun position, DNI, GHI, ranking of solar sites, optimum tilt angle, azimuth of the solar panel, maximum total solar irradiation received and carbon dioxide emission reduction for each solar site.

The first limitation of this study is that all these results are based on the metrological data provided by Solcast © and theoretical formula results. Therefore, a comparison of results between the project results generated and the actual results is needed to be performed, for example on-site solar panel results.

Another limitation of this study is that only some of the company or owner of the case study solar sites such as Scatec Itramas ©, Solarvest© and others, they are willing to provide values of parameters such as optimum tilt angle and azimuth for this study. This is due to the company’s policy, where they are unable to reveal that valuable information. Thus, this study will be used to compare with the simulated results.

Lastly, the carbon dioxide and economic impact in this study is perform. Each study is based on estimation and no reference paper were provided to support the simulated results for the environmental and economic impact respectively. Hence, the simulated results are an estimated value.

1.6 Contribution of the Study

The contribution of the study is to assist researchers or investors in selecting the best solar sites among various location based on variable choices. In addition, a pre-estimated area for solar panel installation, results tabulation based on historical metrological data can be perform without actual travelling to the specific sites to perform the survey. For a traditional method, the individual is needed to set up the solar panel at a particular location while performing the observation, reading and tabulate the results using the measuring equipment that require cost for purchasing. These steps can be reduced significantly by introducing the computation modelling of solar panel, where this model is developed using Python language.

With this modelling, the individual is able to estimate the optimum tilt angle, azimuth of the solar panel, as well as the estimated total solar irradiation received in a year. This programming is able to perform a one-year data, to find out the optimum angle of the solar panel, at a particular site within a day of duration. All these steps can be performed indoor. The value simulated can acts as a reference for the individual to immediately set up the solar panel, adjust the angle based on the results generated without needed to undergo practical experiment.

Besides, the simulation is able to pre-estimate the presence of carbon dioxide due to deforestation and the estimated area of forest clearance for installation purposes. Lastly, the payback period of the solar farm is performed based on investment cost report, annual income based on tariff rate by TNB, bank interest rate and fuel inflation rates.

1.7 Outline of the Report

This report will have contents divided into several chapters, which is easier for viewer to read. The chapters included in this report are Chapter 1, which presents the introduction, objectives, scope and limitation of this project study. In Chapter 2, the methods from various thesis proposed by the researcher will be stated in this chapter. The proposed methodology used for this project will be carried out in Chapter 3. In Chapter 4, the results and discussion will be provided based on the model simulated. Lastly, conclusion and recommendation for the project is given in order to further improve the project as a wrap up.

1.8 Gantt Chart

Table 1.1 and 1.2 shows the Gantt chart for Project 1 (19^{th} September 2021 ~ 3^{rd} December 2021) and Project 2 (17^{th} January 2022 ~ 8^{th} April 2022) respectively.

Table 1.1: Gantt Chart Project 1

Project Activities	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12
Problem formulation, planning and project discussion												
Set up project												
Data gathering												
Preliminary testing/investigation												
Computational of sun position												
Ranking of solar sites												
Report writing												

Table 1.2: Gantt Chart Project 2.

Project Activities	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12
Modelling of optimum tilt angle, azimuth angle and total solar irradiation												
Calibration for accuracy of the modelling												
Calculation of Carbon dioxide reduction for solar farm												
Estimation of investment cost, annual income, interest and inflation rate												
Conclusion and												

Presentation												

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this project, the estimation of optimum tilt angle, orientation angle, maximum total solar irradiation, carbon dioxide emission and avoidance, investment cost, annual income and payback period all can estimated by using the formula derived in CHAPTER 2 and CHAPTER 3.

The general idea of the project is obtained that metrological data from Solcast © based on the specific location. Then, the python programming will capture the data and perform analysis. With this data, the formula for determining parameters such as declination angle, solar time, azimuth angle, zenith angle, cosine angle and others can be calculated. The cosine loss is the main factor that affect the maximum solar irradiation received at the particular time. To minimize the cosine loss, the optimum tilt angle is determined by using the formula review.

The implementation of fixed tilt solar panel requires the deforestation of area for the installation. Hence, it is important to estimate the carbon dioxide is able to be reduce when solar panel is installed. Lastly, the economic impact of the solar farm, where the formula for determine the overall cost is reviewed.

2.2 Time-zone for Case Study

	A	B	C
1	PeriodEnd	PeriodStart	Period
2	2020-08-31T02:00:00Z	2020-08-31T01:00:00Z	PT60M
3	2020-08-31T03:00:00Z	2020-08-31T02:00:00Z	PT60M
4	2020-08-31T04:00:00Z	2020-08-31T03:00:00Z	PT60M
5	2020-08-31T05:00:00Z	2020-08-31T04:00:00Z	PT60M
6	2020-08-31T06:00:00Z	2020-08-31T05:00:00Z	PT60M
7	2020-08-31T07:00:00Z	2020-08-31T06:00:00Z	PT60M
8	2020-08-31T08:00:00Z	2020-08-31T07:00:00Z	PT60M
9	2020-08-31T09:00:00Z	2020-08-31T08:00:00Z	PT60M
10	2020-08-31T10:00:00Z	2020-08-31T09:00:00Z	PT60M
11	2020-08-31T11:00:00Z	2020-08-31T10:00:00Z	PT60M
12	2020-08-31T12:00:00Z	2020-08-31T11:00:00Z	PT60M
13	2020-08-31T13:00:00Z	2020-08-31T12:00:00Z	PT60M
14	2020-08-31T14:00:00Z	2020-08-31T13:00:00Z	PT60M
15	2020-08-31T15:00:00Z	2020-08-31T14:00:00Z	PT60M
16	2020-08-31T16:00:00Z	2020-08-31T15:00:00Z	PT60M
17	2020-08-31T17:00:00Z	2020-08-31T16:00:00Z	PT60M
18	2020-08-31T18:00:00Z	2020-08-31T17:00:00Z	PT60M
19	2020-08-31T19:00:00Z	2020-08-31T18:00:00Z	PT60M
20	2020-08-31T20:00:00Z	2020-08-31T19:00:00Z	PT60M

Figure 2.1: Time-zone of Solcast data

As shown in Figure 2.1, the time zone format provided by Solcast © is in Coordinated Universal Time (UTC) format. Therefore, the UTC Time Zone is needed to be changed into Malaysia Time Zone as Case Study is held in Malaysia as shown in Chapter 3: Methodology. As stated in Konrad (2019), mentioned that the Earth rotates once in 24h, which is approximately 360 degrees, hence by calculation,

$$\frac{360^{\circ}}{24hrs} = \frac{360^{\circ}}{24 * 60} = \frac{360^{\circ}}{1440mins} = \frac{1^{\circ}}{4mins} \qquad \text{Eq.1}$$

In addition, for every 4 minutes, the sun moves to 1 degree of longitude. In order to determine the standard longitude of a location, the difference of local standard clock and the Greenwich Mean Time, then multiply by 15 degrees, as shown in Jonathan (2020) and Jack (2011).

$$Standard\ Longitude = (UTC) * 15 \qquad \text{Eq.2}$$

Coordinated Universal Time (UTC) or can be rephrases as Greenwich Mean Time (GMT), where the time zone of this location is default at 0 longitude. According to Hamdan (2017), stated that Malaysia is 8 hours ahead of GMT and UTC, hence for displayed universal, Malaysia Standard Time is UTC + 8.

2.3 Literature Review on Fixed Tilted Angle

According to Qasir (2021), a study conducted on the titled angle of the solar panel throughout a year of solar irradiation. The motivation for the author to introduce a fixed or flexible tilted angle throughout the year is that the solar tracking system is expensive to initialize. By considering a more economic approach, a fixed optimum tilted angle is recommended in order to achieve maximum power and flexible in retrieving sunrays on different date and time.

Different tilted angle of the solar panel will receive different level of solar irradiation on the surface of the solar panel. The author also mentioned that on a given fixed tilted solar panel, the irradiance level of solar will not only be affected by the tilted solar panel, the declination angle of throughout the month will also affect the received solar irradiance. The suitable tilt angle can be determined by various parameters such as declination angle (Phaphithoun, 2016) and the solar radiation on the surface of the solar panel (estimated value) (Dominykas, 2016). Researcher also suggest that in order to improve the solar radiation received by the solar panel, various parameters such as latitude of solar site, weather condition, tilt and azimuth angle will affect the collected radiation annually.

As a reference in Malaysia, the optimum tilt angle of the solar panel annually was 10 degrees, which is higher than the local latitude (Jin, 2017). Besides, another study found that the optimal tilt angle in Malaysia is within the range of 0 degree to 27 degrees throughout the year, from summer to winter seasons (Asad, 2019). Next, a study conducted on the comparison of solar energy between fixed and flexible tilted angle of solar panel in Malaysia. The study found that the adjustment of the tilted angle of the solar panel based on situation have a 40% increase in solar energy received as compared to fixed tilted angle throughout the year.

Another study conducted by Mark (2018), the author creates a compilation of the optimum angle of solar panel throughout different countries, from North to South contingent, from East to West Country. The author that this tilted angle is determined by using the method of "increasing method", where the panel output is being calculated by configuring the tilted angle, up to a maximum panel output being achieved. When the maximum panel output is determined, the tilted angle is concluded to be the optimum tilted angle of the location.

A comparison between a horizontal surface and a tilt angle of the PV panel equivalent to the declination angle of the location. According to Soteris (2014) and Danny (2007), mentioned that the incident angle is the angle between the normal to the PV module to the sunlight. In addition, the azimuth of the PV panel is facing the direction of west due south. This setting is to maximize the energy output in the noon but would sacrifice the electricity in the morning.

In addition, Mehmet (2015), mentioned that the sun angle of incidence changes throughout time, the sunshine duration also changes. Thus, the panel should be installed in a fixed position at an optimum inclination angle, in order to received maximum sunlight for the annual timeline.

Research done by Yunus (2019), with the optimum fixed tilt angle throughout monthly, seasonally and annually. The author performs their experiment with the combination of simulation and mathematical calculation method. Therefore, the author concludes that the optimum tilt angle for the location above the equator (2.6N to 30 N), the range is within $5° \, to \, 28°$ in order to maximize the solar energy received by the panel.

The preferred choice for the fixed tilt angle in solar panel are the reduction overall cost as compared to flexible axis. According to the report (David, 2020), shows a comparison of overall cost between fixed tilt and axis tracker in a utility-scale. In Figure 2.2 shows that with a 100MW capacity, the overall price in 2020 for fixed tilt and axis tracker are 0.94 USD/Watt and 1.01 USD/Watt. Therefore, in order to generate electricity while reducing the invested cost, a fixed tilt solar panel pattern is chosen.

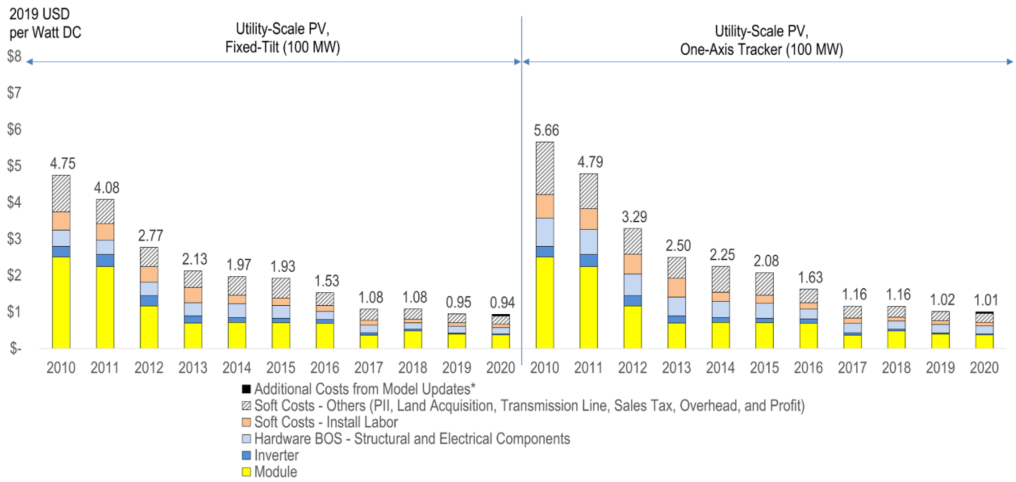


Figure 2.2: Cost difference for Fixed and One Axis PV. (David, 2020).

2.4 Method for Determine Cosine Effect Formula for 3D Modelling

According to Joannes (2019), mentioned that different position of PV panel have the ability to benefit from receiving the sunlight and convert into electricity system, whether horizontally or vertically. By changing the orientation, the output of PV panels may vary. Therefore, the relationship between orientation of the PV panel and position of the sun, results in the outcome of the energy production.

The solar panel diagram adapted by Maryon (2021), and Joannes (2019) is shown in Figure 2.3. The parameters involved in the solar collector and sun position are shown in tabulated table below. The author mention that the range for the PV panel tilt angle is within $0 < \beta < 90$. If the tilt angle, $\beta > 90$, meaning that the PV panel is facing towards the ground or shade itself. The range of the sun altitude angle from morning to noon is between $0 < \alpha < 90$ as well as noon to night $(0 < \alpha < 90)$ (Amaya, 2019).

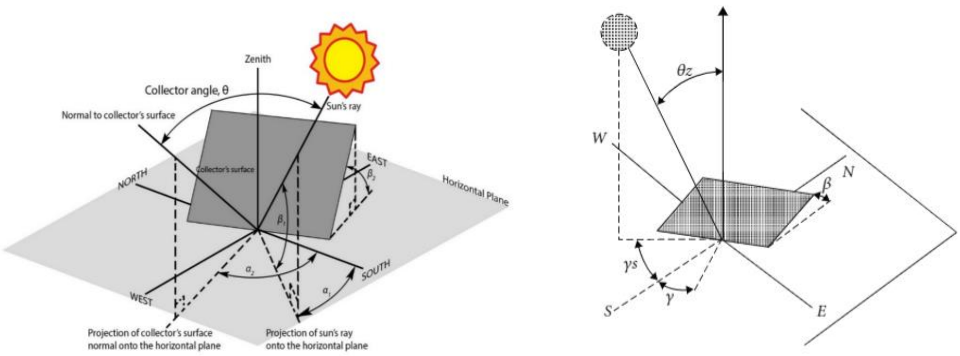


Figure 2.3: Incident Angle for 3D modelling. (Joannes, 2019)

Parameters	Definition
θ_z	Zenith angle of the sun position at the particular time
β	Tilt angle of the PV panel at the particular time
γ	The panel surface azimuth, ES (negative), WS (positive)
γ_s	The sun azimuth angle at the particular time
θ	The angle of incident between the normal of the PV surface and the incoming sunlight
I_{DNI}	The direct normal irradiation on the horizontal surface panel, data retrieved from Solcast.

I_N	The solar irradiation on the normal surface of the PV panel at the particular time

The overall formula for determining the solar incident angle and the sun position angle at the particular time, (John 2013), (William, 2013) and (Lucien, 2018):

$$\cos\theta = \cos\theta_z \times \cos\beta + \sin\theta_z \times \sin\beta \times \cos(A_s - A_{PV}) \quad \text{Eq.3}$$

$$I_N = I_{DNI}\cos\theta \quad \text{Eq.4}$$

$$I_T = I_{DNI} + I_{DHI} \quad \text{Eq.5}$$

Where $\theta = incident\ angle, \theta_z = zenith\ angle, \beta = tilted\ angle, A_s = solar\ azimuth\ starting\ from\ north, A_{pv} = panel\ azimuth\ from\ north.$

In addition, John (2013), mentioned that if the incident angle, $\theta > 90$, the sun position is behind the solar panel, meaning that at this incident angle, the calculation of the solar received on the panel can be ignored.

The derivation of the formula for calculating the incident angle can be discovered based according to the working steps below. (Powerfromthesun, 2022).

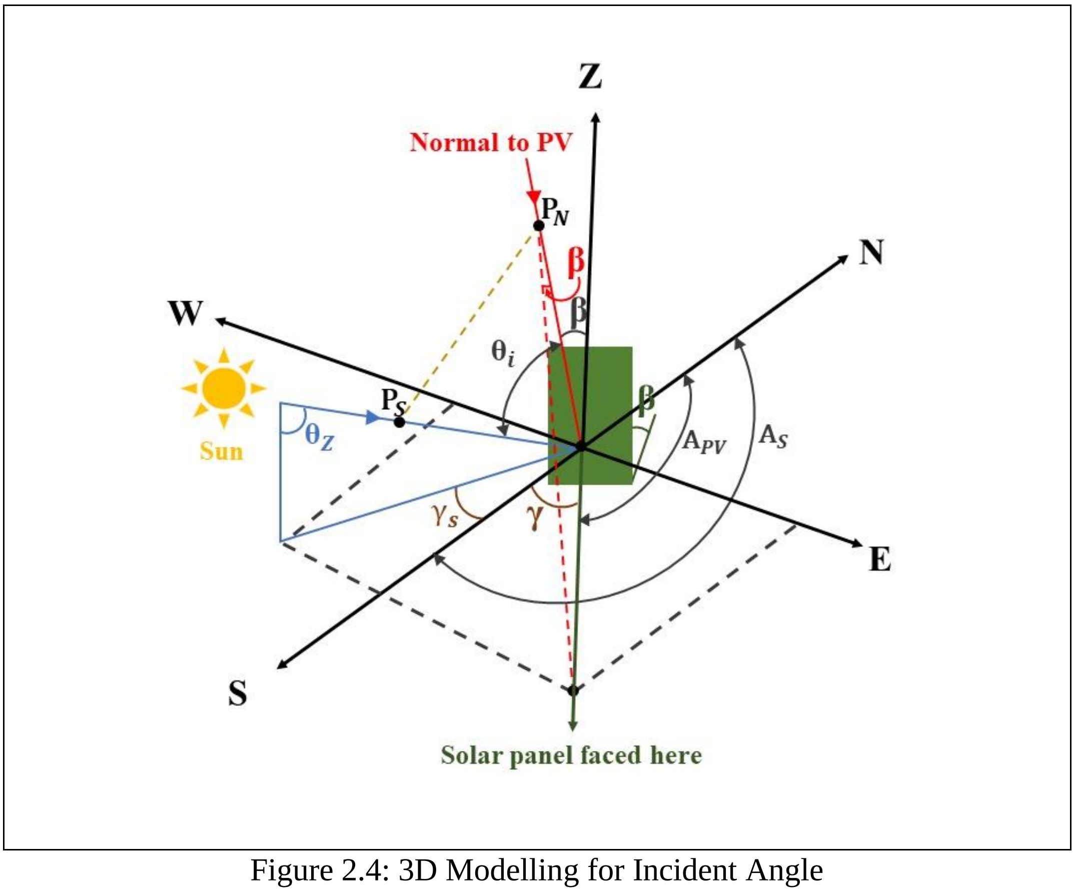


Figure 2.4: 3D Modelling for Incident Angle

Assume both P_N and P_S have the same length from origin, $OP_N = OP_S = l$ Eq.6
In Z-axis, $Z_N = l \times \cos\beta$ Eq.7 $Z_S = l \times \cos\theta_Z$ Eq.8
In X-axis, is the axis from North to South, $X_N = l \times \sin\beta \times A_{PV}$ Eq.9 $X_S = l \times \sin\theta_Z \times A_S$ Eq.10
In Y-axis, is the axis from East to West, $Y_N = l \times \sin\beta \times \sin A_{PV}$ Eq.11 $Y_S = l \times \sin\theta_Z \times \sin A_S$ Eq.12
Find the distance between OP_N and OP_S, $P_N P_S = \sqrt{(X_N - X_S)^2 + (Y_N - Y_S)^2 + (Z_N + Z_S)^2}$ Eq.13   For $(X_N - X_S)^2$, $(X_N - X_S)^2 = (l \times \sin\beta \times A_{PV} - l \times \sin\theta_Z \times A_S)^2$ $= (l \times \sin\beta \times A_{PV})^2 - 2(l \times \sin\beta \times A_{PV})(l \times \sin\theta_Z \times A_S)$ $+ (l \times \sin\theta_Z \times A_S)^2$ Eq.14   For $(Y_N - Y_S)^2$, $(Y_N - Y_S)^2 = (l \times \sin\beta \times \sin A_{PV} - l \times \sin\theta_Z \times \sin A_S)^2$ $= (l \times \sin\beta \times \sin A_{PV})^2 - 2(l \times \sin\beta \times \sin A_{PV})(l \times \sin\theta_Z \times \sin A_S)$ $+ (l \times \sin\theta_Z \times \sin A_S)^2$ Eq.15   For $(Z_N - Z_S)^2$,

$$(Z_N - Z_S)^2 = (l \times \cos\beta - l \times \cos\theta_Z)^2$$
$$= (l \times \cos\beta)^2 - 2(l \times \cos\beta)(l \times \cos\theta_Z) + (l \times \cos\theta_Z)^2 \quad \text{Eq.16}$$

For $(X_N - X_S)^2 + (Y_N - Y_S)^2 + (Z_N - Z_S)^2$,

$$= (l \times \sin\beta \times A_{PV})^2 - 2(l \times \sin\beta \times A_{PV})(l \times \sin\theta_Z \times A_S) + (l \times \sin\theta_Z \times A_S)^2 + (l \times \sin\beta \times \sin A_{PV})^2 - 2(l \times \sin\beta \times \sin A_{PV})(l \times \sin\theta_Z \times \sin A_S) + (l \times \sin\theta_Z \times \sin A_S)^2 + (l \times \cos\beta)^2 - 2(l \times \cos\beta)(l \times \cos\theta_Z) + (l \times \cos\theta_Z)^2$$

$$= l^2(sin^2\theta_z cos^2 A_s - 2sin\theta_z cosA_s sin\beta cosA + sin^2\beta cos^2 A + sin^2\theta_Z sin^2 A_S - 2sin\theta_Z sinA_S sin\beta sinA + sin^2\beta sin^2 A + cos^2\theta_Z - 2cos\theta_Z cos\beta + cos^2\beta \quad \text{Eq.17}$$

Since $cos^2 x = 1 - sin^2 x$, the equation can be reconfigured into:

$$= l^2(sin^2\theta_z * (1 - sin^2 A_s) - 2sin\theta_z cosA_s sin\beta cosA + sin^2\beta * (1 - sin^2 A) + sin^2\theta_Z sin^2 A_S - 2sin\theta_Z sinA_S sin\beta sinA + sin^2\beta sin^2 A + (1 - sin^2\theta_Z) - 2cos\theta_Z cos\beta + (1 - sin^2\beta)$$

$$= l^2(2 - 2sin\theta_z cosA_s sin\beta cosA - 2sin\theta_Z sinA_S sin\beta sinA - 2cos\theta_Z cos\beta) \quad \text{Eq.18}$$

Substitute to $P_N P_S$,

$$P_N P_S = \sqrt{l^2(2 - 2sin\theta_z cosA_s sin\beta cosA - 2sin\theta_Z sinA_S sin\beta sinA - 2cos\theta_Z cos\beta)}$$

$$= l\sqrt{(2 - 2sin\theta_z cosA_s sin\beta cosA - 2sin\theta_Z sinA_S sin\beta sinA - 2cos\theta_Z cos\beta)} \quad \text{Eq.19}$$

Find the angle between OP_N and OP_S,

$$cos\theta_i = \frac{{OP_N}^2 + {OP_S}^2 - {P_N P_S}^2}{2OP_N OP_S} \quad \text{Eq.20}$$

For ${OP_N}^2$,

$${OP_N}^2 = l^2 \quad \text{Eq.21}$$

For ${OP_S}^2$,

$${OP_S}^2 = l^2 \quad \text{Eq.22}$$

For $2OP_N OP_S$,

$$2OP_N OP_S = 2l^2 \quad \text{Eq.23}$$

$$cos\theta_i = \frac{l^2 + l^2 - l^2(2 - 2sin\theta_z cosA_s sin\beta cosA - 2sin\theta_Z sinA_S sin\beta sinA - 2cos\theta_Z cos\beta)}{2l^2} \quad \text{Eq.24}$$

$$2l^2 cos\theta_i = 2l^2 - l^2(2 - 2sin\theta_z cosA_s sin\beta cosA - 2sin\theta_Z sinA_S sin\beta sinA - 2cos\theta_Z cos\beta)$$

$$cos\theta_i = 1 - 1 + sin\theta_z cosA_s sin\beta cosA + sin\theta_Z sinA_S sin\beta sinA + cos\theta_Z cos\beta$$

$$cos\theta_i = sin\theta_z cosA_s sin\beta cosA + sin\theta_Z sinA_S sin\beta sinA + cos\theta_Z cos\beta$$
$$= sin\theta_z sin\beta(cosA_s cosA + sinA_S sinA) + cos\theta_Z cos\beta \quad \text{Eq.25}$$

Since $cosAcosB + sinAsinB = \cos(A - B)$, hence,

$$= sin\theta_z sin\beta \cos(A_s - A) + cos\theta_Z cos\beta \quad \text{Eq.26}$$

Therefore, the equation to find the incident angle of the solar panel is:

$$cos\theta_i = sin\theta_z sin\beta \cos(A_s - A) + cos\theta_Z cos\beta \quad \text{Eq.27}$$

When the tilt angle of the panel lies horizontally, $\beta = 0$, the incident angle between the normal of the panel and sunray will be equals to the zenith angle of the sun, $\theta = \theta_z$. (Sergio, 2020) (Ekadewi, 2013).

If the panel is located at Northern hemisphere and south facing, the surface azimuth angle is 180 degrees starting from clockwise North. When the solar panels are installed in the northern hemisphere, it will be facing south $A_{panel} = 180°$, whereas solar panel installed in the southern hemisphere, it will be facing north ($A_{panel} = 180°$).

In order to determine which formula is suitable for this project, formula is used where assumed at the location site of 6.47N, 100.42E, with the solar time of 2020-08-31 13:48:14, given the tilt angle is 0 degree (horizontal flat PV panel), facing south, the incident angle of the surface for each formula is being tabulated.

Formula description	$\cos\theta = \cos\theta_z \times \cos\beta + \sin\theta_z \times \sin\beta \times \cos(A_s - A_{pv})$
Sun Incident angle	26.88
Sun Zenith angle	26.88
Direct Normal Irradiation	287

Solar Received on panel formula	$I = DNI * \cos(Incident\ angle))$
Solar received on panel	256

By theory, the formula can be used for estimating the solar received on the horizontal surface of the solar panel due to cosine effect, when the solar panel is at horizontal position, the incident angle is equals to the zenith angle.

2.5 Literature Review On-Site Experiment

According to a case study conducted by Nur (2018), which was located at Padang Besar, Perlis, with the geographical Latitude and Longitude of $6°38'58''$ N and $100°15'23''$ E, which is equivalent to 6.649444N, 100.256389E. The author undergoes the experiment with the duration of total 10 days in July 2017, which are 3rd, 5th, 7th, 10th, 12th, 14th, 17th, 19th, 21st and 24th, starting from 9am to 5pm each day with one hour interval.

The author sets up various tilt angles, ranging from -25 to +25 degrees, with intervals of 5, for 6 solar panels. During the testing duration, the author uses SEAWARD irradiance meter for data collection and recorded into CSV file for further analysis and discussion. In addition, 3 orientation angle is being set up which are:

1. North 70-degree East
2. South 20-degree East
3. True South 180 degree.

In summary, the author determined that the optimum tilt and orientation of the solar panel is -10 degree and South 20-degree East in July 2017. Besides, the total solar insolation received within 10 days of July 2017, are within the range of 43922.83 to 43295.46 Wh/m2.

Location	Coordinate	Optimum Tilt Angle
Padang Besar, Perlis	6.649444N, 100.256389	-10 degree

A solar panel set up by Ajao (2013), in Nigeria in order to determine the optimum tilt angle of the solar panel. The solar panel set up in Ilorin, Nigeria, with the experiment duration between May and June 2012 for 10 days. The angle set up for the solar panel ranges from 0 degree to 30 degree. The azimuth of the solar panel is facing true south, which means 180 degrees from North. The summary of the experiment is that the actual optimum tilt angle is 22 degrees as compared to the author theoretical value which is 14 degrees.

Location	Coordinate	Optimum Tilt Angle
Ilorin, Nigeria	8.5373N, 4.5444E	22 degrees

An author from India, Manoj (2020), set up various solar panel with different tilt angle in order to determine the suitable and optimum throughout the Year of 2018, January to December. The location set up at 30.748098N, 76.757141E as shown in Figure 2.5. The methodology of the author is by determine the suitable tilt angle for each season in order to achieve maximum solar irradiation as well as reducing labour cost. The tilt angle installation is between 10 degree and 40 degrees. For every hour in a year, the author recorded the real time data obtained from the solar panel and compare with the theoretical results. Although the author did not specify the orientation of the solar panel, but the optimum tilt angle varies between 26 degree and 28 degrees, with the help of actual real time experiment results.

Location	Coordinate	Optimum Tilt Angle
University Institute of Engineering and Technology (UIET), Panjab University, Chandigarh	30.748098N, 76.757141E	26 degree and 28 degrees

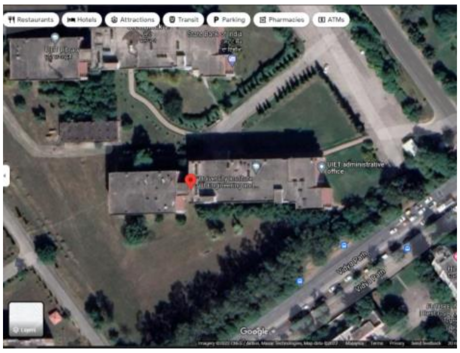


Figure 2.5: India Case Study

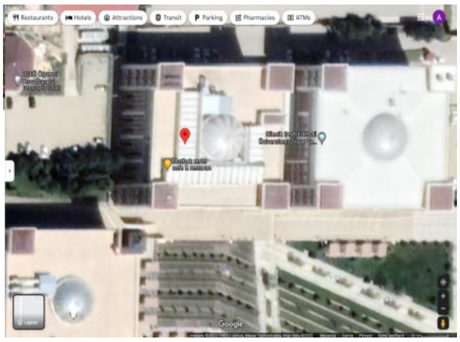


Figure 2.6: Turkey Case Study

Based on a case study conducted by Basharat (2016), the author aims to explore the potential of solar photovoltaic in India by utilizing the subtropical climate conditions. Two locations in India, which are Aligarh city (27.89°N, 78.08°E) and New Delhi (28.61°N, 77.20°E) undergoes the experiment to determine the optimum tilt angle based on the solar radiation throughout the year. The author set up in two locations for three years, which is from 2013 to 2016 for each minute. The settings for tilt angle are ranging from 0 to 90 with 10-degree interval. After compilation and analysis, the author summarizes that the optimum fixed tilt angle annually for Aligarh City is 27.62°, whereas New Delhi is 27.95°, these optimum tilt angles are almost identical to the latitude of both locations. In addition, with the implementation of fixed annual surface, the energy increased compared to horizontal flat surface for Aligarh City and New Delhi are 6.51% and 7.58% respectively. The author also recommends that the annual fixed tilt angle helps in reduction of installation and operation cost which monthly and seasonally tilt angle unable to achieve.

Location	Coordinate	Optimum Tilt Angle
Aligarh city	27.89°N, 78.08°E	27.62°
New Delhi	28.61°N, 77.20°E	27.95°

Akif (2015) also conducts a case study by set up solar panels at Bilecik, Turkey. The author performs this experiment is to determine the optimum tilt angle for Bilecik, with mathematical and practical. The location is situated at 40-degree latitude. 6 solar panels were setted up with the angle range from 10 degree to 60 degree with a duration study from May to August. The author concludes that by fixing the tilt angle of the solar panel, it is 10 degrees, which is differ from the mathematical value. The author discussed that is the practical value is different from mathematical value, meaning that the solar PV results is affected due to the environmental factor.

Location	Coordinate	Optimum Tilt Angle
Bilecik, Turkey	40.189697 N, 29.966415E	10 degrees

Another author from Banu (2019), have set up solar panels on two different locations, which was at Chennai, India and Beijing, China. The latitude and longitude of both of the location are tabulated as below.

Location	Latitude	Longitude
Chennai, India	13.0827 N	80.2707 E
Beijing, China	39.9042 N	116.4074 E

The author selects these two locations for the case study is due to its high population and the demand of power supply stated by ETEnergyWorld (2018). In addition, these two countries are considered to be the as the largest country with the highest amount of installation of solar panel as compared to the world, mentioned by Chisaki (2018). Although the author did not specific the year, date and duration time for the case study, the optimum tilt angle and azimuth based on the parameter’s planes of array. The author specified that the plane of array is the value of direct irradiation shine onto the solar array without including the shading and soiling factors. Through this parameter, the author chooses the highest value of POA by configuring the tilt angle and azimuth angle of the panel as shown in table below. However, the tilt angle is not recommended to be at 0 degree, this is due to the rainwater stagnant on the panel will affect the efficiency of the panel.

Location	Range of Optimum tilt angle	Range of Optimum Azimuth
Chennai, India	0-to-36-degree tilt.	South (180), South-East (135) and South-West (225)
Beijing, China	0-to-54-degree tilt.	South (180), South-East (135) and South-West (225)

Table 2.1shows the comparison on various researchers in the field of solar photovoltaic, along with the proposed optimum tilt angle, azimuth and the total solar received by each author based on the actual results captured by the on-site solar panel.

Table 2.1: Comparison Table of Different On-Site Parameters

No.	Author's Name	Location	Geographic	Date	Duration	Tilt angle	Azimuth	Total solar received
1	Nur (2018)	Padang Besar, Perlis	6.649444N, 100.256389E	July 2017	10 days	-10 degree	South 20-degree East	43922.83 to 43295.46 Wh/m2.
2	Ajao (2013)	Ilorin, Nigeria	8.5373N, 4.5444E	May and June 2012	10 days	22 degrees	Facing South	-
3	Manoj (2020)	Panjab University Chandigarh, India	30.748098N, 76.757141E	Year of 2018	Whole Year	30 degrees to 40 degrees	-	-
4	Basharat (2016)	Aligarh city, India	27.89°N, 78.08°E	Year 2013 to 2016	3 Years	27.62°	-	28.97 MJ/m^2-day (April)
5	Basharat (2016)	New Dehli, India	28.61°N, 77.20°E	Year 2013 to 2016	3 Years	27.95°	-	24.31 MJ/m^2-day (April)
6	Akif (2015)	Bilecik Seyh Edebali University Engineering Faculty, Turkey	40.189697N, 29.966415 E	Year 2014	May to August	Average: 10°	-	-
7	Banu (2019)	Chennai, India	13.0827 N, 80.2707 E	-	-	0° to 36°	South (180), South-East (135) and South-West (225)	-
8	Banu (2019)	Beijing, China	39.9042 N, 116.4074 E	-	-	0° to 54°	South (180), South-East (135) and South-West (225)	-

A comparison in Chapter 4 will be shown in order to prove and determine whether this project is reliable while performing the accuracy of this project. This is because the generated results are based on theoretical results, therefore a comparison between theoretical and on-site results are recommended to further enhance the reliability of the results.

2.6 Types of Solar Panels in the Market.

According to EnergySage (2022), stated that there are various sizes of solar panels, which can be classified into two major sectors: commercial and residential. In this project, the majority of the case study is based on a large solar farm, therefore, the project estimation will be based on the commercial standard size and specifications (A1ASolar, 2022). On average, the residential solar panel have 72 number of solar cells, whereas commercial have 96 cells. The sizing of the residential is 65’’ by 39’’ (1651 x 991mm) whereas the size of commercial solar panel is 78’’ by 39’’ (1981 x 991mm). The commercial standard has rated watts between 200W to 400W being produced into the market. Therefore, commercial sized solar panel is recommended to be installed in most cases due to higher power and efficiency. Table 2.2 below shows the datasheet and specifications of FirstSolar © that one of the solar sites (Bukit Kayu Hitam, SolarVest©) used and as a reference for this project. The solar panel used for the solar site in SolarVest© is FirstSolar© Thin Film, 115W with an efficiency of 16%. (FirstSolar, 2022).

Table 2.2: Specification of FirstSolar Module

Parameters	Commercial Panels
Type	FS-4115-3
Rated Power (W)	115
Open Circuit Voltage (Voc)	87.6
Short Circuit Voltage (Isc)	1.83
Maximum Voltage (Vmp)	69.3
Maximum Current (Imp)	1.66
Efficiency (%)	16

Module Dimension (L x W x H) (mm)	1200 x 600 x 6.8
Number of solar panels used (pieces)	105000

In addition, Table 2.3 below shows the datasheet and specifications of Trina© that some of the solar sites (Pendang, Merchang and Jasin) used and as a reference in this project. The solar panel used for the solar site in Scatec Itramast© is Trina© Monocrystalline, Double Glass, 345W with an efficiency of 17.6%. (TrinaSolar, 2017).

Table 2.3: Specification of TrinaSolar Module

Parameters	Commercial Panels
Type	Monocrystalline, Double Glass
Rated Power (W)	345
Open Circuit Voltage (Voc)	46.4
Short Circuit Voltage (Isc)	9.44
Maximum Voltage (Vmp)	38.4
Maximum Current (Imp)	8.99
Efficiency (%)	17.6
Module Dimension (L x W x H) (mm)	1978 x 992 x 25

Parameters	Pendang	Merchang (Marang, Terengganu)	Jasin (Bemban, Melaka)
Number of solar panels used (pieces)	189510	192420	191130

2.7 Literature Review on Deforestation for Solar Photovoltaic

In this section, literature review on Carbon Dioxide Emission for Solar Photovoltaic will be divided into 3 main parts, which are the production of solar cells, transportation and deforestation. However, for this project, we will focus on the latter, which is the environmental impact of installation of solar photovoltaic by deforestation.

2.8 Reliability of Global Forest Watch

Global Forest Watch (GFW) is a platform that provides data and values online for monitoring forest. GFW is a partnership project which consists of various parties such as World Resources Institute, UNEP, Google and others, in contributing technology and expertise in reviewing the globe's forest landscape that changes in real time (WRI, 2020). With the help of satellite data, advanced computer algorithm and power, GFW provides up to date data for experts and non-experts to access information in order to motivate people by using this information to generate advantages outcome in the future. A study conducted by Zhang (2020), where the accuracy of the Global Forest Watch is being evaluated by utilizing the compare and reference method. The methodology of the author is being using the high-resolution satellite images such as Google Earth and compared with the dataset from Global Forest Watch (GFW). The author selects 100 pixels from GFW randomly and compared with the China satellite images that was divided into several pixels. The sample size of the pixels is about 96364 pixels. The compare and reference are repeated for each pixel, the steps were repeated in order to obtain a better accuracy. Therefore, the author summarizes that the accuracy of the GFW dataset is above 85%. The same author, Zhang (2020), conducted the same experiment, by comparing the satellite images and GFW datasets, found out that the overall accuracy is about 94.5%. The author also concludes that the GFW can be used as a reference data for further reliable assessment.

2.9 Presence of Carbon Dioxide due to Absent of Forest

According to a statistic dashboard done by GlobalForestWatch (2020), mentioned that in the year of 2020 in Malaysia, 122kha of natural forest have been lost, as a result, 85.2Mt of CO2 is present at the surroundings due to the absent of trees that responsible from absorbing the CO2 into O2. By simplification of the equivalent, a simplified equation can be proposed as shown below:

$$122\ kha\ of\ natural\ forest = 85.2Mt\ of\ CO2$$

$$1ha\ of\ natural\ forest = \frac{85.2Mt}{122k}\ of\ CO2$$

$$\mathbf{1}\boldsymbol{ha}\ of\ natural\ forest = \mathbf{698.36}\ \boldsymbol{t\ of\ CO}\mathbf{2} \qquad \text{Eq.28}$$

Hence, by this equation, this case study able to estimate when an area of hectare forest removed, will contribute to 698.36t of CO2 towards the surroundings, where the absent of trees are unable to absorb the CO2 in the environment. In addition, results in increasing of carbon dioxide level in the surroundings. This is because trees naturally will store a large amount of carbon dioxide and convert into oxygen. However, when an area of forest is being cleared out, a significant amount of carbon dioxide will be released from the destroyed trees to the atmosphere. As a result, it will lead to global warming. (Brendan, 2014).

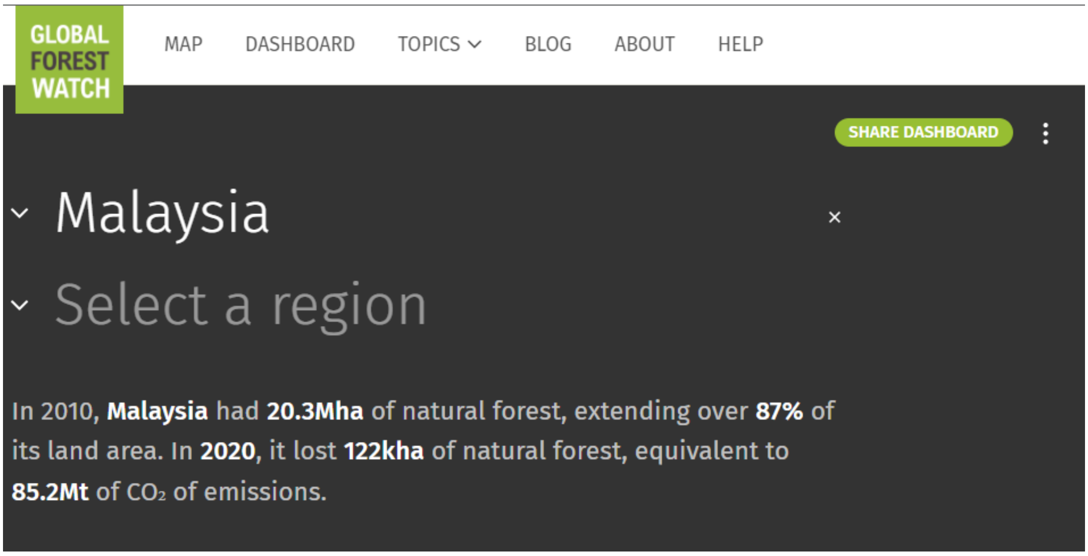


Figure 2.7: Global Forest Watch (GFW, 2020)

2.10 Amount of Energy Generation in a year

According to Susmita (2012), the formula proposed by the author is:

$$Power_{output} = Efficiency \times rate\ of\ solar\ intensity$$

Where the value of efficiency is equals to the efficiency of solar module, the rate of solar intensity is the solar radiation in kwh/m2.

2.11 Calculation of CO2 avoidance

Based on the definition of CO2 avoidance by SMA (2010), stated that the avoidance CO2 contributes to the protection of climate and reduction of greenhouse effect. CO2 avoidance is based on the generation of energy from renewable energy, such as solar energy, which do not produce energy during generation. The higher the country's renewable energy sources, the higher the CO2 avoidance, the lower the CO2 emissions. The amount of CO2 avoided is due to the usage of PV systems, where the power is feed into the grid, therefore reducing CO2 emission of the country. The formula proposed are:

$$Avoided\ CO2\ in\ kg = Generated\ electricity\ in\ kWh \times factor\ for\ CO2\ avoidance\ in\ kg/kwh$$

The CO2 avoidance factor can be determined based on the local energy supplier. This factor can be determined by referring to SEDA (2016) and MGTC (2017), where the generate electricity from renewable energy replace the traditional energy sources, such as fossil fuels, the generation of renewable energy hence reduce the greenhouse gas emission towards the surroundings by connecting to the grid systems. According to the CO2 avoidance factor provided by SEDA Malaysia, it shows that the CO2 avoidance factor for peninsular Malaysia is 0.639 tCO2/ MWh, whereas Sabah and Labuan are 0.512 tCO2/ MWh, while Sarawak is 0.364 tCO2/MWh on the latest date (2016).

Table 2.4: CO2 Avoidance Factor for Different Region

Region	CO2 avoidance factor (tCO2/MWh)
Peninsular Malaysia	0.639
Sabah	0.512
Sarawak	0.364
Labuan	0.512

Note: https://www.seda.gov.my/statistics-monitoring/co2-avoidance/

2.12 Economic Impact

According to Lumen (2022), mentioned that a payback period is the time duration that takes to return the investment into a project. The time duration maybe in months or years, which can be determine based on the equation below:

$$n_{pay} = -\frac{In[1 - S_{total}i'/P_{ann}]}{In(1 + i')}$$

$$i' = \frac{1 + i}{1 + j} - 1$$

where $i = interest\ rate\ and\ j = inflation\ rate$. According to Chong (2011), the value of interest rate and inflation rate settings are based on bank interest rate and fuel inflation rate respectively. The parameter S_{total} is the total cost of the system, whereas P_{ann} is the total cost saving of the system, which is equivalent to income for the system.

The amount invested in a project is the initial amount that the project needed to be set up. Once the project is set up and ready to implement, the annual cash flow is the output or results of the project where determine if the project is profitable. For example, if the amount annual cash flow is lower, meaning that the payback period will be delayed by an extended amount of time. In addition, (Reniers, 2016), payback period can be categories into short payback and long payback. It is logically preferable for shorter payback, as it proves to be a better sustainability and economically compared to longer payback.

In addition, Palmetto (2022) also pointed that the duration of payback period depends on the location of installation, savings and others. For example, the higher the solar installation, the higher the investment cost, the higher the annual income.

2.12.1 Interest Rate and Inflation Rate

The interest rate referred to is the bank interest rate, where according to RinggitPlus (2022) and TradingEconomics (2022), the estimated average interest rate is about 1.75% on March 2022. In addition, the implementation of low interest rate stated by Bank Negara Malaysia is to assists the national economic recovery. Next, for the inflation rate, according to Nur (2022), mentioned that Malaysia's inflation rate could increase more than 2% due to economic impact on the oil and gas price. Izzul (2021) further explanation on the factors that affect the inflation are due to global food and oil prices. Based on the statistic obtained from TradingEconomics (2022), mention that the fuel inflation rate is estimated about 2.3% in January 2022. The Figure 2.8 shows the latest statistic interest rate and inflation rate respectively.

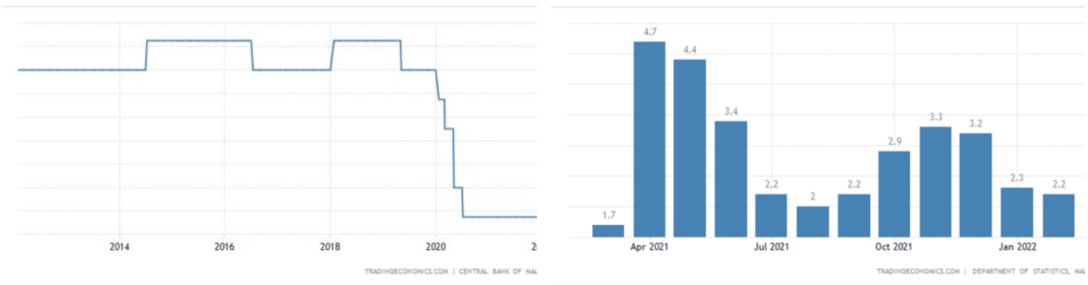


Figure 2.8: Interest and Inflation Rate in Malaysia (TradingEconomics, 2022).

Therefore, based on the literature review of interest rate, inflation rate and formula, the real interest rate formula obtained from Chong (2011) is:

$$i' = \frac{1+i}{1+j} - 1$$

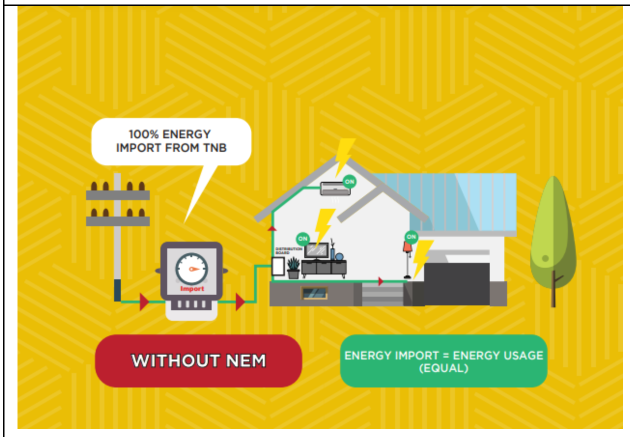
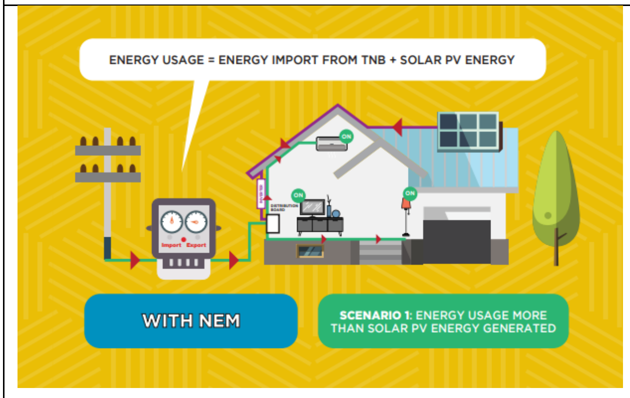
$$= \frac{1+0.0175}{1+0.023} - 1$$

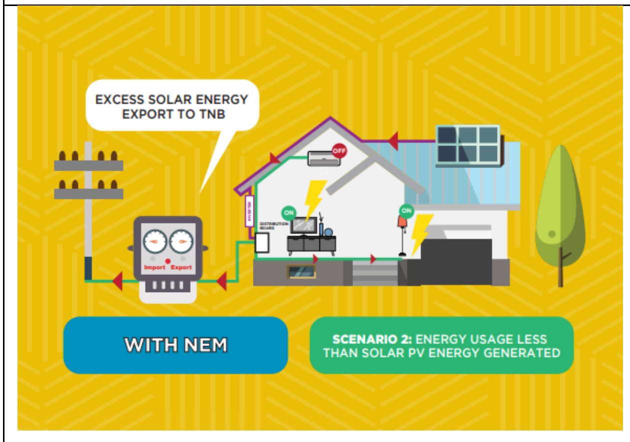
$$= -0.0054$$

2.12.2 Feed in Tariff and Net Metering System

According to the definition by Tenaga National Berhad (TNB), stated that the Net Metering System (NEM) is a new type of systems, which to replace the old system (Tariff System) (FiT) in promoting the usage of renewable energy (TNB, 2022). Feed in Tariff system is different than NEM as it exports all of the solar energy produced into the grid, whereas NEM allows the generation of electrical energy, which results in a lower electricity bill being imposed on. According to the diagram from RE (2020), the concept of NEM can be clearly illustrated.

Table 2.5: Concept of NEM

<table>
<tr><th>Scenarios</th><th>Formula</th></tr>
<tr><td>
</td><td>Energy In = Energy Use</td></tr>
<tr><td>
</td><td>Energy use > Energy Produce

Energy use = Energy In + Energy Produce</td></tr>
<tr><td>
</td><td>Energy use < Energy Produce</td></tr>
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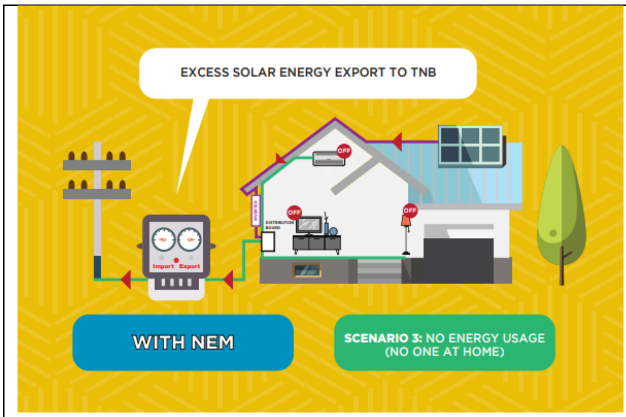
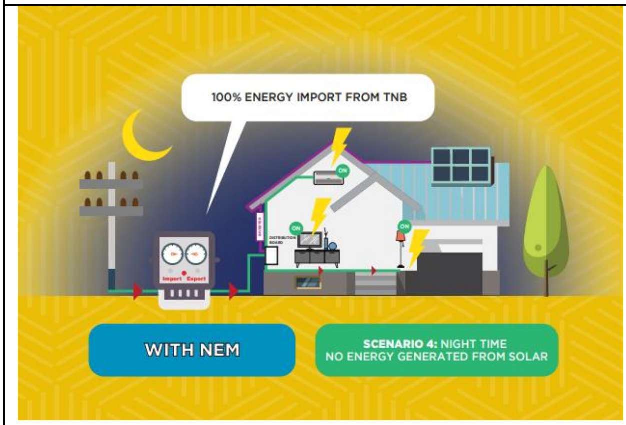
<td>
</td>
<td>Energy use < Energy Produce</td>
</tr>
<tr>
<td>
</td>
<td>Energy Produce = 0

Energy In = Energy Use</td>
</tr>
</table>

If the user did not install any solar panel, the electricity bill will be equals to the energy used. However, if the user install solar panel and it generates electricity, NEM system allows the user to utilize the generated electricity, therefore, the incoming electricity reduces, and the electricity bill imposed on the user is also reduced. In addition, if the user produces extra electricity, the additional will be injected back to the grid (SEDA, 2022). According to Abdul (2019), the author concluded that by introducing the Net Metering System in Malaysia, it helps to promote the solar PV installation on every section, including residential and utility. However, this system benefits more towards the medium and large consumers, which is the higher the PV installation size, the higher the cost energy saving as shown in Figure 2.9.

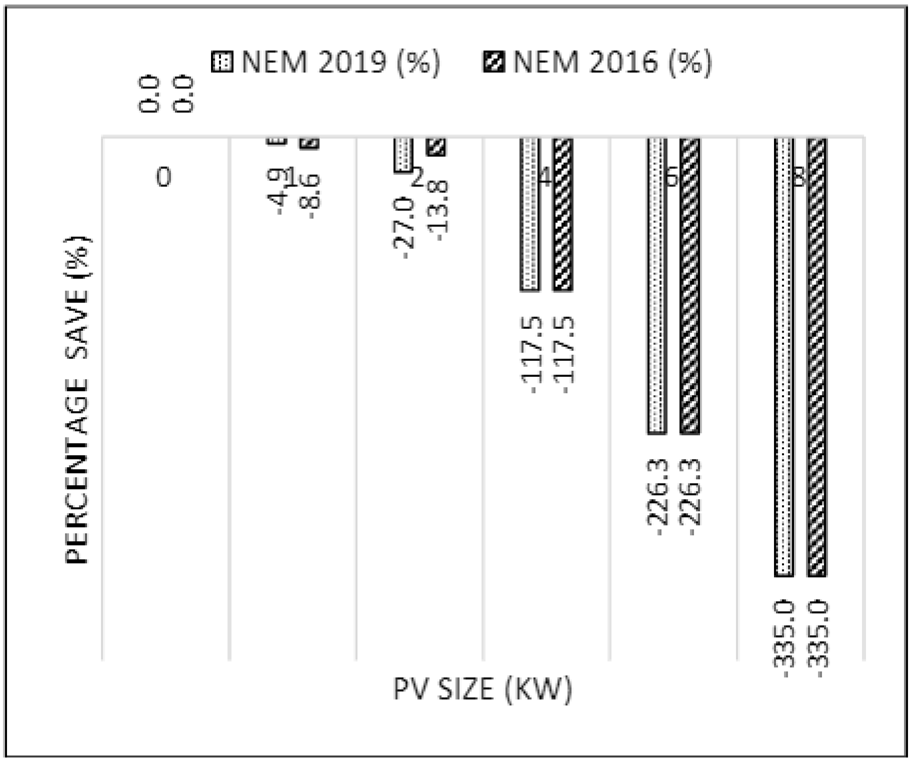


Figure 2.9: NEM with Capacity. (Abdul, 2019).

In this project, the Net Metering System will be used for the analysis of economic impact on the solar farm in Malaysia.

2.12.3 Rates Credit for Electricity Produced

According to a newspaper article from TMR (2022), stated the tariff rate is fixed at **RM 0.395/kwh** in the peninsular Malaysia until further announcement from the Government. A statement by the Energy and Natural Resources Minister, Datuk Dr Shamsul Anuar Nasarah mentioned that the tariff rate is remain unchanged and will be fixed due to the difficulty of Movement Control Order (MCO) experience by the people. In addition, the Malaysian will not suffer from the increasing rate of electricity tariff. Figure 2.10 shows the article published on the newspaper.

Electricity tariff rate remains at 39.5 sen kWh for now, says TNB

Govt has decided to suspend the implementation of the National Energy IBR for the Regulatory Period 3 on Dec 31, 2021

THE average basic electricity tariff rate remains at 39.45 sen per kilowatt hour (kWh) in the peninsula pending the government's announcement on the new tariff rate, Tenaga Nasional Bhd (TNB) said.

In a recent statement, TNB said the government has decided to suspend the implementation of the National Energy Incentive-Based Regulation (IBR) for the Third Regulatory Period (RP3) on Dec 31, 2021.

In the meantime, the government also decided to postpone the implementation of electricity tariff adjustment under the Imbalance Cost Pass Through (ICPT) mechanism from Jan 1, 2022, until a date to be determined. As such, the current rebate rate of two sen/kWh to all electricity consumers in the peninsula is maintained for that period.

With the decision to postpone this RP3 and ICPT, users in the peninsula will not experience an increase in basic electricity tariff rates.

In June last year, the Energy and Natural Resources Minister Datuk Dr Shamsul Anuar Nasarah said due to the challenges faced by the people caused by the Movement Control Order, the government agreed to finance an additional rebate of 0.87 sen/kWh which involved an allocation amounting to RM493 million from the Electricity Industry Fund (KWIE) to maintain the tariff rate throughout the year.

TNB said the ICPT rebate is partly the result of the overall reduction in actual generation costs for the period of January to June 2021.

During the period, it said there was a slight increase of average coal price in the global market at US$70.06 (RM292) per metric tonne (MT) compared to the benchmark coal price set in the base tariff at US$67.45/MT.

Starting from January 2020, the gas price is set based on Reference Market Price (RMP) which replaced the former two-tier gas pricing mechanism that comprises Regulated Gas Price and liquified natural gas price.

For the period January to June 2021, the average RMP price is RM17.16 per million British thermal unit (mmBTU) which is lower than the benchmark gas price for the year set in the base tariff at RM27.20/mmBTU, it explained.

"Any shortfall or excess in the ICPT will be funded or transferred to customers via the KWIE fund to aid in the stabilisation of electricity tariff in the future via the gradual build-up of the fund.

"TNB also wishes to inform that the impact of ICPT implementation is neutral on TNB and will not have any effect on its business operations and financial position," it added. — *TMR*

The electricity firm informs that the impact of ICPT implementation is neutral on TNB and will not have any effect on its business operations and financial position TMRpic

Figure 2.10: Electricity Tariff (RM/kWh) (TMR (2022).

Hence, with the given value for the rates, an example, if a solar photovoltaic farm with an installation capacity of 10MW and inverter, the total tariff rates is:

$$Total\ tariff\ rates = RM\ 0.395/kwh$$

2.12.4 Investment Cost on Solar PV

In order to produce electricity by utilizing the solar energy, a solar photovoltaic system is needed to be purchase, install, operate and maintain. Therefore, any estimation on the modelling of investment cost can be found in the report (Lyu, 2019), Section 2.3 In this report, the cost breakdown for the PV installation can be classified into two main categories, which are the hardware cost and soft cost. The hardware cost is the module, inverter, structural and electronical components, whereas the software cost consists of planning, installation work, direct labour cost and others. Table 2.6 shows the average estimation ratings for each parameter used for the modelling in the report that can be accessed through the report. (Ir. Dr. Sanjayan, 2019).

Table 2.6: Cost Breakdown for Investment Cost

Parameters	Model value (RM/W)
Module	1.65
Inverter	0.33
Structural material	
Miscellaneous (electrical cables, etc.)	0.72
Planning	
Installation work	2.91
Shipping and travel	
Permits and direct labour	
Project margin	
Sales & Services Tax (SST)	6%
Total	5.9466

Based on the table and values obtained, it, shows that the structural material is the mounted materials such as rack are included into the miscellaneous for the hardware cost. As for the software cost, the installation work price per watt are summaries with planning, shipping and labour cost included. Lastly, with the sales & service tax of 6%, the total price per watt (RM/W) for the solar photovoltaic is about RM 5.9466 for capacity > 10MW.

2.13 Summary

In summary, the literature review for this project has been performed where the literature review on the fixed tilt angle of the solar panel. Most of the reviewed papers utilize the ability of fixed tilt solar PV as compared to flexible tilt. One of the main contributions on the selection of fixed tilt PV is the cost of installation is affordable as compared to flexible tilt. Next, the formula for determine the cosine angle of the solar irradiation has been reviewed in 3D modelling. In addition, various papers on the actual on-site experiment by the authors were reviewed. The locations are from Malaysia, India, Turkey and China. The purpose for the on-site results is used to compare with the results estimated in the 3D modelling. Besides, the statistic results from the deforestation, interest rate, inflation rate, tariff rate are reviewed. These results are important for estimation of the carbon dioxide avoidance and the annual income for the solar farm. Lastly, the annual report was reviewed for the investment cost of the solar farm in order to estimate the payback period, which can be obtained from the literature review. Therefore, with the appropriate literature review, the planning and application in constructing this project can be refer to CHAPTER 3 METHODOLOGY AND WORK PLAN.

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

In this section, the methodology and work plan on how the project being carried out is shown. In the first part, choose and select the desired solar sites for case study purposes. Next, the solar irradiation data will need to be downloaded from Solcast© manually for each solar sites, with a duration of one year (31st August 2019 to 1st September 2020), then the python programming will be able to start its operation. During the process, list of formula is used in order to determine the number of days, angle x, equation of time, solar time, declination angle, hour angle, altitude angle, zenith angle and azimuth angle. After the sun position in being determined for each of the datetime in the data, the determination of suitable tilt angle and orientation of the solar panel is able to calculate based on the formula derived. The method for determine if the tilt angle and orientation is optimum is based on the total maximum value of solar received in a year. Next, the carbon dioxide presence due to deforestation, carbon dioxide avoidance due to electricity generated from solar farm and net carbon dioxide of a location is performed to estimate the environmental impact of a project. Lastly, the investment cost, annual income and payback period of a solar project is estimated to undergo the economic impact of a project.

3.2 Metrological Data

In this project, the metrological data will obtain from Solcast ©, a solar irradiation data modelling company, which provides free access for various location of meteological data. The company provides various services, such as historical data, forecast data and real time data. (Dr. Nick, 2019). Solcast utilize the satellite images, perform machine learning, big data and computer vison to obtain the accuracy results of solar irradiation data with the latest technology. (Solcast, 2022). The accuracy table for the solcast data is shown in Table 3.1, where difference continent has different bias and RMSE.

Table 3.1: Accuracy of Solcast

Location	Bias	RMSE
North & South America	-2.38% to +1.38%	9.51% to 21.46%
Europe, Africa & West Asia	-7.06% to +6.93%	5.72% to 27.85%
East Asia & Oceania	-3.64% to +1.93%	9.41% to 21.56%

In this project, the metrological data chosen is Solcast© where this company provides not only a reliable and accurate solar irradiation data, but it does also not require an upfront payment to utilize the service provided by Solcast ©. A comparison of the service provided from various solar data from websites such as:

Website	Remarks
https://joint-research-centre.ec.europa.eu/pvgis-photovoltaic-geographical-information-system/pvgis-data-download/nsrdb-solar-radiation_en	Provides only historical data from 2005 to 2015
https://globalsolaratlas.info/map	Provides only the total amount of solar irradiation data.
https://solargis.com/products	Need to purchase the service before allowing to access the data.

3.3 Software

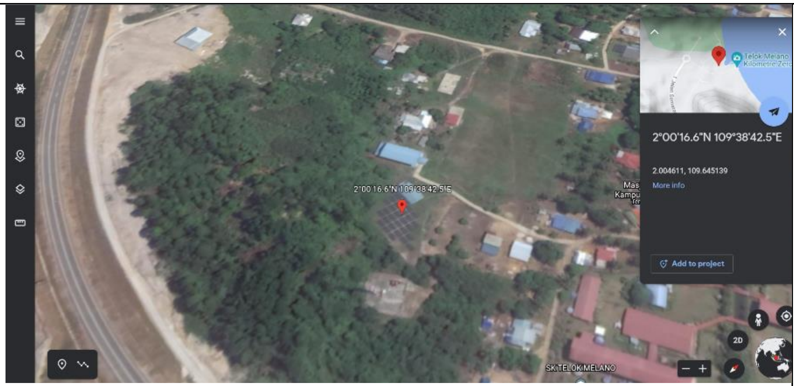
In this project, the only software that needed is Microsoft Excel and Python programming. The purpose of Microsoft Excel is to output the results generated by the Python programming, such as total maximum solar irradiation received for all types of angles. As for python programming, the optimization, modelling and comparison between various solar technologies is able to carry out. Python program is selected for this project as it is independence across platforms, such as windows, MacOS, Linux without any additional configuration. CFI (2015) stated that python language is able to perform various tasks such as data analysis, where it attracts community of developers, as it is easily accessible, simple and stable than other programming language such as C, C++, Matlab and others. In addition, Scarlett (2019), mention that Python not only flexible and also versatile, where python programming can be used for data analysis, machine learning, artificial intelligence (AI) and others. This creates an additional advantage where it helps to save time and money of the developer for a quick testing on various platform as well as the overall process and efficiency increases.

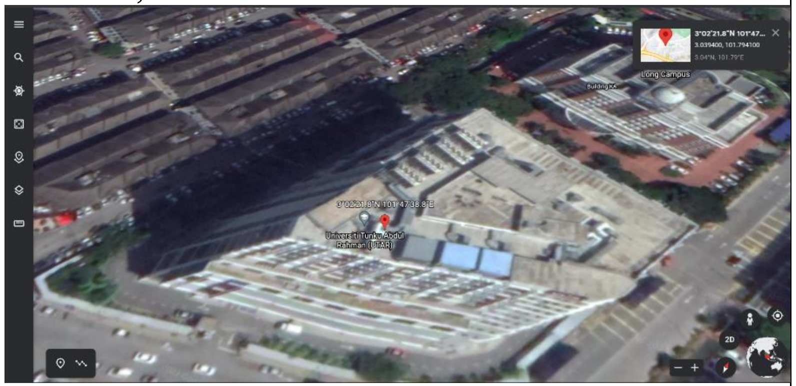
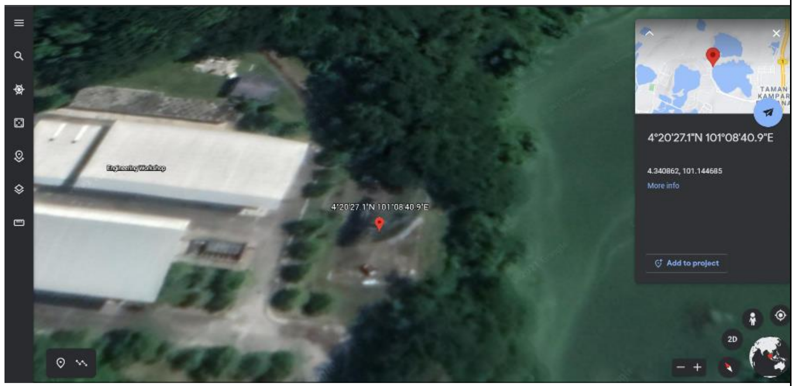
3.4 Solar Sites

The data of yearly solar irradiance data obtained from Solcast © with a duration from 1/9/2020 to 31/8/2021, which is 1 year duration. There are 17 solar sites are taken into considerations, with the objectives of which solar sites are suitable to perform solar analysis. The images of the solar sites' location is retrieved from Google Maps ©. Table 3.2 shows each of the solar site's name, states, coordinates and images of the sites.

Table 3.2: 17 Solar Sites for Modelling

Solar Site Numbe r	Solar Site Name, States and Coordinate	Solar Site Numbe r	Solar Site Name, States and Coordinate
1	Tanjung Batu Hybrid Solar Power Plant Sandakan, Sabah 5°48'01.8"N 118°09'29.2"E 	2	Comtec Solar International (m) Sdn Bhd Kuching, Sarawak 1°31'10.6"N 110°23'50.0"E 
3	Solar Power Plant Telok Melano, Sarawak Energy Berhad Lundu, Sarawak 2°00'16.6"N 109°38'42.5"E	4	Bukit Kayu Hitam Solarvest 12MWp Bukit Kayu Hitam, Kedah 6°28'40.8"N 100°25'42.0"E

			
5	Pokok Sena Solar PV plant Jitra, Kedah 6°10'51.3"N 100°28'21.0"E 	6	LSS PV 30MWac Kuala Muda Kedah Sungai Petani, Kedah 5°39'25.3"N 100°34'21.2"E 
7	Elsoft Research Berhad Bayan Lepas, Pulau Pinang 5°17'33.0"N 100°17'21.0"E	8	Taruc, Setapak Setapak, Wilayah Persekutuan Kuala Lumpur 3°13'00.8"N 101°43'58.8"E

			
9	Utar, Bandar Sungai Long, KB block roof top Bandai Sungai Long, Selangor 3.0394° N, 101.7941° E 	10	Utar, Kampar Campus Kampar, Perak 4°20'27.1"N 101°08'40.9"E 
11	Scatec Itramas solar 65MW Gurun Solar Power Plant Pendang, Kedah 5°51'46.6"N 100°32'20.2"E	12	Scatec Itramas Solar 66MW Jasin Solar Power Plant Bemban, Melaka 2°17'56.7"N 102°21'16.0"E

			
13	Scatec Itramas Solar 66 MW Merchang Solar Power Plant Marang, Terengganu 4°56'04.4"N 103°20'13.4"E 	14	Pekan Pahang Solar Farm Pekan, Pahang 3°19'24.9"N 103°25'20.9"E 
15	UITM Solar Park II (LSS2 Pasir Gudang) Masai, Johor 1°31'36.7"N 103°51'50.4"E	16	Pasir Mas Solar Farm Pasir Mas, Kelantan 5°59'31.9"N 102°06'39.8"E

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<td>17</td>
<td>Kenyir Gunkul Solar Sdn Bhd
Kuala Dungun, Terengganu

4°38'55.8"N 103°23'13.5"E

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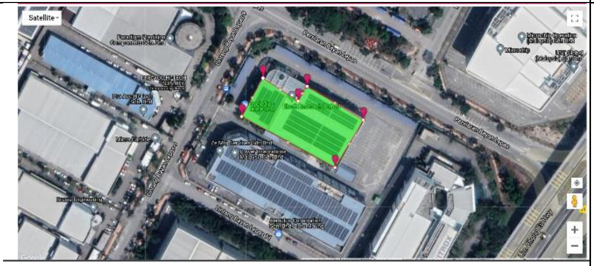
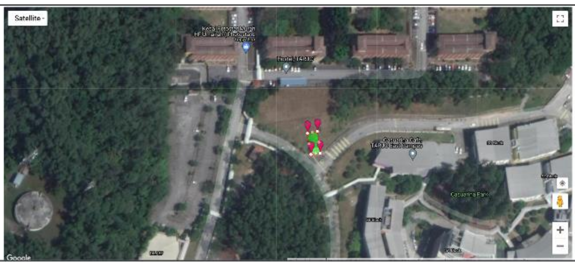
In addition to the Table above, the area for each of the solar site is also being estimated by using the "Google Maps Area Calculator Tools", retrieved from Daftlogic (2022). Table 3.3 shows the estimated area of the selected solar sites in Malaysia.

Table 3.3: Area of Each Solar Sites

Solar Site Number	Name and Coordinate	Solar Site	Area
1	Sandakan, Sabah 5°48'01.8"N 118°09'29.2"E 5.800498388299525, 118.15811098553932		2043.99m^2 0.51 acres 0.20 hectares 22001.28 $feet^2$
2	Kuching, Sarawak 1°31'10.6"N 110°23'50.0"E 1.519615, 110.397216		7355.08 m^2 1.82 acres 0.74 hectares 79169.45 $feet^2$
3	Lundu, Sarawak 2°00'16.6"N 109°38'42.5"E 2.004611, 109.645139		612.96 m^2 0.15 acres 0.06 hectares 6597.82 $feet^2$
4	Bukit Kayu Hitam, Kedah 6°28'40.8"N 100°25'42.0"E 6.478000450954776, 100.4283292590189		175301.82 m^2 43.32 acres 17.53 hectares 1886933.09 $feet^2$

5	Jitra, Kedah 6°10'51.3"N 100°28'21.0"E 6.18092040158725, 100.4725068913063		238087.17 m² 58.83 acres 23.81 hectares 2562749.03 feet²
6	Sungai Petani, Kedah 5°39'25.3"N 100°34'21.2"E 5.657036399589651, 100.57256748038222		405248.59 m² 100.14 acres 40.52 hectares 4362059.55 feet²
7	Bayan Lepas, Pulau Pinang 5°17'33.0"N 100°17'21.0"E 5.2925078467591025, 100.28916532697262		3089.49 m² 0.76 acres 0.31 hectares 33254.96 feet²
8	Setapak, Wilayah Persekutuan Kuala Lumpur 3°13'00.8"N 101°43'58.8"E 3.216889, 101.733000		119.63 m² 0.03 acres 0.01 hectares 1287.68 feet²
9	Bandai Sungai Long, Selangor 3.0394° N, 101.7941° E 3.039400, 101.794100		193.16 m² 0.05 acres 0.02 hectares 2079.10 feet²
10	Kampar, Perak 4°20'27.1"N 101°08'40.9"E 4.340862, 101.144685		304.09 m² 0.08 acres 0.03 hectares 3273.22 feet²

11	Pendang, Kedah 5°51'46.6"N 100°32'20.2"E 5.862950268444186, 100.5389354405749 3		674400.75 m² 166.65 acres 67.44 hectares 7259189.2 4 feet²
12	Bemban, Melaka 2°17'56.7"N 102°21'16.0"E 2.299072, 102.354431		291212.29 m² 0.29 km² 71.96 acres 29.12 hectares 3134583.0 1 feet²
13	Marang, Terengganu 4°56'04.4"N 103°20'13.4"E 4.934544, 103.337056		662380.10 m² 163.68 acres 66.24 hectares 7129800.0 3 feet²
14	Pekan, Pahang 3°19'24.9"N 103°25'20.9"E 3.323589, 103.422471		458379.53 m² 113.27 acres 45.84 hectares 4933956.2 6 feet²
15	Masai, Johor 1°31'36.7"N 103°51'50.4"E 1.526846, 103.864002		380982.34 m² 94.14 acres 38.10 hectares 4100859.8 0 feet²
16	Pasir Mas, Kelantan 5°59'31.9"N 102°06'39.8"E 5.992184, 102.111054		48307.22 m² 11.94 acres 4.83 hectares 519974.62 feet²

17	Kuala Dungun, Terengganu 4°38'55.8"N 103°23'13.5"E 4.648842330141924, 103.38708024416017		298248.64 m² 73.70 acres 29.82 hectares 3210321.64 feet²

According to Carol (2020), stated that Google Earth update their database by obtaining sources through satellite images. However, these obtained data takes months to process, comparing between old data and new data, then finally only to be displayed as an update on the Google Earth Map. Based on the Table 3.3, each of the solar sites may appeared to be unfinished project, which shows only half of the solar farm is completed. For example, Kenyir Gunkul Solar Sdn Bhd, the Google Earth images shows that an empty land is selected to construct a solar farm in Kuala Dungun, Terengganu. Hence, this assuming that this solar site is in process, a study is being conducted on the impact of the deforestation for large solar farm in Malaysia.

3.5 List of Formulas

In this section, formulas will be listed out for including in the python programming, which will be suitable and easier for calculation, user is able to reconfigure the code if a newer formula is able to obtain a more accurate result.

3.5.1 Declination angle

$$\sin\delta = 0.39795\cos[0.98563(N-173)]$$

$$\delta = \sin^{-1}\{0.39795\cos[0.98563(N-173)]\}$$

According to Zhang (2016), Where N is the number of the day, and its starts with N = 1. For example, on 5 February 2021, meaning that the number of the day is:

$$31\,January + 5\,Febuary = 31\,days + 5\,days\ = 36\,days$$

3.5.2 Hour angle

$$\omega = 15\,(t_s - 12)$$

Where ts indicates the solar time in hours. Hour angle is presented in hour's form, where the hour angle is positive (+) during afternoon and negative (-) before noon (Akif, 2015).

3.5.3 Equation of time (EOT)

$$EOT = 0.258\cos x - 7.416\sin x - 3.648\cos 2x - 9.228\sin 2x$$

Where EOT is displayed in minutes form, in order to determine x,

$$x = \frac{360(N-1)}{365.242}$$

Where x is displayed in degree form.

3.5.4 Solar Time

$$LCT = t_s - \frac{EOT}{60} + LC + D$$

Where LCT is Local Clock Time, the time which is visible on the clock/watches, whereas LC can be determined by:

$$LC = \frac{local\ longitude - longitude\ of\ standard\ time\ zone\ meridiann}{15}$$

Where LC is displayed in degree form. For both longitude parameters, East is considered to be negative whereas West is considered to be positive. Since Malaysia does not have daylight saving, hence the solar time equation can be reorganized to be:

$$t_s = LCT + \frac{EOT}{60} - LC$$

3.5.5 Altitude angle

The altitude angle is the angle between the sunray and horizontal plane, where is also known as the angle of position of the sun from the horizontal plane.

$$\alpha = \sin^{-1}(\sin\delta \sin\varphi + \cos\delta \cos\omega \cos\varphi)$$

Where δ is the declination angle, φ is the latitude of the location and ω is the hour angle calculated.

3.5.6 Azimuth angle

The azimuth angle is the angle measured starting from North up to the horizontal plane of the altitude angle. The measured angle starting from North with a clockwise direction (CW) is the positive value (+), whereas North with a counter-clockwise direction (CCW) is the negative value (-). In other words, if the measured angle started with North and move to the clockwise direction, where the East is 90º, South is 180º, West is 270º, and North can be either 0 or 360º. In order for the determination on which direction of the azimuth angle, an if-else statement is established:

1. When $\cos A > 0$, which indicates that the angle is within the range of:
   North (N) -> East (E) and West (W) -> North (N)

$$\cos A = (\sin\delta \cos\varphi - \cos\delta \cos\omega \sin\varphi)/\cos\alpha > 0$$

$$A = \sin^{-1}\left[-\frac{\cos\delta \sin\omega}{\cos\alpha}\right]$$

2. When $\cos A < 0$, which indicates that the angle is within the range of:
   East (E) -> South (S) and South (S) -> West (W)

$$\cos A = (\sin\delta \cos\varphi - \cos\delta \cos\omega \sin\varphi)/\cos\alpha < 0$$

$$A = 180° - \sin^{-1}\left[-\frac{\cos\delta \sin\omega}{\cos\alpha}\right]$$

According to Baghzouz (2013), mentioned that at northern hemisphere, the azimuth angle of the sun is positive (A = +) in the morning, which the sun position rises from the East. In addition, at noon, the azimuth angle of the sun is zero (A = 0) whereas the negative azimuth angle (A = -) with the sun position sets to the West.

3.5.7 Zenith Angle

The zenith angle is the opposite of altitude angle, where the zenith angle is the angle between sunray and vertical plane, which the vertical is normal perpendicular to the horizontal plane.

$$\theta_z = 90 - \alpha$$

Where θ_z is equals to 0 degree when the sun position is directly overhead, which is also during solar noon. Alternatively, the zenith angle is equals to 90 degrees before sunrise and during night time, where the sun is not present within the time period of the location. The range of the zenith angle is: 0 – 90 degrees.

3.5.8 Daily Solar Irradiation

On a single day, where the solar panel receive the sunlight on a particular spot, it is known as solar radiation (W/m2). However, if the solar panel receive the sunlight on a particular spot for an hour, it is known as solar irradiation (Wh/m2).

3.5.9 Annual Solar Irradiation

The annual solar irradiation is the sum of solar received by the solar panel for watt hour per meter square (Wh/m2) per day for a year. However, in order to determine the annual solar irradiation of the particular location, an average solar irradiation is taken into consideration with the formula:

$$Average\ Solar\ Irradiation\ (Wh/m^2) = \frac{Sum\ of\ solar\ irradiation\ of\ the\ location\ for\ everyday}{The\ number\ of\ days\ of\ the\ year}$$

3.5.10 Cosine effect

The solar panel is able to convert incoming sunlight into electrical energy for electrical application connected to the panel. When the solar panel is placed horizontally and the incoming sunray is shine directly to normal of the solar panel, the solar panel is able to receive the maximum amount of solar radiation. However, when the solar panel is remained horizontal and the sunray is not normal towards the solar panel, the incoming solar radiation received by the solar panel reduces as compared to the maximum solar radiation. This phenomenon is called cosine effect, where the received sunlight by the solar panel is dependent on the incoming sunrays.

Assume that when the sun is normal to the horizontal solar panel, with the solar radiation of 1000 W/m2:

The receive sunlight is calculated to be 1000 W/m2 under ideal condition, which is,

$$I_{o,h} = I_o \cos \theta_z$$
$$= (1000) * \cos(0)$$
$$= 1000\, W/m2$$

Where $I_{o,h}$ is the solar radiation received by the solar panel, I_o is the incoming sunlight towards the solar panel, θ_z is the zenith angle of the sun position.

Hence, in order to receive the maximum solar radiation on the solar panel, the solar panel is needed to be tilted as according to the sun position. For example, when the sun altitude angle is 20 degree, the zenith angle is calculated to be 90 – 20 = 70 degree. During this time, the horizontal solar panel can increase the tilted angle according to the zenith angle.

The comparison between receive sunlight of horizontal solar panel and tilted solar panel when the sun altitude angle is 20 degree under ideal condition is, horizontal solar panel is able to receive about 342.02 W/m2, when the sun altitude angle is 20 degree.

$$I_{o,h} = I_o \cos \theta_z$$
$$= (1000) * \cos(70)$$
$$= 342.02\, W/m2$$

Titled solar panel is able to receive about 1000 W/m2, when the solar panel is facing towards the normal of the sunray with the tilted angle of 70 degree.

$$I_{o,h} = I_o \cos \theta_z$$
$$= (1000) * \cos(0)$$
$$= 1000\, W/m2$$

Under ideal condition, by the difference between horizontal and titled angle under different sun position, the solar radiation loss by the solar panel is approximately,

$$I_{loss} = I_{titled} - I_{horizontal}$$
$$= 1000 - 342.02$$
$$= 657.98\ W/m2$$

Hence, the example shows that the important for solar panel for introducing the solar tracker. The purpose of the solar tracker is the track the position of the sun, shifted and tilted the solar panel towards the direction of the sun ray in order to capture the maximum solar radiation.

3.5.10.1 Cosine loss experienced by the solar panel

Baghzouz (2013) mentioned that cosine loss occurs due to the cosine effect event. The cosine effect is defined as the decrease in receiving area caused by the cosine angle formed between solar radiation and the normal line, as shown in Figure 3.1. In other words, cosine effect is the main cause for energy loss in solar energy on the PV panel.

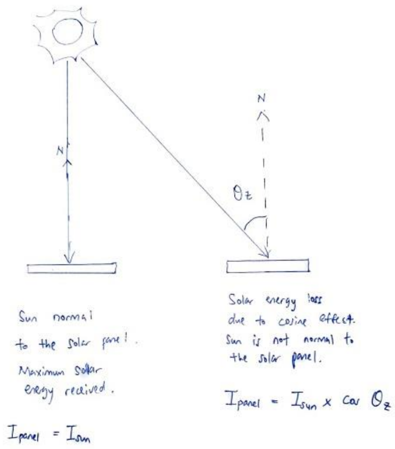
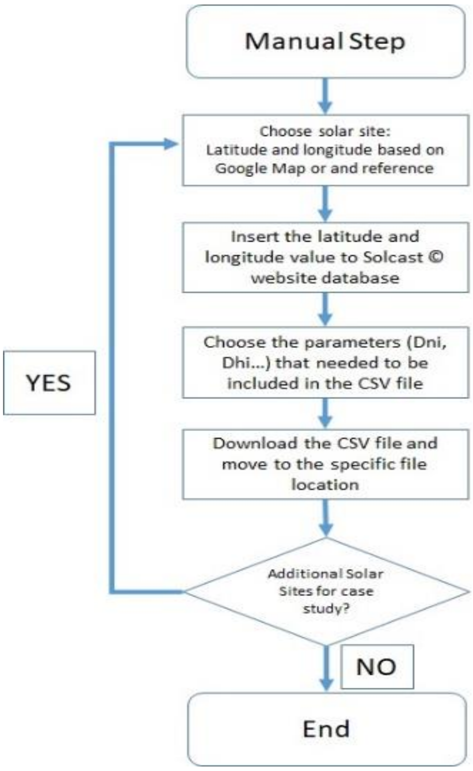
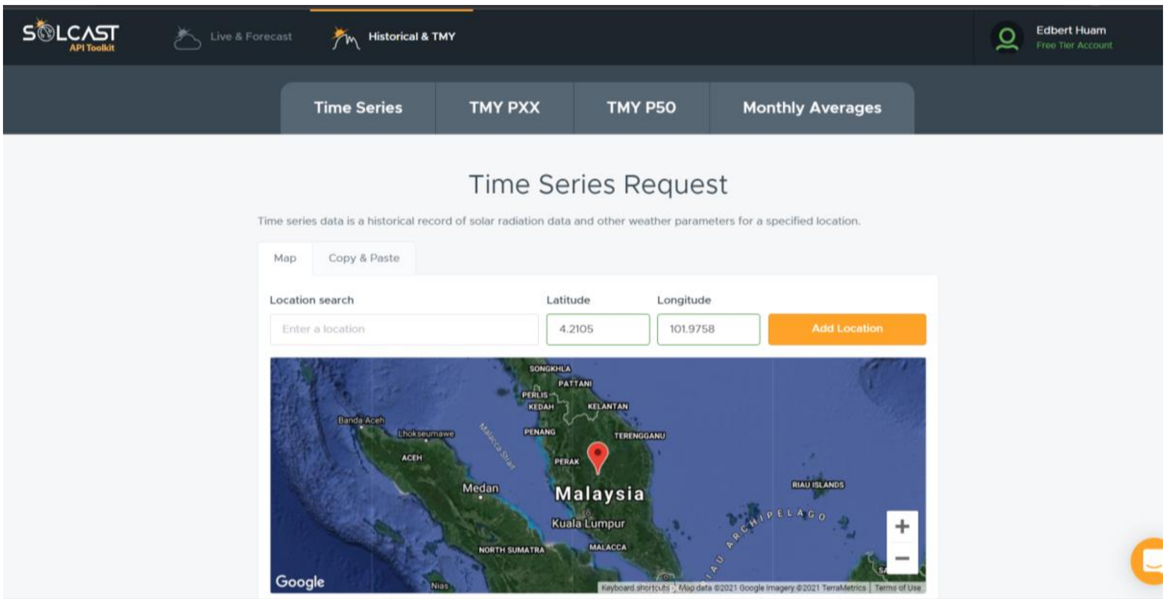


Figure 3.1: Cosine Loss on Horizontal Plane (2D)

3.6 Manual Steps for Downloading Data from Solcast©





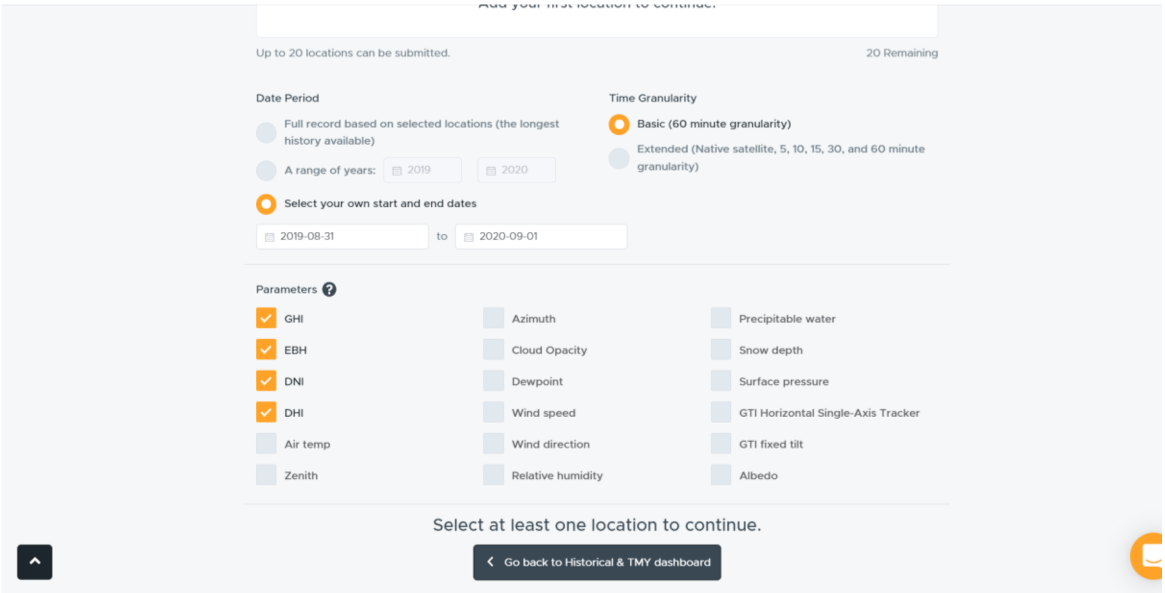


Figure 3.2: Flowchart on Downloading Solcast Data.

The flowchart above shows the steps of the project in order to determine the optimum tilt angle and orientation of the solar panel. The programming language used for analysis is Python programming. The coding for this project can be inspected at Appendix. The flowchart can be divided into 2 sections, which are the manual steps and programming steps. As for the manual steps, first, a solar site or a location is chosen for analysis, with the value of latitude and longitude as shown in the Google map. The Solcast is able to detect and zoom in the chosen latitude and longitude. Once the latitude and longitude are being determined, the value can be input into the Solcast Database website for downloading the raw data of the solar received at the determined locations. The database provided any range of year, but for this project, we will focus from 31/8/2019 to 1/9/2021, which is equivalent to 1 year data. There are various types of data that can be obtained, where the important parameters provided by the raw data is Dhi, Dni, Ebh and Ghi. The data obtained from Solcast © will be used as the input data into the python programming in the form of CSV files. The downloaded CSV file is recommended to move to a specific file location for more organized structure. The steps are repeated if there are many solar sites needed to undergo case studies.

3.7 Determination of Number of Days, Angle X and Equation of Time (EOT)

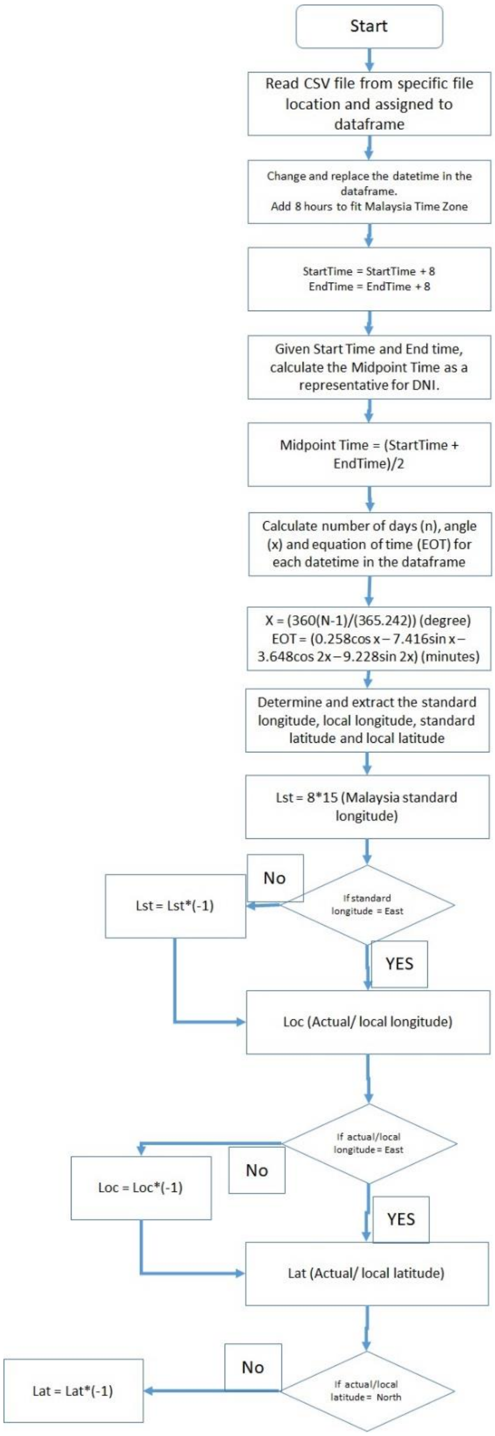


Figure 3.3: Flowchart on the Formula of Days, Angle and EOT.

Once the manual steps are completed, the programming section can be initialized. The python program is able to read the CSV files from the specific file location and will assigned to a dataframe by the python, in order to carry out a series of separation and analysis. First, the datetime provided by the Solcast Data is in UTC time (Greenwich Time). For example, 0:00 at

Greenwich is equivalent to 8:00 in Malaysia. Therefore, the datetime from the data is needed to add 8 hours to localize with Malaysia Time. The date-time in the data can be classified into two categories, which are the start time and end time. The midpoint time can be determined through the start time and end time. The midpoint time will set as a label time of the DNI.

In the next section, the series of steps will be undergone to determine the sun position for each datatime of the data in the dataframe. First, the number of days will be determined by the label "n", the angle "x" in degree form can be determined where it is related with the number of days using the formula in python language:

Formula in Programming Code	Remarks
df5['n'] = df4.dt.dayofyear	To determine the number of days based on the datetime
df5['x'] = ((360*(df5['n']-1))/365.242)*(m.pi/180)	To determine the angle x of the number of day

Next, with the number of days and angle x in degree form, the value can be substitude into the other formula, which is the Equation of Time (EOT) in minutes form as well as converting the EOT into hours for easier calculation. If the EOT is negative, meaning that the Solar Time is delayed by the number of EOT minutes as compared to Local Time, otherwise, if positive EOT, solar time is ahead of Local Time.

Formula in Programming Code	Remarks
df5['eot'] = (0.258*np.cos(df5['x']) - 7.416*np.sin(df5['x']) - 3.648*np.cos(2*df5['x']) - 9.228*np.sin(2*df5['x']))/60	To determine the equation of time (EOT) in minutes.
df5['eot'] = pd.to_timedelta(df5['eot'], unit='h')	To convert the EOT into hours

Before solar time is determine for each datetime provided by the data, the standard longitude, local longitude, standard latitude and local latitude is determined by using the formula. The local latitude and local longitude can be extracted from the filename of the CSV. For example, the sign of longitude is positive (+) if East, negative (-) if West. The sign of latitude is positive (+) if North, negative (-) if South.

Formula in Programming Code	Remarks

Lst = 8*15
LstEW = 'E'
 	
if LstEW == 'E':
Lst = Lst*(1)
elif LstEW == 'W':
Lst = Lst*(-1)
	To determine standard longitude of the site. For example, the distance time difference between Greenwich and Malaysia is 8 hours, and each longitude is 15 degrees, the standard longitude can be calculated by multiplication.
	
	If the longitude is East, positive sign.
	If the longitude is West, negative sign.

Loc = float(filename.split('_')[1])
LocEW = 'E'
 	
if LocEW == 'E':
Loc = Loc*(1)
elif LocEW == 'W':
Loc = Loc*(-1)
	The actual/local longitude of the site is extracted from the filename. The LocNS is preset as ‘E’ = East.
	
	If the longitude is East, positive sign.
	If the longitude is West, negative sign.

Lat = float(filename.split('_')[0])
LatNS = 'N'
 	
if LatNS == 'N':
Lat = Lat*(1)
elif LatNS == 'S':
Lat = Lat*(-1)
	The actual/local latitude of the site is extracted from the filename. The LatEW is preset as ‘E’ = East.
	
	If the longitude is East, positive sign.
	If the longitude is West, negative sign.

With the given standard longitude and local longitude, the solar time for each datetime can be determined by the formula. The differences between local longitude and standard longitude will be converted into hours for easier calculation.

Formula in Programming Code	Remarks
df5['solar_datetime'] = df4 + df5['eot'] - timedelta(hours = (Loc - Lst)/15)	Df4 = dataframe containing the midpoint of start time and end time (local clock time) Df5[‘EOT”] = dataframe with the column “EOT” in hours. Loc = local longitude Lst = standard longitude

3.8 Determine Sun Position

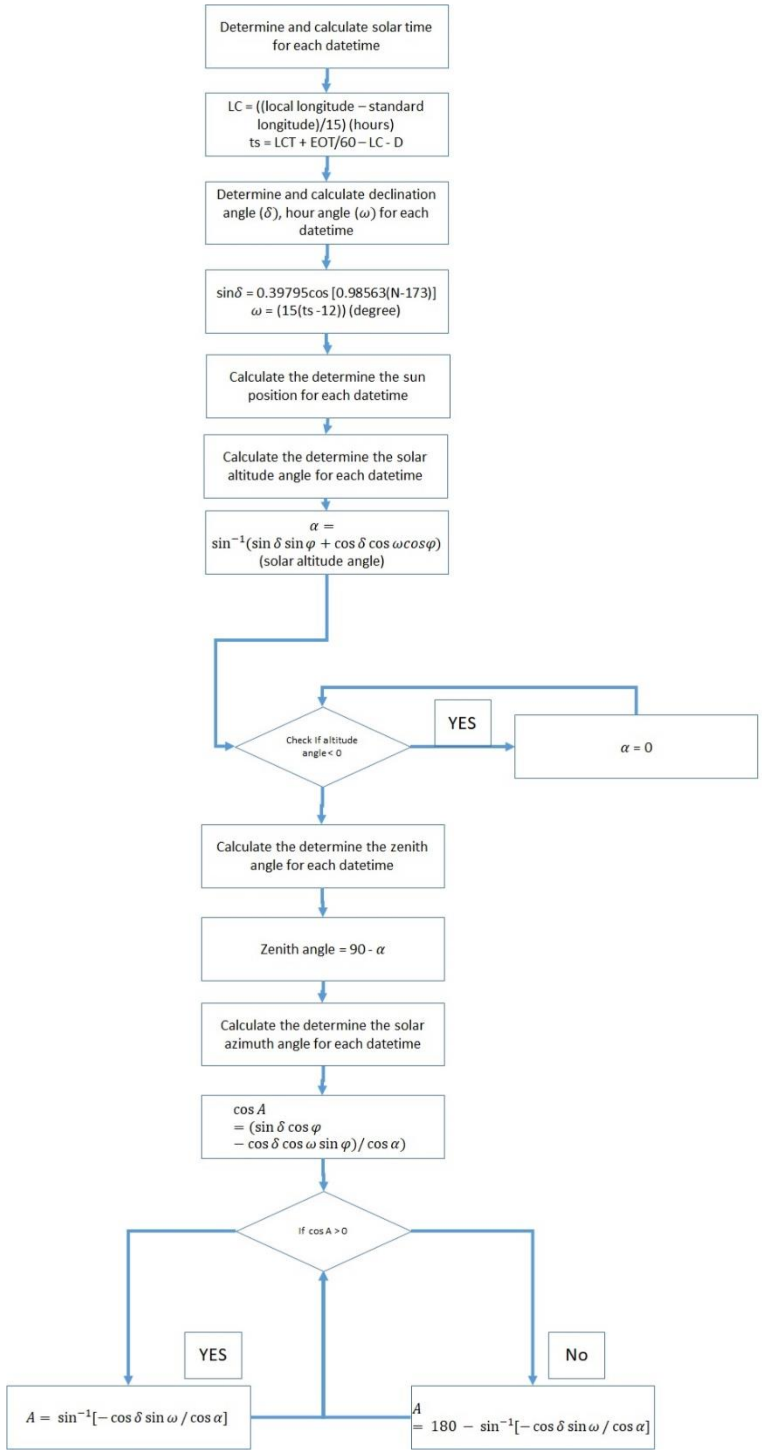


Figure 3.4: Flowchart on Determine Sun Position

Next, the sun position for each datetime in the data can be determine with the parameters of number of days, decline angle, hour_angle, altitude angle, zenith angle, and azimuth angle.

Formula in Programming Code	Remarks
df5['decline_angle'] = np.arcsin(0.39795*np.cos(0.98563*(df5['n'] - 173)*(m.pi/180)))*(180/m.pi)	To determine the declination angle for each datetime based on the solar time
df5['hour_angle'] = 15*((df5.solar_datetime.dt.hour + df5.solar_datetime.dt.minute/60 + df5.solar_datetime.dt.second/3600)-12)	To determine the hour angle for each date time based on the solar time
df5['altitude_angle'] = np.arcsin(np.sin(df5['decline_angle']*(m.pi/180)) *np.sin(Lat*(m.pi/180)) + np.cos(df5['decline_angle']*(m.pi/180)) *np.cos(df5['hour_angle']*(m.pi/180)) *np.cos(Lat*(m.pi/180)))*(180/m.pi)	To determine the altitude angle for each datetime based on the solar time. Lat = local latitude
df5['altitude_angle'].values[df5['altitude_angle'].values < 0] = 0.0	If the altitude angle is lesser than zero, meaning that the sun is no longer presence at the location (night time), therefore will assign as zero.
df5['zenith_angle'] = 90 - df5['altitude_angle']	To determine the zenith angle of the sun.
df5['cosA'] = (np.sin(df5['decline_angle']*(m.pi/180))*np.cos(Lat*(m.pi/180)) - np.cos(df5['decline_angle']*(m.pi/180))*np	A predetermination of the value of CosA which is the cosine of azimuth angle

.cos(df5['hour_angle']*(m.pi/180))*np.sin(Lat*(m.pi/180)))/(np.cos(df5['altitude_angle']*(m.pi/180)))	
df5.loc[df5['cosA'] > 0, 'Azimuth'] = np.arcsin((-np.cos(df5['decline_angle']*(m.pi/180)) *np.sin(df5['hour_angle']*(m.pi/180))) /(np.cos(df5['altitude_angle']*(m.pi/180)))) *(180/m.pi)	If CosA is more than 0, this formula is chosen to determine the azimuth angle.
df5.loc[df5['cosA'] < 0, 'Azimuth'] = 180 - np.arcsin((-np.cos(df5['decline_angle']*(m.pi/180)) *np.sin(df5['hour_angle']*(m.pi/180))) /(np.cos(df5['altitude_angle']*(m.pi/180)))) *(180/m.pi)	If CosA is less than 0, this formula is chosen to determine the azimuth angle.

3.9 Determine Optimum Tilt and Orientation Angle for Solar Panel

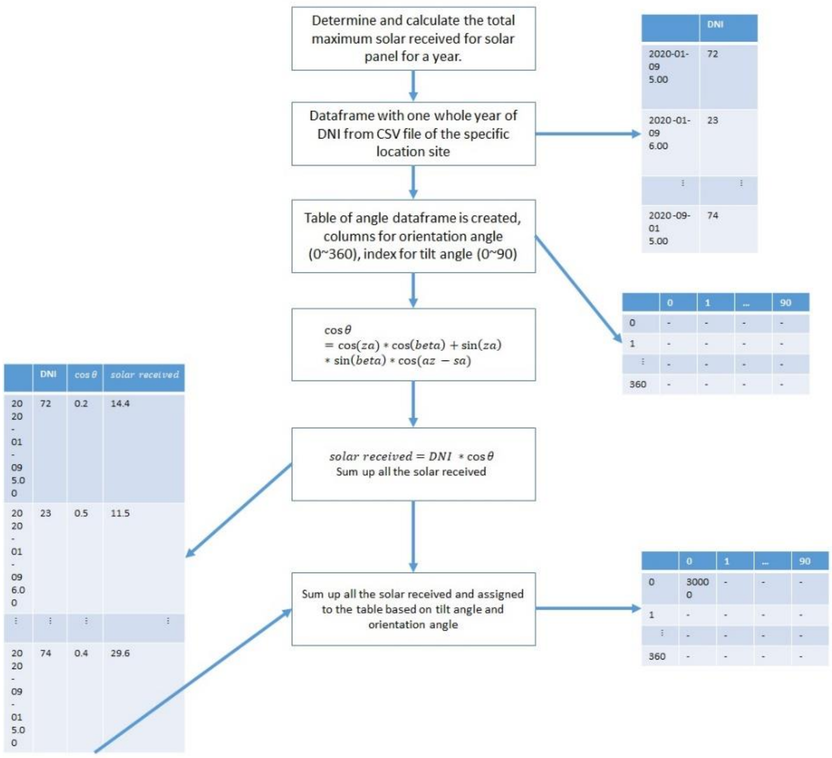


Figure 3.5: Flowchart on the Summation of Total Solar Irradiation on a Given Angle.

Once the sun position of the location is calculated, the determination for the suitability for the tilt angle and orientation of solar panel is carried out. The summary for determining the tilt angle and orientation of the solar panel is by looping method. For example, given the setting of solar panel with the tilted angle of 1 degree, the orientation of solar panel is remained at 0 degree. With the selected tilt angle and orientation angle, the value will be substitute into the formula to determine the incident angle between solar panel and the sun. The solar received on the surface of the panel can be determined by the multiplication of the solar received with the incident angle.

Formula in Programming Code	Remarks
cosiafc = np.cos((za)*(rd))*np.cos((beta)*(rd)) + np.sin((za)*(rd))*np.sin((beta)*(rd))*np.cos(((az)-(sa))*(rd))	To determine the incident angle between the solar panel and the sun at the given tilt angle and orientation angle for each datetime

	Beta: the tilt angle Sa: the orientation angle
solar_received = dni*cosiafc	To determine the solar received on the surface of the solar panel with tilt and oriented panel due to cosine effect for each datetime
solar_received = solar_received + dhi	After the direct solar irradiation with cosine effect being included, the diffuse solar irradiation is added to obtained the total solar irradiation on the surface of the PV panel.
d[beta][sa] = solar_received.sum()	After solar received on the solar panel for each datetime is determined, the data will be sum up, then assigned to a table with the value of summation of solar received throughout the year.

The solar collected on the surface of the solar panel is calculated for the whole year and will be sum up as the total solar received on the surface of the solar panel based on the setting given. The steps are repeated for each orientation and tilt angle. The range of the tilt angle is set from 0 to 90 degree, where 0 degree indicates the solar panel lies flat on the horizontal surface of the ground, whereas 90 degree indicates the solar panel is vertical or perpendicular to the surface of the ground. The range of the orientation of the solar panel is from 0 degree to 360 degree. At 0-degree, 90-degree, 180 degree and 270 degrees, the solar panel at the northern hemisphere is facing towards North, East, South and West respectively as shown in Figure 3.6.

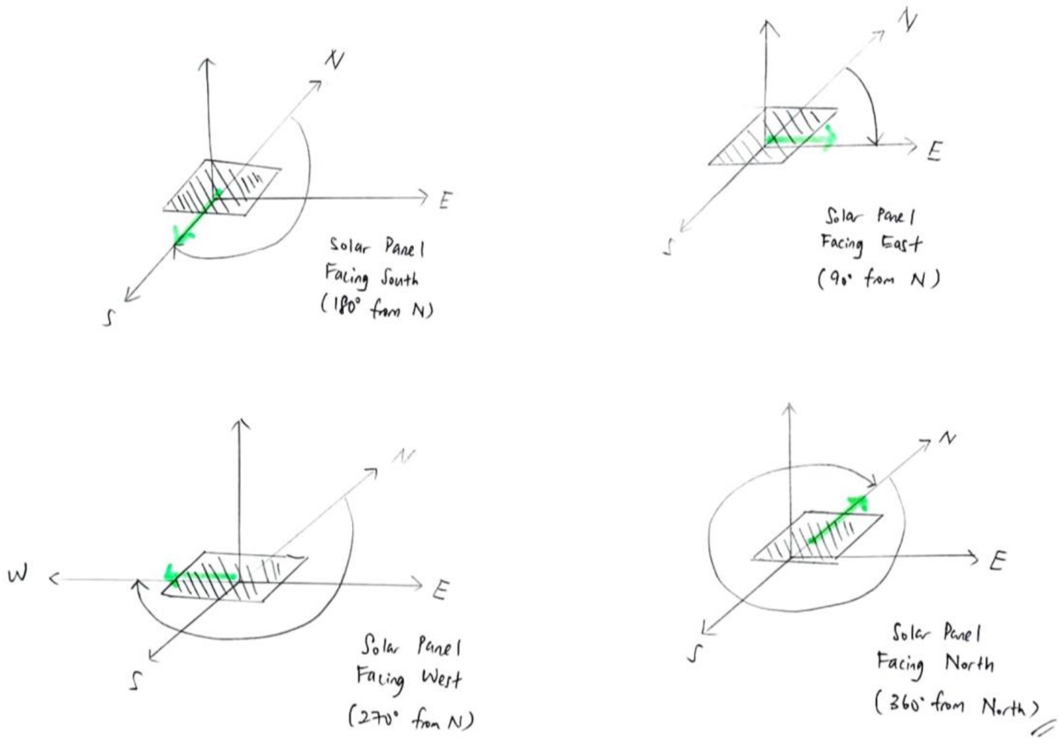


Figure 3.6: Solar Panel Facing Direction Angle

Once the table with tilt angle and orientation angle is filled up with the total sum maximum solar received, the selection of optimum tilt angle and orientation angle is being carried out. The method for determination is by choosing the highest total sum maximum solar received with the given tilt angle and orientation angle as shown in the Figure 3.7. The obtained value of the table with tilt and orientation angle will be plotted on a graph.

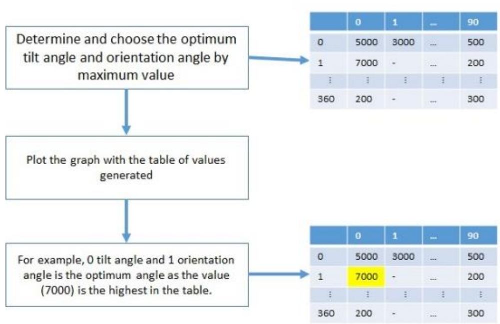


Figure 3.7: Flowchart on Choosing the Maximum Total Solar Irradiation

3.10 Amount of Energy Generation in a Year

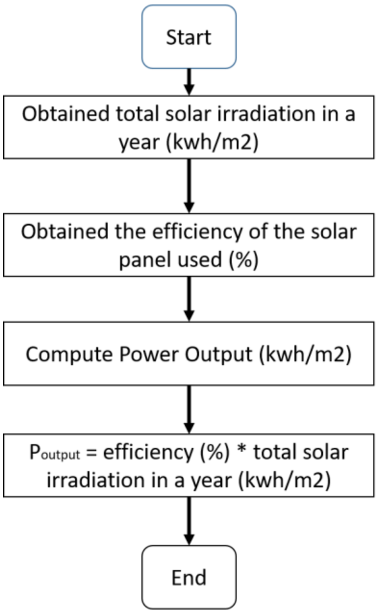


Figure 3.8: Flowchart on Calculation of Energy Output with effieicny (kWh/m2)

Figure 3.8 shows the flow chart on estimating the amount of energy generated per year. According to the formula derived from Chapter 2, it provides an ideal estimation on the power output of the solar panels obtained in a year at a particular location. For example, assume the solar sites in Bukit Kayu Hitam, with the geographic coordinate of 6.478000450954776N, 100.4283292590189E, the total direct solar irradiation obtained based on the optimum tilt angle and azimuth angle is 942217.92 Wh/m2. The value of the efficiency of the solar panel used is 16.0%, where the FirstSolar© 115W solar panel will be used as a reference. By substituting into the equation, the estimated power output for a solar panel at the location is:

$$P_{output} = \ Efficiency * total\ solar\ irradiation\ a\ year$$

$$= 0.16 * 942217.92\ \mathrm{Wh/m2}$$

$$= 150754.87\ Wh/m2$$

$$= 150.75\ kWh/m2$$

The power output of a solar panel at Bukit Kayu Hitam in a year is estimated to be $150.75\ kWh/m2$. The power output of the solar panel is dependent on the location, total area size of solar panel, efficiency and the types of solar panel brands.

3.11 Presence of Carbon Dioxide due to Absent of Forest

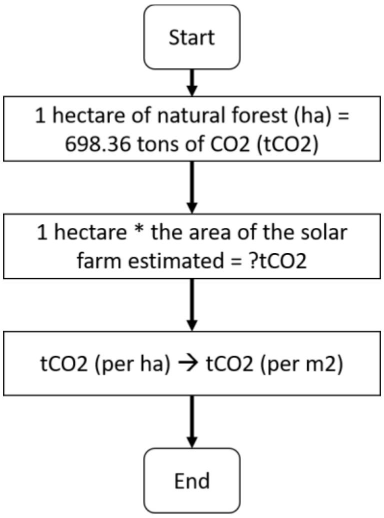


Figure 3.9: Flowchart on estimating the presence of carbon dioxide due to deforestation (tCO2/m2)

Figure 3.9 shows the flow chart on estimating the presence of carbon dioxide due to absent of forest in per meter square. According to the formula derived from Chapter 2, it shows that based on a statistic forest in Malaysia, 1 ha of natural forest is equivalent to 698.36 t of CO2. This equation also means that for every 1 ha of natural forest is being removed, 698.36t of CO2 is present towards the surroundings due to the absent of these trees. For example, the solar site in Bukit Kayu Hitam have an area of 17.53 hectares, by substituting into the equation:

$$1\ ha\ of\ natural\ forest = 698.36t\ CO2$$
$$17.53\ ha\ of\ natural\ forest = 698.36 * 17.53\ tCO2$$
$$17.53\ ha\ of\ natural\ forest = \mathbf{12242.2508t\ CO2}$$

Based on the calculation above, 17.53 ha of natural forest being removed will contribute to 12242.2508t of CO2 being present to the surrounding. 17.53 ha is approximately 175301.82m2. Hence, by substituting the parameters into the equation, 1 meter square of a natural forest being removed is approximately 0.069835274t CO2 is present towards the surrounding.

$$17.53ha\ of\ natural\ forest = 175301.82m2 = 12242.2508t\ CO2$$
$$1m2 = \frac{12242.2508t\ CO2}{175301.82}$$
$$1m2 = 0.069835274t\ CO2$$
$$CO2\ increased\ from\ deforestation = 0.069835274t\ CO2/m2$$

3.12 Calculation of CO2 avoidance

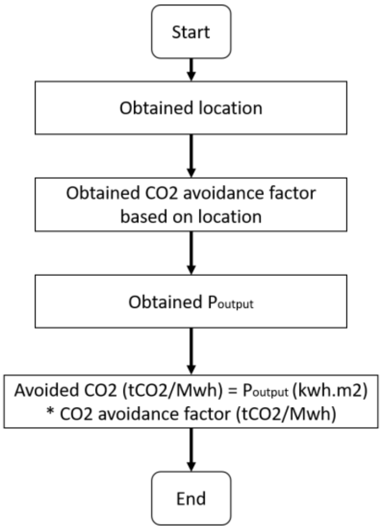


Figure 3.10: Flowchart on Calculation of CO2 Avoidance.

Figure 3.10 shows the flow chart on the calculation of CO2 avoidance when solar farm is in operation. According to the formula in Chapter 2, the important parameters required for the avoidance of carbon dioxide is the generated electricity (kWh) and the baseline factor of CO2 avoidance (kg/kwh). According to the baseline standard by SEDA Malaysia, by selecting the latest year, the CO2 avoidance factor is 0.639 tCO2/MWh in Peninsular, whereas 0.512 tCO2/MWh in Sabah, Wilayah Persekutuan, Labuan, whereas 0.364 tCO2/MWh in Sarawak based on SEDA (2016) and MGTC (2017).

Table 3.4: CO2 Avoidance Factor for Different Region

Location	CO2 avoidance factor (tCO2/MWh)
Peninsular Malaysia	0.639
Sabah, Wilayah Persekutuan, Labuan	0.512
Sarawak	0.364

For example, the CO2 avoidance in Bukit Kayu Hitam, which is situated in Peninsular Malaysia,

$$Avoided\ CO2\ in\ tCO2/m2$$
$$= Generated\ Electricity\ in\ kWh\ x\ factor\ for\ CO2\ avoidance\ in\ kg/kWh$$
$$= 150.75\ kWh/m2\ x\ 0.639tCO2/MWh$$
$$= 0.151\ MWh/m2\ \ x\ \ 0.639tCO2/MWh$$
$$= 0.096\ tCO2/m2$$

Hence, in order to determine the Net Carbon Dioxide in Bukit Kayu Hitam for example, by substituting the value of CO2 presence from deforestation and CO2 Avoided,

$$Net\ Carbon\ Dioxide = CO2\ Emission - CO2\ Avoided$$
$$= 0.069835274\ tCO2/m^2 - 0.096\ \ tCO2/m^2$$
$$= -0.0265\ tCO2/m2$$

In summary, for Bukit Kayu Hitam, the net carbon dioxide in a year is approximately -0.0265 tCO2/m2, the negative sign of the value indicates that the amount of carbon dioxide present in the surrounding due to the deforestation is able to payback by installation of solar panels within a year. If the sign of the value is positive, meaning that within a year, the carbon dioxide avoided by solar panel installation are unable to cover up the carbon dioxide emission due to deforestation.

3.13 Economic Impact

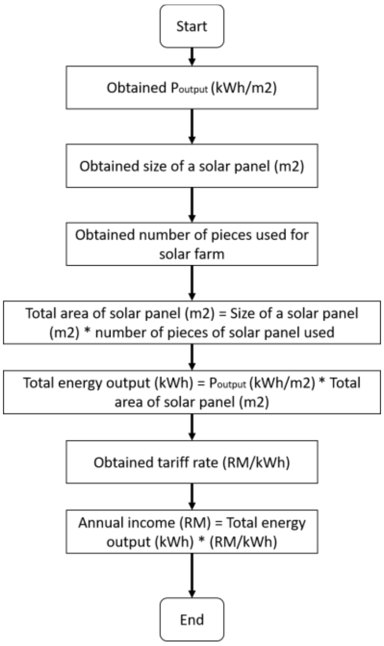


Figure 3.11: Flowchart on Calculation of Annual Income with Various Parameter Given

Figure 3.11 shows the flow chart to estimate the annual income of the solar farm, with energy output and tariff rate. Take the case study in Bukit Kayu Hitam, where the energy output in a year is $150.75\ kWh/m2$. Table 3.5(a), 3.5(b), 3.5(c) shows the investment cost, total energy output, total solar panels, total solar panel area respectively in order to estimate the payback period of the solar farm in Bukit Kayu Hitam.

Table 3.5(a): Working Step of Estimating the Annual Income of Solar Farm.

Energy Output (kwh/m2)	Size of a solar module used (m2)	Number of Pieces	Total area of solar panel (m2)	Total Energy Output (kwh)	Total Income (RM) Tariff = RM0.395/kwh
150.75	1.2 *0.6 = 0.72	105000	75600	11397067.92	4,501,841.83

Table 3.5(b): Working Step of Calculation Total Capacity of Solar Farm.

Rated power solar panel used (W)	Total rated power solar panel (W)
115	115*105000 = 12075000

Table 3.5(c): Working Step of Calculation of Investment Cost of Solar Farm.

Parameters	Model value (RM/W)	Watt (W)	Total value (RM)
Module	1.65	12,075,000	19,923,750
Inverter	0.33	12,075,000	3,984,750
Structural material			
Miscellaneous (electrical cables, etc.)	0.72	12,075,000	8,694,000
Planning			
Installation work	2.91	12,075,000	35,138,250
Shipping and travel			
Permits and direct labor			
Project margin			
Total without Tax			67,740,750
Sales & Services Tax (SST)	6%		4,064,445
Total	5.9466		71,805,195

Therefore, the payback period of Bukit Kayu Hitam can be estimated as:

$$n_{pay} = -\frac{In[1 - S_{total}i'/P_{ann}]}{In(1 + i')}$$

Where $i' = \frac{1+i}{1+j} - 1, interest\ rate, i = 1.75\%$, $inflation\ rate, j = 2.3\%$

$$S_{total} = Total\ Investment\ Cost$$

$$P_{ann} = Annual\ cost\ saving$$

$$i' = \frac{1+i}{1+j} - 1$$

$$= \frac{1+0.0175}{1+0.023} - 1$$

$$= -0.0054$$

$$n_{pay} = -\frac{In\left[1 - \frac{S_{total} * i'}{P_{ann}}\right]}{In(1+i')}$$

$$= -\frac{In\left[1 - \frac{(71{,}805{,}195)(-0.0054)}{4{,}501{,}841.83}\right]}{In(1-0.0054)}$$

$$= 15.259\ years$$

Based on the estimation of Bukit Kayu Hitam, with the annual income of RM 4501841.83, while having an initial investment cost of about RM 71,805,195, the project needed 15.26 years in order to return the investment cost. Once the project reaches the operation more than 15.26 years, the project is able to generate profit.

3.14 Summary

In summary, no hardware is needed in this project. As for software, the Python library is used for the comprehensive modelling, for determining the solar time, sun position, maximum solar received for each datetime based on the tilt and orientation angle generated. Python programming is able to undergo complex calculation and able to generate the desired parameters, such as solar time, sun position, maximum solar received, optimum tilt and orientation angle for a year (2019 to 2020) within a one-day period. In addition, in terms of cost, this project has the lowest investment, however, it able to produce a reliable yet inexpensive outcome, while able to estimate the environmental impact and economic impact of the case study solar sites. Fortunately, the project is able to run without errors. With the necessary libraries and software, the design and implementation for the project can undergo comprehensive modelling of solar photovoltaic technologies. The compilation of GHI for each solar sites, ranking for each solar site based on GHI, Optimum tilt angle and orientation for each solar site and its maximum total solar received a year. Next, the presence of carbon dioxide due to deforestation, carbon dioxide avoidance and the net carbon dioxide will be shown in environmental section. Lastly, the investment, annual income, payback period will be estimated and tabulated respectively in Chapter 4: RESULTS AND DISCUSSION.

CHAPTER 4

RESULTS AND DISCUSSIONS

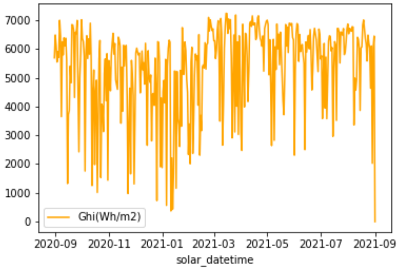
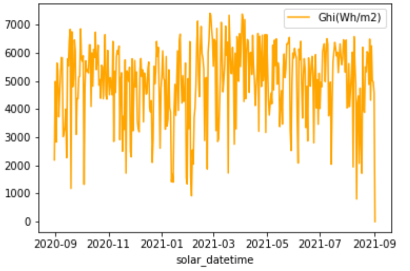
4.1 Introduction

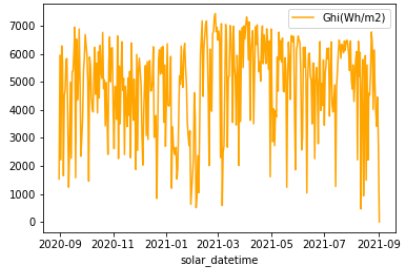
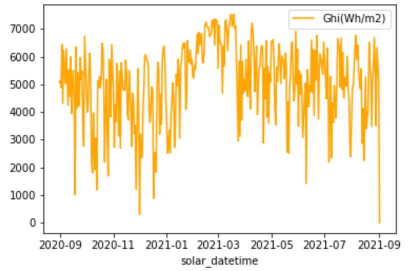
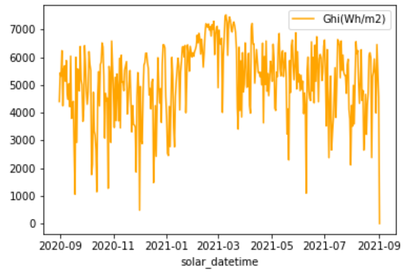
In this section, the compilation of GHI, number ranking, optimum tilt angle and orientation for each solar site and its maximum total solar received a year respectively will be generated and tabulated in graph. As for compilation of GHI, each of the solar sites will have its solar radiation data, and the graph will display the total solar radiation of each month for a year, with the annually average peak hour and solar irradiation. Once the compilation is completed, the ranking of the solar sites is able to carry out. The higher the total GHI, the higher the ranking for the solar sites. Next, each of the solar site's data will be used for undergoing the determination of optimum tilt angle and orientation for solar panel in order to receive maximum solar irradiation. In addition, the environmental impact of the case study solar farm will be performed as well as the economic impact of the case study, where investment cost, annual income and payback period will be estimated with the report and statistic obtained.

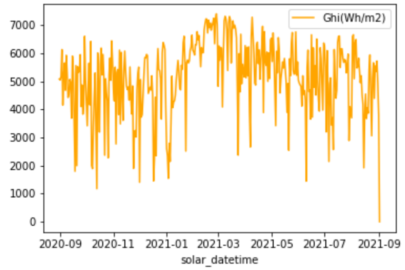
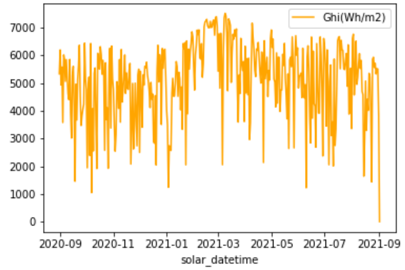
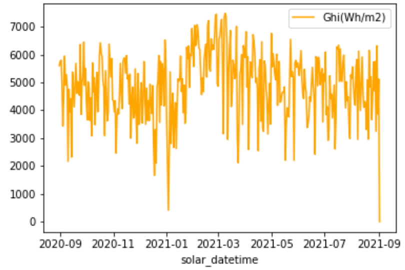
4.2 Compilation of GHI for Each Solar Sites

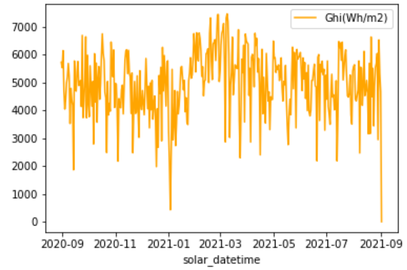
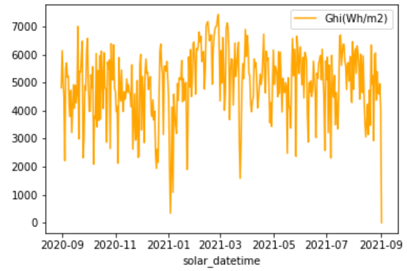
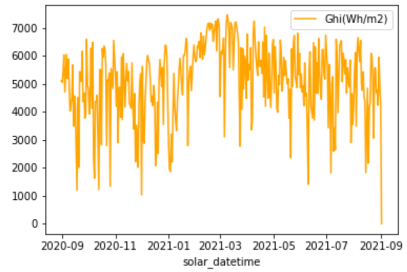
The yearly solar irradiance data obtained from Solcast for each of the solar sites is being tabulated in the Table 4.1. There are 17 solar sites in total, where the solar sites are located and recognized in each region in Malaysia. The annual average solar irradiation shows that the daily average solar received on the particular solar sites, wherelse, the annual average peak sun hours is just the value of daily average solar received divided by 1000 kWh/m^2, meaning that the particular solar sites will have how many hours of sunshine throughout the day in average.

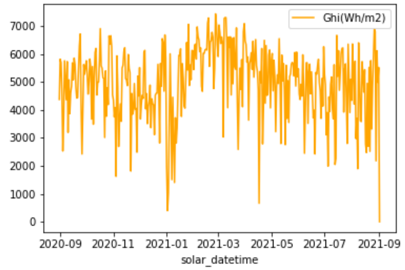
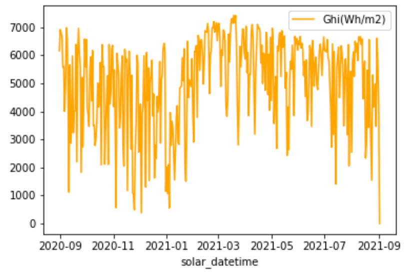
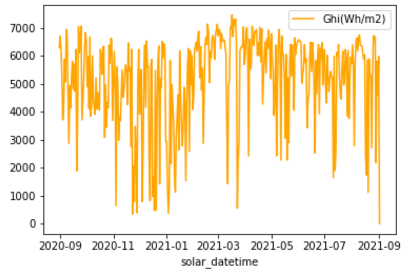
Table 4.1: GHI for Each Solar Sites

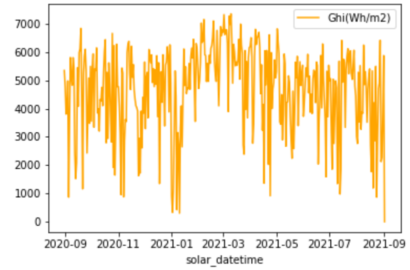
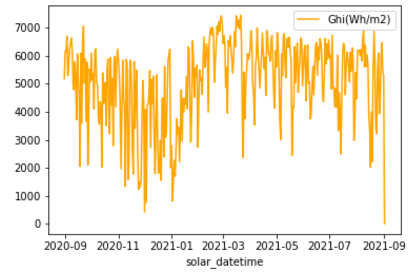
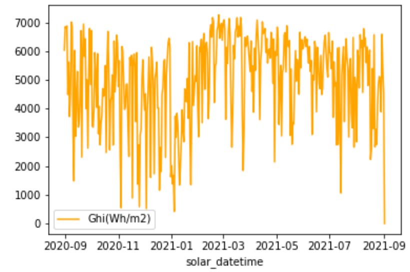
	Solar Site and Coordinate	GHI	Annual Daily average Solar Irradiation (kWh/m^2) ($\sum GHI$)	Annual Daily average Peak Sun Hours (PSH) (h)
1	Tanjung Batu Hybrid Solar Power Plant 5°48'01.8"N 118°09'29.2"E		5.349270491803279	5.349270491803276
2	Comtec Solar International (m) Sdn Bhd 1°31'10.6"N 110°23'50.0"E		4.965588555858311	4.9655885558583135

3	Solar Power Plant Telok Melano, Sarawak Energy Berhad 2°00'16.6"N 109°38'42.5"E		4.860604904632153	4.86060490463215
4	Bukit Kayu Hitam Solarvest 6°28'40.8"N 100°25'42.0"E		5.081128065395095	5.0811280653950925
5	Pokok Sena Solar PV plant 6°10'51.3"N 100°28'21.0"E		5.1953351498637605	5.1953351498637605

6	LSS PV 30MWac Kuala Muda Kedah 5°39'25.3"N 100°34'21.2"E		5.1596403269754765	5.159640326975479
7	Elsoft Research Berhad 5°17'33.0"N 100°17'21.0"E		5.1258310626703	5.125831062670299
8	Taruc, Setapak 3°13'00.8"N 101°43'58.8"E		4.897831062670299	4.8978310626703

9	Utar, Bandar Sungai Long, KB block roof top 3.0394° N, 101.7941° E		4.971261580381472	4.971261580381473
10	Utar, Kampar Campus 4°20'27.1"N 101°08'40.9"E		4.957956403269755	4.957956403269755
11	Scatec Itramas solar 65MW Gurun Solar Power Plant 5°51'46.6"N 100°32'20.2"E		5.119405994550409	5.119405994550409

12	Scatec Itramas Solar 66MW Jasin Solar Power Plant 2°17'56.7"N 102°21'16.0"E		4.982108991825613	4.982108991825611
13	Scatec Itramas Solar 66 MW Merchang Solar Power Plant 4°56'04.4"N 103°20'13.4"E		5.052016348773842	5.052016348773841
14	Pekan Pahang Solar Farm 3°19'24.9"N 103°25'20.9"E		5.139629427792915	5.139629427792918

15	UITM Solar Park II (LSS2 Pasir Gudang) 1°31'36.7"N 103°51'50.4"E		4.704269754768392	4.704269754768396
16	Pasir Mas Solar Farm 5°59'31.9"N 102°06'39.8"E		5.072152588555858	5.072152588555857
17	Kenyir Gunkul Solar Sdn Bhd 4°38'55.8"N 103°23'13.5"E		4.976272479564033	4.976272479564028

4.3 Ranking of Solar Sites

Based on the tabulated Annual average GHI and Peak Sun Hours, the ranking for each solar sites is also being sorted in descending order, where the highest annual average GHI will be the first and lowest annual average GHI will be the last ranking.

According to the sorted ranking based on the annual average GHI for each solar sites, it shows that the **Top 3** annual average GHI among the 17 chosen solar sites are Tanjung Batu Hybrid Solar Power Plant, Pokok Sena Solar PV Plant and LSS PV 30MWac Kuala Muda Kedah, with the annual average GHI of 5320.19837 Wh/m2, 5181.217391 Wh/m2 and 5145.619565 Wh/m2 respectively.

In addition, the **Last 3** annual average GHI among the 17 chosen solar sites are Taruc, Setapak, Solar Power Plant Telok Melano, Sarawak Energy Berhad and UITM Solar Park II (LSS2 Pasir Gudang), with the annual average GHI of 4884.521739 Wh/m2, 4847.396739 Wh/m2 and 4691.486413 Wh/m2 respectively.

Table 4.2: Ranking of Each Solar Site based on GHI

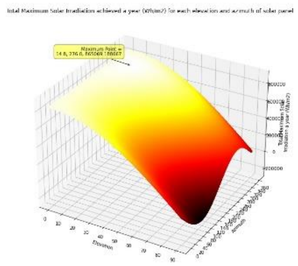
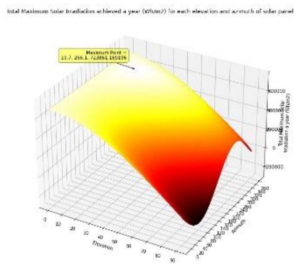
Rating_Ranking	Solar Site Name	Coordinate	Annual Average GHI (Wh/m2)
1	Tanjung Batu Hybrid Solar Power Plant	5.800498388299525, 118.15811098553932	5320.19837
2	Pokok Sena Solar PV Plant	6.18092040158725, 100.4725068913063	5181.217391
3	LSS PV 30MWac Kuala Muda Kedah	5.657036399589651, 100.57256748038222	5145.619565
4	Pekan Pahang Solar Farm	3.323589, 103.422471	5125.663043
5	Elsoft Research Berhad	5.2925078467591025, 100.28916532697262	5111.902174
6	Scatec solar 65MW Gurun Solar Power Plant	5.862950268444186, 100.53893544057493	5105.494565
7	Bukit Kayu Hitam Solarvest	6.478000450954776, 100.4283292590189	5067.320652
8	Pasir Mas Solar Farm	5.992184, 102.111054	5058.369565
9	Scatec Solar 66MW Merchang Solar Power Plant	4.934544, 103.337056	5038.288043

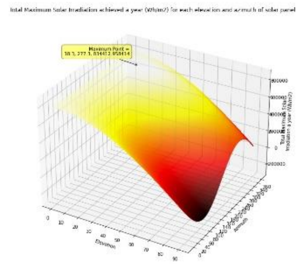
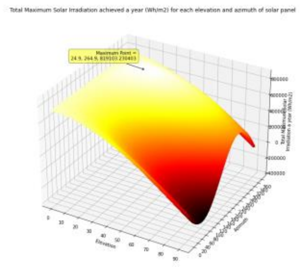
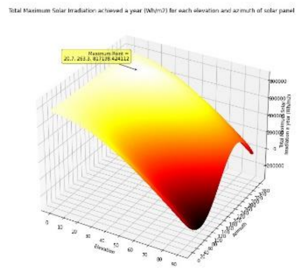
10	Scatec Solar 66MW Jasin Solar Power Plant	2.299072, 102.354431	4968.570652
11	Kenyir Gunkul Solar Sdn Bhd	4.648842330141924, 103.38708024416017	4962.75
12	Utar Bandar Sungai Long, KB block roof top	3.0394, 101.7941	4957.752717
13	Comtec Solar International (m) Sdn Bhd	1.519615, 110.397216	4952.095109
14	Utar, Kampar Campus	4.340862, 101.144685	4944.483696
15	Taruc, Setapak	3.216889, 101.733	4884.521739
16	Solar Power Plant Telok Melano, Sarawak Energy Berhad	2.004611, 109.645139	4847.396739
17	UITM Solar Park II (LSS2 Pasir Gudang)	1.526846, 103.864002	4691.486413

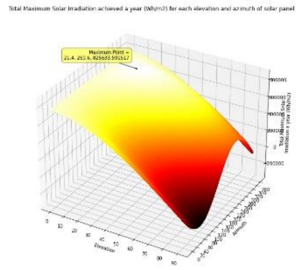
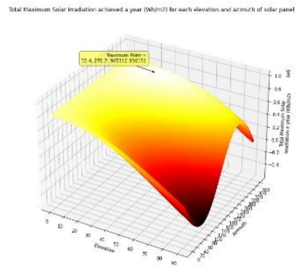
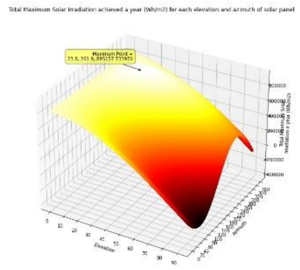
4.4 Maximum Total Solar Irradiation (Wh/m2) with Optimum Tilt and Orientation Angle

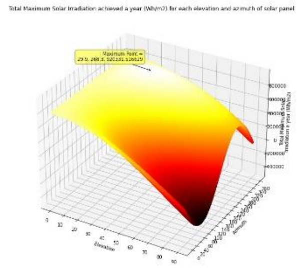
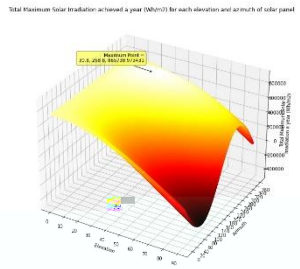
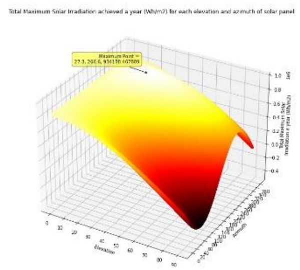
In this section, the maximum total solar irradiation (Wh/m2) for a year and the suitable tilt angle and orientation angle for the specific location of the solar sites. Table 4.3 below shows the compilation of each solar sites' total solar irradiation, tilt angle and orientation angle of the solar panel. The higher the total solar, the tilt angle and orientation angle is chosen to be the suitable angle for the solar panel in order to achieve a higher output. The graph also indicates that for each tilt angle and orientation angle, the maximum total solar irradiation is being plotted out, hence the tilt angle is range from 0 to 90 degrees, whereas the orientation angle ranges from 0 to 360 degrees.

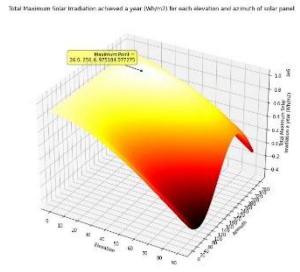
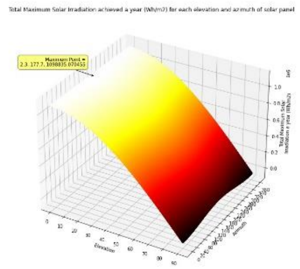
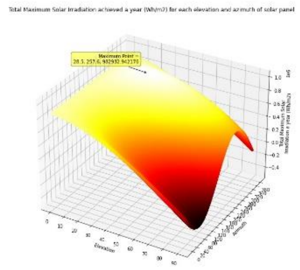
Table 4.3: The Optimum Tilt and Orientation Angle for Each Solar Sites

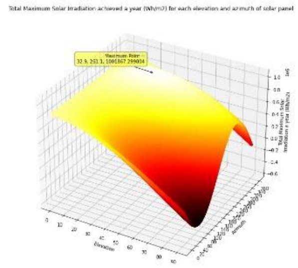
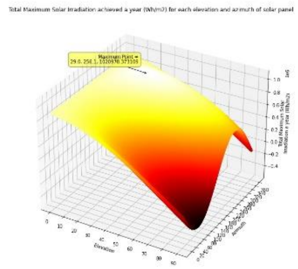
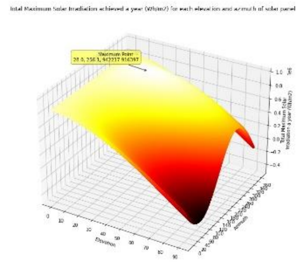
Location	Graph	Remarks
Comtec Solar International (m) Sdn Bhd		14.8-degree elevation angle 276.0 azimuth angle 865069.12 Wh/m2
UITM Solar Park II (LSS2 Pasir Gudang)		19.7-degree elevation angle 266.1 azimuth angle 723861.167 Wh/m2

Solar Power Plant Telok Melano, Sarawak Energy Berhad		18.3-degree elevation angle. 277.3 azimuth angle 834412.96 Wh/m2
Scatec Itramas Solar 66MW Jasin Solar Power Plant		24.9-degree elevation angle. 264.9 azimuth angle 819103.23 Wh/m2
Utar Bandar Sungai Long, KB block roof top		20.7-degree elevation angle. 263.3 azimuth angle 817198.42 Wh/m2

Taruc, Setapak		21.4-degree elevation angle. 260.6 azimuth angle 825633.59 Wh/m2
Pekan Pahang Solar Farm		32.4-degree elevation angle. 270.7 azimuth angle 965110.94 Wh/m2
Utar, Kampar Campus		23.8-degree elevation angle. 261.9 azimuth angle 895157.73 Wh/m2

Scatec Itramas Solar 66 MW Merchang Solar Power Plant		29.9-degree elevation angle. 268.3 azimuth angle 920331.52 Wh/m2
Kenyir Gunkul Solar Sdn Bhd		30.8-degree elevation angle. 268.8 azimuth angle 865738.97 Wh/m2
Pasir Mas Solar Farm		27.8-degree elevation angle. 266.6 azimuth angle 934188.47 Wh/m2

LSS PV 30MWac Kuala Muda Kedah		26.0-degree elevation angle. 256.4 azimuth angle 975184.08 Wh/m2
Tanjung Batu Hybrid Solar Power Plant		2.3-degree elevation angle. 177.7 azimuth angle 1098835.07 Wh/m2
Scatec Itramas solar 65MW Gurun Solar Power Plant		28.5-degree elevation angle. 257.6 azimuth angle 982932.94 Wh/m2

Elsoft Research Berhad		32.9-degree elevation angle. 261.1 azimuth angle 1001867.3 Wh/m2
Pokok Sena Solar PV plant		29.0-degree elevation angle. 256.1 azimuth angle 1020978.37 Wh/m2
Bukit Kayu Hitam Solarvest		28.0-degree elevation angle. 256.1 azimuth angle 942217.92 Wh/m2

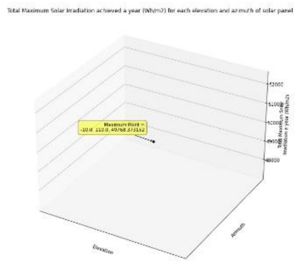
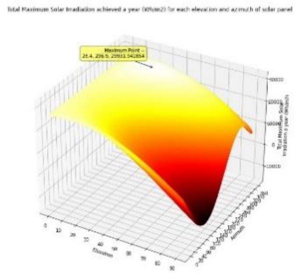
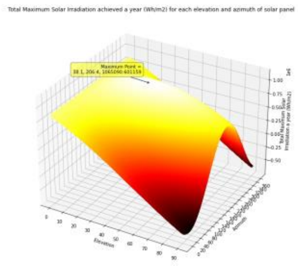
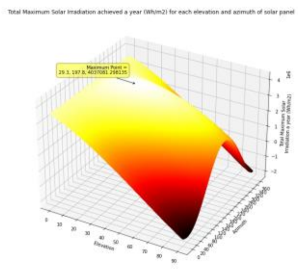
4.5 Comparison with On-site results

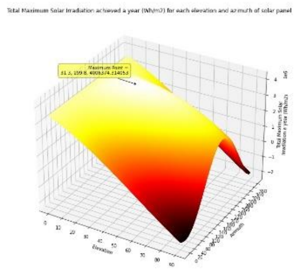
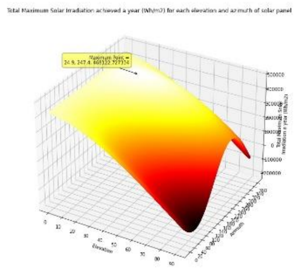
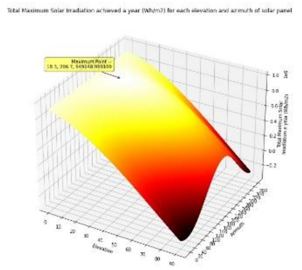
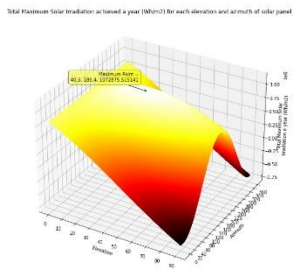
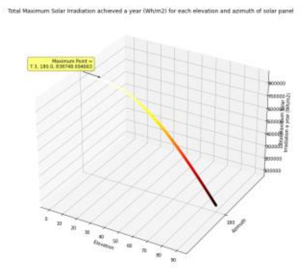
In this section, the comparison with the simulated results and on-site results is necessary, it is because to determine whether the simulation model is safe and reliable for future purposes. In addition, the big local company firm for solar energy such as Scatec Itramas ©, Gunkul © and others, unable to provide and disclose the information such as optimum tilt angle, optimum azimuth angle, types of solar panel used. Due to these various limitations, the thesis paper published by various researchers, who undergo physical experiment on-site, set up solar panel and record the results will be used as a comparison reference for this model. Fortunately, some renown local company, which are SolarVest© and Scatec Itramas © willing to enclose the details (Optimum tilt angle, azimuth angle, types of solar panel brand used). Based on the literature review, there are some steps that needed to be compared with, in order to stat the accuracy of this program.

1. If the thesis paper provided optimum tilt angle, azimuth angle and total solar irradiation, we will first fix the tilt angle and azimuth angle based on the researcher, then compare the difference between total solar irradiation by the researcher with the simulation.
2. If the thesis paper did not provide the azimuth angle and total solar irradiation, the program will run 0 to 90 degrees for tilt angle and 0 to 360 degrees for azimuth angle.
3. If the thesis paper provides the optimum tilt angle and azimuth angle, the program will also run 0 to 90 degrees for tilt angle and 0 to 360 degrees for azimuth angle.
4. If the thesis paper provides the optimum tilt angle and total solar irradiation, the program will still run 0 to 90 degree and 0 to 360 degrees.
5. Special Case: If the Solar Photovoltaic Company kindly provided the optimum tilt angle and azimuth angle, the program would fix the azimuth angle as the reference and determine the tilt angle.

Table 4.4 and 4.5 show the comparison of the simulation and actual results provided by the researchers and local company.

Table 4.4: Simulation Results for Each Literature Review

Location	Graph	Simulation Results
Padang Besar, Perlis		-10-degree tilt angle. 160 orientation angles. 49768.37 Wh/m2
Ilorin, Nigeria		28.4-degree tilt angle. 296.9 azimuth angle of solar panel. 29931.94 Wh/m2
Panjab University Chandigarh, India		38.1-degree tilt angle. 206.4 orientation angle of solar panel. 1065090.60 Wh/m2
Aligarh city, India		29.3-degree tilt angle. 197.8 azimuth angle of solar panel. 4037081.3 Wh/m2

New Dehli, India		31.3-degree tilt angle. 199.8 azimuth angle. 4006374.31 Wh/m2
Bilecik Seyh Edebali University Engineering Faculty, Turkey		24.9-degree tilt angle. 247.4 azimuth angle. 468122.73 Wh/m2
Chennai, India		18.3-degree tilt angle. 206.7 azimuth angle. 949149 Wh/m2
Beijing, China		40.5-degree tilt angle. 186.4 azimuth angle. 1072875.52 Wh/m2
Bukit Kayu Hitam, SolarVest© , Malaysia		7.3-degree tilt angle. 180.0 azimuth angle. 838748.69 Wh/m2

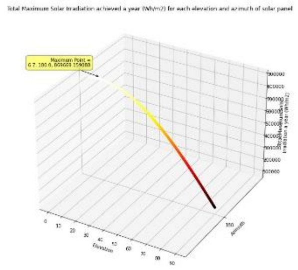
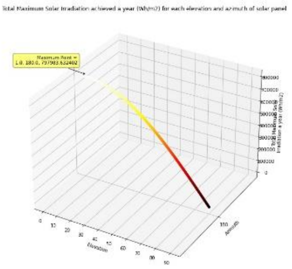
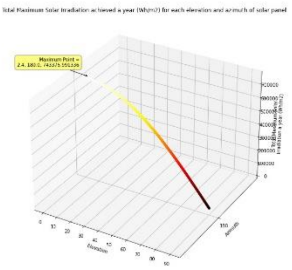
Scatec Itramas solar 65MW Gurun Solar Power Plant, Pendang, Kedah		6.7-degree tilt angle. 180 azimuth angles. 869669.16 Wh/m2
Scatec Itramas Solar 66 MW Merchang Solar Power Plant, Marang, Terrenganu		1 degree tilt angle. 180 azimuth angles. 797983.63 Wh/m2
Scatec Itramas Solar 66MW Jasin Solar Power Plant, Bemban, Melaka		2.4-degree tilt angle. 180 azimuth angles. 743376 Wh/m2

Table 4.5: Summary and Comparison with Simulation and On-site Results

Location	Geographic	On-site Tilt angle	On-site Azimuth angle	Total Solar Irradiation	Simulation Tilt angle	Simulation Azimuth Angle	Simulation Total Solar Irradiation	Remarks
Padang Besar, Perlis	6.649444N, 100.256389E	-10	South 20-degree East. (160 degree from North)	43.23 - 43.92 kwh/m2	-10.0 degree	160 azimuth angles.	48.95 kWh/m2	The simulated total solar irradiation on the given tilt angle and azimuth angle will have a range of 5.03 to 5.72 difference. Therefore, the solar irradiation from Solcast © and formula can be accepted.

Ilorin, Nigeria	8.5373N, 4.5444E	22 degrees	Facing south	-	28.4-degree tilt angle.	296.9 azimuth angle.	29931.94 Wh/m2	The simulation results unable to obtain similar site results. Therefore, it is rejected.
Panjab University Chandigarh, India	30.748098N, 76.757141E	30 degrees to 40 degrees	-	-	38.1-degree tilt angle.	206.4 azimuth angle	1065090.6 Wh/m2	By comparing, it is observed that between simulated and actual results have a range of 1.9 to 8.1 difference. The solar panel is facing towards south area. Therefore, it is acceptable.

Aligarh city, India	27.89°N, 78.08°E	27.62°	-	8.05 kWh/m2-day	29.3 degree	197.8 azimuth angle	4037081.3 Wh/m2 (11.21 kWh/m2-day)	By comparing, it is observed that the tilt angle between simulated and actual have a 1.68 difference. The solar panel is facing towards south area. Therefore, it is acceptable.
New Dehli, India	28.61°N, 77.20°E	27.95°	-	6.75 kwh/m2-day	31.3 degree.	199.8 azimuth angle.	4006374.31 Wh/m2 (11.13 kwh/m2-day)	By comparing, it is observed that the tilt angle between simulated and actual have a 3.35 difference. The

								solar panel is facing towards south area. Therefore, it is acceptable.
Bilecik Seyh Edebali University Engineering Faculty, Turkey	40.189697N, 29.966415 E	Average: 10 degrees	-	-	24.9-degree tilt angle.	247.4 azimuth angle.	468122.73 Wh/m2	By comparing, it is observed that the tilt angle between simulated and actual have a significant 14.9 difference. Therefore, it is rejected.
Chennai, India	13.0827 N, 80.2707 E	0-to-36-degree tilt.	South (180), South-East	-	18.3-degree tilt angle.	206.7 azimuth angle.	949149 Wh/m2	By comparing, the tilt angle and azimuth angle simulated are

			(135) and South-West (225)					within the range of the actual results. Therefore, it is acceptable.
Beijing, China	39.9042 N, 116.4074 E	0-to-54-degree tilt.	South (180), South-East (135) and South-West (225)	-	40.5-degree tilt angle.	186.4 azimuth angle.	1072875.52 Wh/m2	By comparing, the tilt angle and azimuth angle simulated are within the range of the actual results. Therefore, it is acceptable.
Bukit Kayu Hitam, SolarVest©, Malaysia	6.478000450954776 N, 100.4283292590189 E	10-degree tilt.	180 azimuth angles.	-	7.3-degree tilt angle.	180.0 azimuth angle.	838748.7 Wh/m2	Since the thesis paper provided the azimuth angle, the simulation will

								determine the optimum tilt angle by fixing the provided azimuth angle. Therefore, the obtained tilt angle has a difference of 2.7 and it is accepted.
Scatec Itramas solar 65MW Gurun Solar Power Plant, Pendang, Kedah	5.862950268444186 N, 100.53893544057493 E	10-degree tilt	180 azimuth angles	-	6.7-degree tilt	180 azimuth angles	869669.16 Wh/m2	Since the thesis paper provided the azimuth angle, the simulation will determine the optimum tilt angle by fixing the provided

								azimuth angle. Therefore, the obtained tilt angle has a difference of 3.3 and it is accepted.
Scatec Itramas Solar 66 MW Merchang Solar Power Plant, Marang, Terrenganu	4.934544 N, 103.337056 E	10-degree tilt	180 azimuth angles	-	1.0-degree tilt angle.	180.0 azimuth angle	797983.63 Wh/m2	The simulation will determine the optimum tilt angle by fixing the provided azimuth angle. Therefore, the obtained tilt angle have a difference of 9 and it is rejected.

Scatec Itramas Solar 66MW Jasin Solar Power Plant, Bemban, Melaka	2.299072 N, 102.354431 E	10-degree tilt	180 azimuth angles	-	2.4-degree tilt angle.	180.0 azimuth angle	743376 Wh/m2	The thesis paper provided the azimuth angle and will determine the optimum tilt angle by fixing the azimuth angle. Therefore, the obtained tilt angle have a difference of 7.6 and it is rejected.

4.6 Accuracy of Simulation

Table 4.6 below shows the accuracy of the model, where various thesis paper results are used to compare with the simulated results.

Table 4.6: Accept/Reject for Similarity of Results.

On-site Location	On-site Results	Simulated Results	Accept/Reject
Padang Besar, Perlis	-10-degree tilt South 20-degree East 43.92 - 43.3 kwh/m2	-10-degree tilt 160 degrees from North 48.95 kWh/m2	Accept
Ilorin, Nigeria	22-degree tilt Facing South	28.4-degree tilt angle. 296.9 degree from North. 29931.94 Wh/m2	Reject
Panjab University Chandigarh, India	30 degrees to 40 degrees	38.1-degree tilt angle. 206.4 orientation angle of solar panel. 1065090.60 Wh/m2	Accept
Aligarh city, India	27.62-degree tilt 8.05 kWh/m2-day	29.3-degree tilt 197.8 degree from North 11.21 kWh/m2-day	Accept
New Dehli, India	27.95-degree tilt 6.75 kwh/m2-day	31.3-degree tilt 199.8 degree from North 11.13 kwh/m2-day	Accept
Bilecik Seyh Edebali University Engineering Faculty, Turkey	Average: 10-degree tilt.	24.9-degree tilt. 247.4 degree from North. 468122.73 Wh/m2	Reject

Chennai, India	0-to-36-degree tilt. South (180), South-East (135) and South-West (225)	18.3-degree tilt angle. 206.7 azimuth angle. 949149 Wh/m2	Accept
Beijing, China	0-to-54-degree tilt. South (180), South-East (135) and South-West (225)	40.5-degree tilt angle. 186.4 azimuth angle. 1072875.52 Wh/m2	Accept
Bukit Kayu Hitam, SolarVest©, Malaysia	10-degree tilt. South (180)	7.3-degree tilt angle. 180 azimuth angles. 838748.7 Wh/m2	Accept
Scatec Itramas solar 65MW Gurun Solar Power Plant, Pendang, Kedah	10-degree tilt. South (180)	6.7-degree tilt 180 azimuth angles. 869669.16 Wh/m2	Accept
Scatec Itramas Solar 66 MW Merchang Solar Power Plant, Marang, Terrenganu	10-degree tilt. South (180)	1.0-degree tilt angle. 180 azimuth angles. 797983.63 Wh/m2	Reject
Scatec Itramas Solar 66MW Jasin Solar Power Plant, Bemban, Melaka	10-degree tilt. South (180)	2.4-degree tilt angle. 180 azimuth angles. 743376 Wh/m2	Reject

The purpose for the simulation to fix the tilt angle and surface azimuth of the solar panel according to the thesis paper in Padang Besar, Perak is to cross check the solar irradiation received. By fixing -10 tilt angle and 160 azimuth angles, the simulated total solar irradiation is 48.95 kWh/m2, whereas Padang Besar have range of solar irradiation 43.3 ~ 43.92 kwh/m2. The difference between simulated and actual parameter is ranging 5.03 ~ 5.65. Therefore, the simulated solar irradiation is accepted.

The solar irradiation in Padang Besar is lesser than the simulated value is due to external factors experienced by the solar panel, such as cloud and shadings that affect the solar received on the solar panel (Arun, 2016).

The case study in Ilorin, Nigeria, have a 22-degree facing south solar panel as the optimum settings. By comparison, the simulated results recommended a 28.4-degree tilt, 296.9 azimuth angle for a total maximum solar irradiation. The simulated results are rejected due to the simulation unable to obtain similar results, where the difference of tilt angle is a significant 22 degree. In addition, the simulated azimuth angle is facing Northwest, as compared to facing south of Ilorin.

For the case study in Bilecik Seyh Edebali University Engineering Faculty, Turkey, the author set up 6 solar panels into different tilt angle ranging from 10 degrees to 60 degrees with 10-degree intervals each. The author found out that within the duration of May to August 2014, the optimum tilt angle is 10 degrees throughout the months. Therefore, the optimum tilt angle of this case study can be considered as 10 degrees. By comparing with the simulated model, it is shown that the optimum tilt angle and azimuth angle are 24.9-degree tilt and 247.4 azimuth angle. However, the simulated results are rejected due to unable to simulate similar results, where the difference of tilt angle is 14.9 degree.

The case study in Aligarh City, India, the author determined that the optimum tilt angle with the average total solar irradiation per day are 27.62-degree tilt and 8.05 kWh/m2-day respectively. The simulated model determines that the optimum tilt angle with the average total solar irradiation per day are 29.3-degree tilt and 11.21 kWh/m2-day respectively. By comparison, the difference of tilt angle and solar irradiation are 1.68 degree and 3.16 kWh/m2-day respectively. Although the author did not specify the orientation of the solar panel, the simulated recommended that the azimuth angle should be 197.8 degree, where it is facing towards south. In addition, the tilt angle is similar to the latitude of the location, with is consider as the optimum tilt angle (Danny, 2007). Therefore, the simulated result is accepted.

The case study in New Dehli, India, with the optimum tilt angle with the average total solar irradiation per day are 27.95-degree tilt and 6.75 kwh/m2-day respectively. The simulated model estimates that the optimum tilt angle with the average total solar irradiation per day are 31.3-degree tilt and 11.13 kwh/m2-day respectively. By comparison, the difference of tilt angle and solar irradiation are 3.35 degree and 4.376 kWh/m2-day respectively. Although the author did not specify the orientation of the solar panel, the simulated recommended that the azimuth angle should be 199.8 degree, where it is facing towards south. Therefore, the simulated result is accepted.

For the case study in Chennai, India and Beijing, China, the author did not specify the year, date and duration of the case study, an assumption of a one-year duration is taken, which is 2019 to 2020 to fit in the project algorithm. As for Chennai, the thesis paper optimum tilt and azimuth angle are 0-36 degree and 180 to 225 degrees respectively. The simulated results recommended are 18.3 tilt and 206.7 azimuth angle. This simulated result is accepted as it fits the range of tilt angle and azimuth angle in Chennai. The description for the solar panel facing towards Southeast for the simulation is accepted due to more energy can be generated in the evening and more people are able to utilize (Laura, 2021).

The thesis paper optimum tilt and azimuth angle in Beijing, China are 0-54 degree and 180 to 225 degrees respectively. The simulated results recommended are 40.5 tilt and 186.4 azimuth angle. This simulated result is accepted as it fits the range of tilt angle and azimuth angle in Beijing. In addition, Maryon (2021), also recommended that the solar panel should be facing south, if the solar panel is installed in the Northern Hemisphere.

Thus, based on the comparison between various case study and the simulated model, the accuracy of the model can be determined by the formula below:

$$Accuracy = \frac{Number\ of\ case\ study\ accepted}{Number\ of\ case\ study\ compared} * 100\%$$

$$= \frac{8}{12} * 100\% = 66.67\%.$$

Hence, this simulated model has an accuracy rate of 66.67% based on 12 samples with 8 samples acceptance results. This accuracy comparison is carried out is because to prove that this project is reliable and safe for future project purposes.

4.6.1 Comparison of GHI received with on-site results

In this section, the total maximum solar irradiation received in a year with be compared between the optimum tilt angle and azimuth angle of computational model and actual solar sites. According to the parameters provided by each solar sites company, the optimum tilt angle and azimuth angle for each solar sites are 10-degree tilt and 180 azimuth angles. Table 4.7 below shows the comparison for the total solar irradiation for each solar site. The formula for the differences is:

$$Differences = Total\ Solar\ Irradiation\ recieved\ with\ simulated\ parameters - Total\ Solar\ Irradiation\ received\ with\ provided\ parameters$$

$$Percentage\ DIfference = \frac{Differences}{Total\ solar\ irradaition\ received\ with\ provided\ parameters} * 100\%$$

Table 4.7: Percentage Difference between Simulation and Site Parameters

Solar site	Site Parameters	Simulation Parameters	Total solar irradiation received based on Site (Wh/m2)	Total solar irradiation received based on Simulation (Wh/m2)	Differences (Wh/m2)	Percentage Difference (%)
Bukit Kayu Hitam, SolarVest©, Malaysia	10-degree tilt. 180 azimuth angles.	7.3-degree tilt. 180 azimuth angles.	837788.099	838748.69	960.596	0.1147
Scatec Itramas solar 65MW	10-degree tilt.	6.7-degree tilt.	868190.47	869669.16	1,478.69	0.1703

Gurun Solar Power Plant, Pendang, Kedah	180 azimuth angles.	180 azimuth angles.				
Scatec Itramas Solar 66 MW Merchang Solar Power Plant, Marang, Terrenganu	10-degree tilt. 180 azimuth angles.	1.0-degree tilt angle. 180 azimuth angles.	788116.43	797983.63	9,867.21	1.252
Scatec Itramas Solar 66MW Jasin Solar Power Plant, Bemban, Melaka	10-degree tilt. 180 azimuth angles.	2.4-degree tilt angle. 180 azimuth angles.	736798.02	743376	6,577.97	0.893

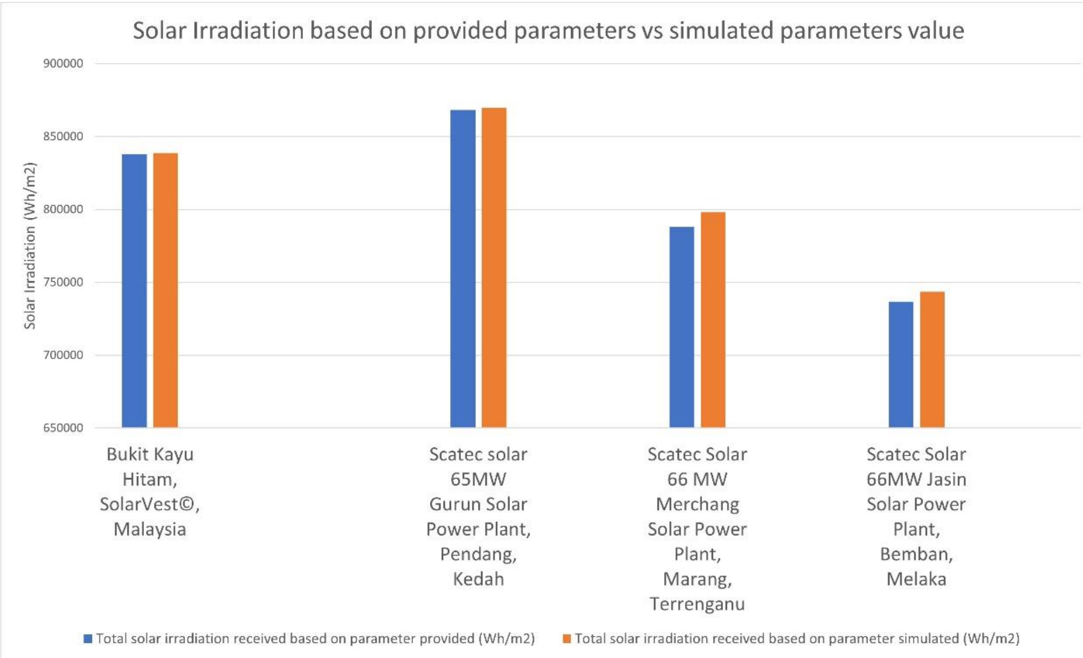


Figure 4.1: Percentage Difference between Simulation and On-site Parameters

Based on the tabulated results and graph, all the parameters for tilt angle and azimuth angle for all solar sites are standardized as 10 degree and 180 degrees respectively. For the solar site in Bukit Kayu Hitam, the optimum simulated angle is 7.3 degree and 180 degrees. By computing the solar irradiation received in a year, the differences are 960.6 Wh/m2, which is equivalent to 0.9 peak sun hours. The percentage difference is about 0.1147%. The solar site in Pendang, Kedah, the optimum simulated angle is 6.7 degree and 180 degrees, with the computational solar irradiation received are 1478.7 Wh/m2, which is equivalent to 1.4 peak sun hours. The percentage difference is approximately 0.17032%. As for the solar site in Marang, Terrenganu, the simulated degree is 1.0 tilt angle and 180 azimuth angles. The differences of the solar irradiation received is 9867.21 Wh/m2, which equals to 9.8 peak sun hours, with a approximated percentage difference of 1.252%. Lastly, the solar site in Bemban, Melaka have a simulated degree of 2.4 tilt and facing true south (180 degree). The solar irradiation differences between the simulated angle and provided angle are 6577.97 Wh/m2, where equals to 6.5 peak sun hours, with a percentage difference of 0.893%.

According to the results above, the percentage difference for all 4 solar sites with the comparison of solar irradiation in a year, the range of percentage difference obtained are between 0 and 2, which is lesser than 10%. Based on Anne (2022) and Dr. Zeinab (2021), stated that if the experiment percentage variance obtained is lesser than 10%, the experiment results is considered acceptable. Therefore, the results are acceptable.

4.7 Presence of Carbon Dioxide due to Deforestation

In this section, the selected 17 solar sites are chosen to undergo case study, with the objective to determine the annual average solar irradiation, ranking, optimum tilt angle, azimuth angle and total solar irradiation in a year. However, in order to develop a large solar farm, an area of forest is needed to be cleared out to fully utilize the potential of solar harvesting energy. In other words, the area of forest is being cut down, known as deforestation will emit carbon dioxide towards the surroundings. Therefore, Table 4.8

below shows each of the solar sites is with the estimated carbon dioxide emission annually, based on the equivalent formula in Chapter 2.

Table 4.8: Estimation Carbon Dioxide Presence

Solar Site Number	Solar Site and Coordinate	Area	Carbon Dioxide Presence due to deforestation (tCO_2/m^2)
1	Tanjung Batu Hybrid Solar Power Plant Sandakan, Sabah 5°48'01.8"N 118°09'29.2"E	$2043.99m^2$ 0.51 acres 0.20 hectares 22001.28 $feet^2$	0.068333015
2	Comtec Solar International (m) Sdn Bhd Kuching, Sarawak 1°31'10.6"N 110°23'50.0"E	7355.08 m^2 1.82 acres 0.74 hectares 79169.45 $feet^2$	0.070262512
3	Solar Power Plant Telok Melano, Sarawak Energy Berhad Lundu, Sarawak 2°00'16.6"N 109°38'42.5"E	612.96 m^2 0.15 acres 0.06 hectares 6597.82 $feet^2$	0.068359436
4	Bukit Kayu Hitam Solarvest 12MWp Bukit Kayu Hitam, Kedah 6°28'40.8"N 100°25'42.0"E	175301.82 m^2 43.32 acres 17.53 hectares 1886933.09 $feet^2$	0.069835274
5	Pokok Sena Solar PV plant Jitra, Kedah 6°10'51.3"N 100°28'21.0"E	238087.17 m^2 58.83 acres 23.81 hectares 2562749.03 $feet^2$	0.069839763

6	LSS PV 30MWac Kuala Muda Kedah Sungai Petani, Kedah 5°39'25.3"N 100°34'21.2"E	405248.59 m² 100.14 acres 40.52 hectares 4362059.55 feet²	0.069827626
7	Elsoft Research Berhad Bayan Lepas, Pulau Pinang 5°17'33.0"N 100°17'21.0"E	3089.49 m² 0.76 acres 0.31 hectares 33254.96 feet²	0.070073572
8	Taruc, Setapak Setapak, Wilayah Persekutuan Kuala Lumpur 3°13'00.8"N 101°43'58.8"E	119.63 m² 0.03 acres 0.01 hectares 1287.68 feet²	0.058376661
9	Utar, Bandar Sungai Long, KB block roof top Bandai Sungai Long, Selangor 3.0394° N, 101.7941° E	193.16 m² 0.05 acres 0.02 hectares 2079.10 feet²	0.072308966
10	Utar, Kampar Campus Kampar, Perak 4°20'27.1"N 101°08'40.9"E	304.09 m² 0.08 acres 0.03 hectares 3273.22 feet²	0.068896708
11	Scatec Itramas solar 65MW Gurun Solar Power Plant Pendang, Kedah 5°51'46.6"N 100°32'20.2"E	674400.75 m² 166.65 acres 67.44 hectares 7259189.24 feet²	0.069835922
12	Scatec Itramas Solar 66MW Jasin Solar Power Plant Bemban, Melaka 2°17'56.7"N 102°21'16.0"E	291212.29 m² 0.29 km² 71.96 acres 29.12 hectares	0.069833052

		3134583.01 feet²	
13	Scatec Itramas Solar 66 MW Merchang Solar Power Plant Marang, Terengganu 4°56'04.4"N 103°20'13.4"E	662380.10 m² 163.68 acres 66.24 hectares 7129800.03 feet²	0.069838098
14	Pekan Pahang Solar Farm Pekan, Pahang 3°19'24.9"N 103°25'20.9"E	458379.53 m² 113.27 acres 45.84 hectares 4933956.26 feet²	0.069839118
15	UITM Solar Park II (LSS2 Pasir Gudang) Masai, Johor 1°31'36.7"N 103°51'50.4"E	380982.34 m² 94.14 acres 38.10 hectares 4100859.80 feet²	0.069839237
16	Pasir Mas Solar Farm Pasir Mas, Kelantan 5°59'31.9"N 102°06'39.8"E	48307.22 m² 11.94 acres 4.83 hectares 519974.62 feet²	0.069825562
17	Kenyir Gunkul Solar Sdn Bhd Kuala Dungun, Terengganu 4°38'55.8"N 103°23'13.5"E	298248.64 m² 73.70 acres 29.82 hectares 3210321.64 feet²	0.06982461

4.8 Amount of Energy Generation in a Year

In this section, the amount of Energy generation in a year is being tabulated for the 17 solar sites. However, since that deforestation is able to emit carbon dioxide towards the environment, this calculation is needed to estimate how much carbon dioxide can be avoided if these solar panels are being installed, at the substitution of the land loss due to deforestation. In addition, the energy generation also depends on the local climate of the locations, the optimum tilt and azimuth angle. Therefore, Table 4.9 shows each of the solar sites with the estimated carbon dioxide avoided annually, based on the equivalent in Chapter 2. However, for this case study of energy generation in a year, the estimation will undergo based on the information provided by the solar sites company.

Table 4.9: Power Output from Solar Irradiation

Solar Site Number	Name and Coordinate	Total Maximum Solar Irradiaiton (Wh/m2)	Efficiency (%)	Power Output (kWh/m2)
1	Bukit Kayu Hitam Solarvest 12MWp 6°28'40.8"N 100°25'42.0"E	942217.92	16	150.75
2	Scatec Itramas solar 65MW Gurun Solar Power Plant 5°51'46.6"N 100°32'20.2"E	982932.94	17.6	173.00
3	Scatec Itramas Solar 66MW Jasin Solar Power Plant 2°17'56.7"N 102°21'16.0"E	819103.23	17.6	144.16
4	Scatec Itramas Solar 66 MW	920331.52	17.6	161.98

	Merchang Solar Power Plant 4°56'04.4"N 103°20'13.4"E			

4.9 Calculation of CO_2 avoidance

In this section, the Carbon Dioxide Avoidance and the net carbon dioxide between deforestation and solar panel installation for each solar site are tabulated. The formula for determining the CO_2 avoidance and Net CO_2 is shown in Chapter 2. Due to the power generation from solar panels, how much carbon dioxide is able to be avoided and by comparing with the carbon dioxide emission from deforestation, a net carbon dioxide is being calculated. If the Net carbon dioxide is negative, meaning that the carbon dioxide avoided is higher than carbon dioxide emission. In other words, the solar panel is able to avoid the additional carbon dioxide being emitted to the surroundings. The carbon dioxide avoidance is based on the power output of the solar panel and the local climate with the optimum tilt and azimuth angle to achieve maximum carbon dioxide avoidance. However, for this case study of CO_2 avoidance in a year, the estimation will undergo based on the information provided by the solar sites company.

Table 4.10: Carbon Dioxide Avoided.

Solar Site Number	Name and Coordinate	Power Output (kWh/m2)	Carbon Avoidance Factor (tCO2/MWh)	Carbon Dioxide Avoided (tCO2/m2)
1	Bukit Kayu Hitam Solarvest 12MWp 6°28'40.8"N 100°25'42.0"E	150.75	0.639	0.096

2	Scatec Itramas solar 65MW Gurun Solar Power Plant 5°51'46.6"N 100°32'20.2"E	173.00	0.639	0.11
3	Scatec Itramas Solar 66MW Jasin Solar Power Plant 2°17'56.7"N 102°21'16.0"E	144.16	0.639	0.092
4	Scatec Itramas Solar 66 MW Merchang Solar Power Plant 4°56'04.4"N 103°20'13.4"E	161.98	0.639	0.104

Once the carbon dioxide emission due to deforestation and carbon dioxide avoidance due to solar panel installation is obtained annually for each solar sites, the net carbon dioxide can be computed as shown in Table 4.11. The net carbon dioxide formula is:

$$Net\ carbon\ dioxide = Estimated\ carbon\ dioxide\ emission - Carbon\ dioxide\ avoided$$

Table 4.11: Net Carbon Dioxide for Each Solar Sites.

Solar Site Number	Solar Site	Estimated Carbon Dioxide Presence (tCO_2/m^2)	Carbon Dioxide Avoided (tCO_2/m^2)	Net Carbon Dioxide (tCO_2/m^2)
1	Tanjung Batu Hybrid Solar Power Plant	0.068333015	-	-
2	Comtec Solar International (m) Sdn Bhd	0.070262512	-	-
3	Solar Power Plant Telok Melano, Sarawak Energy Berhad	0.068359436	-	-
4	Bukit Kayu Hitam Solarvest 12MWp	0.069835274	0.096	-0.026
5	Pokok Sena Solar PV plant	0.069839763	-	-
6	LSS PV 30MWac Kuala Muda Kedah	0.069827626	-	-
7	Elsoft Research Berhad	0.070073572	-	-
8	Taruc, Setapak	0.058376661	-	-
9	Utar, Bandar Sungai Long, KB block roof top	0.072308966	-	-
10	Utar, Kampar Campus	0.068896708	-	-
11	Scatec Itramas solar 65MW Gurun Solar Power Plant	0.069835922	0.11	-0.041

12	Scatec Itramas Solar 66MW Jasin Solar Power Plant	0.069833052	0.092	-0.022
13	Scatec Itramas Solar 66 MW Merchang Solar Power Plant	0.069838098	0.104	-0.033
14	Pekan Pahang Solar Farm	0.069839118	-	-
15	UITM Solar Park II (LSS2 Pasir Gudang)	0.069839237	-	-
16	Pasir Mas Solar Farm	0.069825562	-	-
17	Kenyir Gunkul Solar Sdn Bhd	0.06982461	-	-

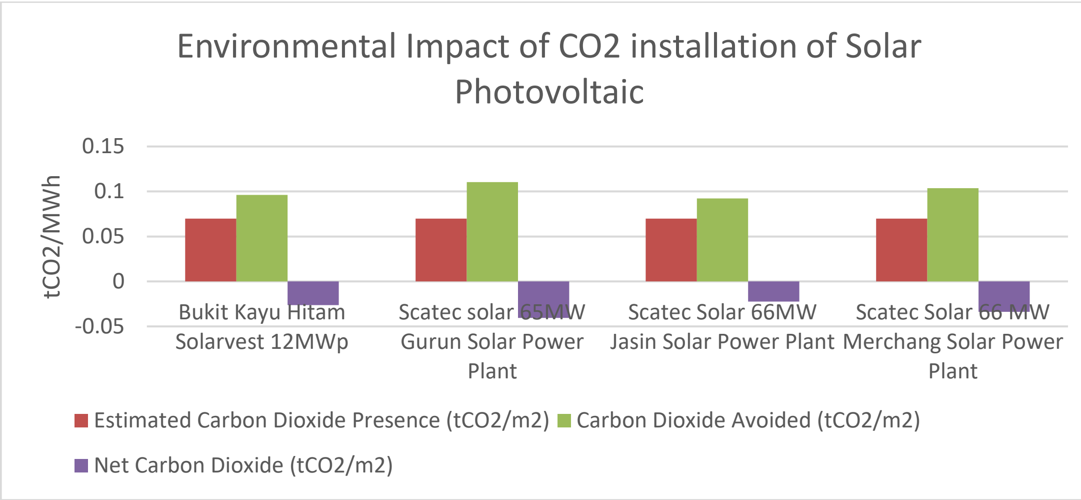


Figure 4.2: Environmental Impact of Installation of Solar PV.

According to the computation of the net carbon dioxide, the solar sites with parameters provided have the similar value between carbon dioxide emission and carbon dioxide reduction, which results in a negative net carbon dioxide in a year. If one of the solar sites estimated a positive net carbon dioxide in a year shows that the carbon dioxide avoided per meter square in a year are unable to cover up the carbon dioxide emission per meter square in a year due to deforestation. One of the reasons that affect the net carbon dioxide is due to the local climate of the solar sites, where the lower the solar irradiation, the lower the power output. Another reason is the efficiency of the solar panel used. The higher the efficiency of the solar panel, the higher the power conversion from solar to electrical, therefore increases the carbon dioxide avoidance in a year. As a result, reduce the net carbon dioxide per meter square in a year.

4.10 Economic Impact

To calculate the economic impact in installation of solar farms, the formula given in Chapter 2, with the interest rate 1.75%, and inflation rate of 2.23%:

$$n_{pay} = -\frac{In[1 - S_{total} i'/P_{ann}]}{In(1 + i')}$$

Where $i' = \frac{1+i}{1+j} - 1$, $i = 0.0175$ $j = 0.0223,$ $i' = -0.0054$

Therefore, the economic cost and payback period for the four solar sites is estimated to be:

Table 4.12(a): Annual Income Calculation for Each Solar Sites

Solar site	Energy Output (kwh/m2)	Size of a solar module used (m2)	Number of Pieces	Total area of solar panel (m2)	Total Energy Output (kwh)	Total Income (RM) Tariff = RM0.395/kwh
Bukit Kayu Hitam, Kedah	150.75	1.2 x 0.6	105000	75600	11397067.92	4,501,841.83
Pendang, Kedah	173.00	1.978 x 0.992	189510	371851.97376	64328977.61	25,409,946.16
Bemban, Melaka	144.16	1.978 x 0.992	191130	375030.69888	54065238.82	21,355,769.34
Marang, Terengganu	161.98	1.978 x 0.992	192420	377561.90592	61156853.38	24,156,957.086

Table 4.12(b): Total Capacity for Each Solar Sites

Solar site	Rated power solar panel used (W)	Number of Pieces	Total rated power solar panel (W)
Bukit Kayu Hitam, Kedah	115	105000	12,075,000
Pendang, Kedah	345	189510	65,380,950

Bemban, Melaka	345	191130	65,939,850
Marang, Terengganu	345	192420	66,384,900

Table 4.12(c): Investment Cost for Each Solar Sites

Bukit Kayu Hitam, Kedah:

Parameters	Model value (RM/W)	Watt (W)	Total value (RM)
Module	1.65	12,075,000	19,923,750
Inverter	0.33	12,075,000	3,984,750
Structural material			
Miscellaneous (electrical cables, etc.)	0.72	12,075,000	8,694,000
Planning			
Installation work	2.91	12,075,000	35,138,250
Shipping and travel			
Permits and direct labour			
Project margin			
Total without Tax			67,740,750
Sales & Services Tax (SST)	6%		4,064,445
Total	5.9466		71,805,195

Pendang, Kedah

Parameters	Model value (RM/W)	Watt (W)	Total value (RM)
Module	1.65	65380950	107,878,567.5
Inverter	0.33	65380950	21,575,713.5
Structural material			
Miscellaneous (electrical cables, etc.)	0.72	65380950	47,074,284
Planning			
Installation work	2.91	65380950	190,258,564.5
Shipping and travel			
Permits and direct labour			
Project margin			
Total without Tax			366,787,129.5
Sales & Services Tax (SST)	6%		22,007,227.77
Total	5.9466		388,794,357.27

<u>Bemban, Melaka</u>

Parameters	Model value (RM/W)	Watt (W)	Total value (RM)
Module	1.65	65939850	108,800,752.5
Inverter	0.33	65939850	21,760,150.5
Structural material		65939850	
Miscellaneous (electrical cables, etc.)	0.72	65939850	47,476,692
Planning			
Installation work	2.91	65939850	191,884,963.5
Shipping and travel			
Permits and direct labour			
Project margin			
Total without Tax			369,922,558.5
Sales & Services Tax (SST)	6%		22,195,353.51
Total	5.9466		392,117,912.01

<u>Marang, Terengganu</u>

Parameters	Model value (RM/W)	Watt (W)	Total value (RM)
Module	1.65	66384900	109,535,085
Inverter	0.33	66384900	21,907,017
Structural material			
Miscellaneous (electrical cables, etc.)	0.72	66384900	47,797,128
Planning			
Installation work	2.91	66384900	193,180,059
Shipping and travel			
Permits and direct labour			
Project margin			
Total without Tax			372,419,289
Sales & Services Tax (SST)	6%		22,345,157.34
Total	5.9466		394,764,446.34

Table 4.12(d): Payback Period Estimated

Solar site	Investment cost	Annual Income	Real Interest Rate, i’	Payback formula	Estimated Payback period
Bukit Kayu Hitam, Kedah	71,805,195	4,501,841.83	-0.0054	$-\frac{In[1-S_{total}i'/P_{ann}]}{In(1+i')}$	15.26
Pendang, Kedah	388,794,357.27	25,409,946.16	-0.0054	$-\frac{In[1-S_{total}i'/P_{ann}]}{In(1+i')}$	14.66
Bemban, Melaka	392,117,912.01	21,355,769.34	-0.0054	$-\frac{In[1-S_{total}i'/P_{ann}]}{In(1+i')}$	17.46
Marang, Terengganu	394,764,446.34	24,156,957.09	-0.0054	$-\frac{In[1-S_{total}i'/P_{ann}]}{In(1+i')}$	15.62

After all the total investment cost, annual income is calculated, the payback period is estimated for all 4 solar sites. According to the payback period table, the earliest payback period is Pendang, Kedah, with the period of 14.66 years, followed by Bukit Kayu Hitam, with the period of 15.26 years. Next, the payback period in Marang, Terengganu is 15.62 years. Lastly, the payback period in Bemban, Melaka is 17.46 years. Hence, the payback period is successfully being estimated. Figure 4.3 below shows the graph for the summary of payback period for 4 solar sites.

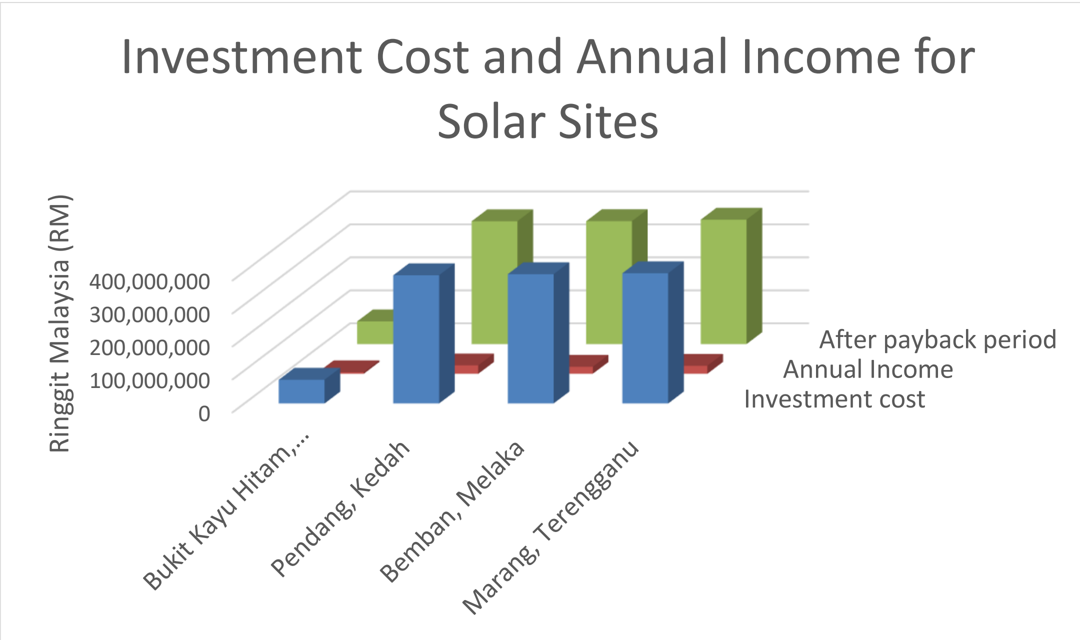


Figure 4.3: Investment Cost, Annual Income, Payback Period

There are a few main reasons regarding the payback period that can be observed:

1. Pendang, Kedah have the earliest payback period, this is due to having the highest annual income among the other solar sites. The high annual income is associated to the solar irradiation received in a year and the income rates (RM/kwh), which will affect the annual income.
2. Bemban, Melaka have the latest payback period, due to having the highest investment cost among the other solar sites. As compare with the other 3 solar sites, the solar irradiation received in a year is the lowest. The high investment cost is associated with the number of panels, whereas the annual income is associated with the solar irradiation received in a year.

3. The efficiency of the solar panel used affected both electricity generated and the annual income. As the higher the efficiency of the solar panel, the more electricity is generated, hence, annual income increases, while reducing the duration of payback period.

4.10.1 Special Case Study on Interest Rate

In this section, assume that a higher interest rate is impose for the payback period value, which is about 6%, while maintaining the inflation rate of 2.3%. By substituting into the payback period formula:

$$n_{pay} = -\frac{In[1 - S_{total}i'/P_{ann}]}{In(1+i')}$$

Where $i' = \frac{1+i}{1+j} - 1$, $i = 0.06, j = 0.023$, $i' = 0.036$, which is a positive real interest rate.

Therefore, by comparing the low interest rate and high interest rate, the payback period for the 4 solar sites is shown in Table 4.13.

Table 4.13: Effect of Interest Rate on Payback Period.

Solar site	Investment cost	Annual Income	Low Real Interest Rate, i'	Estimated Payback period (Low)	High Real Interest Rate, i'	Estimated Payback Period (High)
Bukit Kayu Hitam, Kedah	71,805,195	4,501,841.83	-0.0054	15.26	0.036	24.14
Pendang, Kedah	388,794,357.27	25,409,946.16	-0.0054	14.66	0.036	22.63
Bemban, Melaka	392,117,912.01	21,355,769.34	-0.0054	17.46	0.036	30.59
Marang, Terengganu	394,764,446.34	24,156,957.09	-0.0054	15.62	0.036	25.09

Based on the comparison between high interest rate and low interest rate of a country, it will affect the payback period of the solar farm invested. According to Chris (2021), mentioned that as the interest rate increases, each individual will reduce the usage of currency, therefore, stock price drops. However, as the interest rate decreases, the individual will increase their spending, business and stock therefore increases. Hence, the one of the limitations of the solar farm is that the payback period is related to the country's economy.

In summary, in order to effectively installed and build a solar farm, while having a low payback period, the main parameters that needed to take account is the solar irradiation received at the particular location. This is to increase the total annual income and energy produced, while able to maintain operation for many years. In addition, given that the tariff rate is low, the efficiency of the solar panel used is also important, as the higher the efficiency, the higher the electricity generated, therefore, generate higher income.

4.11 Summary

In summary, Section 4 shows the various results by applying the formula in CHAPTER 2 and methodology in CHAPTER 3. There are 17 solar sites that undergoes the simulation of the optimum tilt angle. The various research paper review in CHAPTER 2, the results of the research paper will be used to compare with the simulated results obtained from the python modelling in order to prove that the simulation model is reliable. Hence, the accuracy obtained from the simulation results is about 66.67%, which is acceptable. In addition, the 4 solar sites result obtained from case study is also compared with the simulated results. The percentage error difference obtained are within the range of between 0 and 2. Hence, it is acceptable. Besides, the carbon dioxide presence, carbon dioxide reduction and net carbon dioxide are also being simulated in this model. Overall, the net carbon dioxide for all solar sites is negative, meaning that it is a positive remark, where the installed solar farm is able to reduce the amount of carbon dioxide in the surroundings. Due to lack of information in other solar sites, only 4 solar sites will be used to model and estimated the payback period. The payback period of a solar farm has a relationship with the economy of the country. Hence, the payback period is successfully estimated and simulated.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This project is aimed to simulate and model the optimum tilt angle of a location automatically using computer. This project was developed using python, a software that enables to compute the suitable optimum tilt angle of a location. There are 4 main steps that were involved in this project, which are the manually download the metrological data from Solcast ©, Determine the optimum tilt angle based on the data, Estimate the carbon dioxide reduction for installation of solar farm and the estimation of payback period of the solar farm. When the metrological data is downloaded, the python program is able to capture the data and perform analysis. During the analysis, with the suitable formula and modelling, the optimum tilt angle was estimated, by simulation of a solar panel from 0 to 90 degrees elevation angle and 0 to 360 degrees orientation of a solar panel. This optimum tilt angle is to obtain the maximum solar irradiation in a year. In this section, the simulated results will be used to compare with other various researcher results, and hence, the obtained accuracy of the modelling is about 66.67%. In addition, with the given parameters, the percentage error obtained were ranging between 0 to 2%. Next, the carbon dioxide reduction of the location is performed and estimated with python programming. All the selected solar farm is able to reduce the carbon dioxide level. Last, the economic impact and payback period of the solar farm is estimated. In conclusion, the aim and objectives of this project have been achieved. This programming for the optimum tilt angle has a limitation, which is time consuming, as it may take minimum one hour to simulate a one-year metrological data. In summary, the overall accuracy for the optimum tilt angle is about 66.67%. Hence, the proposed system with reasonably accuracy works well.

5.2 Recommendations for future work

The first problem encounter in this project is the accuracy of the simulation carbon dioxide reduction and economic impact. Although the optimum tilt angle in this project achieves a reasonable accuracy of 66.67%, the accuracy of the estimated carbon dioxide reduction and the economic impact do not have any reference to be compared. Hence, the results in this simulation are based on estimation. The solution for the first problem is to engage in a meeting with the renowned Solar Photovoltaic company in order to enclose the information for reference purposes.

The next problem encounter in this project is the running simulation for determine the optimum tilt angle. The minimum running time for a one-year simulation is about 1 hour, maximum is about 3 hours. The solution of the problem is to further enhance the looping system of the programming in order to reduce the simulation running time and further increase the capacity of the year of metrological data.

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APPENDICES

APPENDIX A: Python Programming Part 1: Read and Input File into Python

```
# -*- coding: utf-8 -*-
"""
Created on Fri Jan 21 22:03:10 2022

@author: Edbert
"""

import pandas as pd
from datetime import datetime
from datetime import timedelta
from mpl_toolkits import mplot3d
import numpy as np
import matplotlib.pyplot as plt
from IPython import get_ipython
import math as m
import pytz
import csv
from datetime import datetime
start=datetime.now()
print(start)

'-----------------------------------------------------------------------------'

filepath = r'C:\Users\Edbert\Desktop\MEEK25110 PROJECT\Project Report 1\Yearly Solar Irradiance Data\\'
filename = '5.862950268444186_100.53893544057493_Solcast_PT60M.csv'


df = pd.read_csv(filepath+filename)


'-----------------------------------------------------------------------------'
```

APPENDIX B: Python Programming Part 2: Reconfigure the Datetime of the Input File into Malaysia Timing

```
'-----------------------------------------------------------------------------'


# Start handling the date/time
# Dataframe 6 is the Period End in UTC timing
df2 = (pd.to_datetime(df['PeriodStart']).dt.tz_localize(None)) + timedelta(hours = 8)

#Dataframe 7 is the Period Start in UTC timing
df3 = (pd.to_datetime(df['PeriodEnd']).dt.tz_localize(None)) + timedelta(hours = 8)



#find the midpoint between two dates for easy plotting of graph
# midpoint date = periodstart + (periodend - periodstart)/2
df4 = df2 + (df3 - df2)/2
'-----------------------------------------------------------------------------'

#create a dataframe of df11 for the sun position purpose
df5 = pd.DataFrame()

df5['Middle_datetime'] = df4

'-----------------------------------------------------------------------------'
```

APPENDIX C: Python Programming Part 3: Determine the Number of Days, Angle X and Equation of Time

```
'--------------------------------------------------------------------------------'

#find the day number, n, using middle_datetime
df5['n'] = df4.dt.dayofyear
# print(df11['n'])

#find the angle x of the day number n, the x is in degree form
df5['x'] = ((360*(df5['n']-1))/365.242)*(m.pi/180)
# print(df11['x_d'])


#find the equation of time EOT, the EOT is in minutes
df5['eot'] = (0.258*np.cos(df5['x']) - 7.416*np.sin(df5['x']) - 3.648*np.cos(2*df5['x']) - 9.228*np.sin(2*df5['x']))/60


#convert the EOT hours to timedelta
df5['eot'] = pd.to_timedelta(df5['eot'], unit='h')

'--------------------------------------------------------------------------------'
```

APPENDIX D: Python Programming Part 4: Determine the Solar Time

```
'-------------------------------------------------------------------------------'

#standard longitude of a location (EW) (E negative) (W positive) (malaysia = UTC + 8)
Lst = 8*15
LstEW = 'E'

if LstEW == 'E':
    Lst = Lst*(1)
elif LstEW == 'W':
    Lst = Lst*(-1)

#actual longitude of a location (EW) (E negative) (W positive)
#get the longitude angle from filename
Loc = float(filename.split('_')[1])
LocEW = 'E'

if LocEW == 'E':
    Loc = Loc*(1)
elif LocEW == 'W':
    Loc = Loc*(-1)

#solar datetime is the date and time of the solar time
df5['solar_datetime'] = df4 + df5['eot'] - timedelta(hours = (Loc - Lst)/15)
# print(df11)
'-------------------------------------------------------------------------------'
```

APPENDIX E: Python Programming Part 5: Determine the Sun Position

```
'-------------------------------------------------------------------------------'

#Latitude angle of a location (NS)
#get the latitude angle from the filename
Lat = float(filename.split('_')[0])
LatNS = 'N'

if LatNS == 'N':
    Lat = Lat*(1)
elif LatNS == 'S':
    Lat = Lat*(-1)

#declination angle in degree
df5['decline_angle'] = np.arcsin(0.39795*np.cos(0.98563*(df5['n'] - 173)*(m.pi/180)))*(180/m.pi)


df5['hour_angle'] = 15*((df5.solar_datetime.dt.hour + df5.solar_datetime.dt.minute/60 + df5.solar_datetime.dt.second/3600)-12)

'-------------------------------------------------------------------------------'
#find the solar altitude angle, in degree
#a = sin^-1(sin(d_a)*sin(lat)+cos(d_a)*cos(w)*cos(Lat))
df5['altitude_angle'] = np.arcsin(np.sin(df5['decline_angle']*(m.pi/180))
            *np.sin(Lat*(m.pi/180))
                + np.cos(df5['decline_angle']*(m.pi/180))
                    *np.cos(df5['hour_angle']*(m.pi/180))
                        *np.cos(Lat*(m.pi/180)))*(180/m.pi)

df5['altitude_angle'].values[df5['altitude_angle'].values < 0] = 0.0

#find the solar zenith angle, in degree
df5['zenith_angle'] = 90 - df5['altitude_angle']


#find tbe solar azimuth angle
df5['cosA'] = (np.sin(df5['decline_angle']*(m.pi/180))*np.cos(Lat*(m.pi/180))
-
np.cos(df5['decline_angle']*(m.pi/180))*np.cos(df5['hour_angle']*(m.pi/180))*np.sin(Lat*(m.pi/180)))/(np.cos(df5['altitude_angle']*(m.pi/180)))
```

```
#if cosA > 0, do this calculation
df5.loc[df5['cosA'] > 0, 'Azimuth'] = np.arcsin((-np.cos(df5['decline_angle']*(m.pi/180))
                                      *np.sin(df5['hour_angle']*(m.pi/180)))
                                     /(np.cos(df5['altitude_angle']*(m.pi/180))))*(180/m.pi)

#if cosA < 0, do this calculation
df5.loc[df5['cosA'] < 0, 'Azimuth'] = 180 - np.arcsin((-np.cos(df5['decline_angle']*(m.pi/180))
                                      *np.sin(df5['hour_angle']*(m.pi/180)))
                                     /(np.cos(df5['altitude_angle']*(m.pi/180))))*(180/m.pi)



'------------------------------------------------------------------------------'
```

APPENDIX F: Python Programming Part 6: Determine the Optimum Tilt and Orientation of Solar Panel for Total Maximum Solar Received for a year

```
'-------------------------------------------------------------------------------'


df5['Dni'] = df['Dni']
df5[‘Dhi’] = df[‘Dhi’]
beta1 = float(input("Input the minimum value of elevation angle:") or 0)
beta2 = float(input("Input the maximum value of elevation angle:") or 90)
beta = np.arange(beta1, beta2, 0.1).round(1)
# beta = np.arange(10, 70, 10)
# sa = np.arange(180, 181.1, 0.1).round(1)
print("Orientation angle:\n1. North (0)\t2. East (90)\t3. South (180)\t4. West (270)")
sa1 = float(input("Input the minimum value of orientation angle:"))
sa2 = float(input("Input the maximum value of orientation angle:"))
sa = np.arange(sa1, sa2, 0.1).round(1)
# print(beta)
# print(sa)

df20 = pd.DataFrame(index = sa, columns=(beta))
print(df20)



def generate_items(za, az, dni, df20, dhi):
    rd = m.pi/180
    for b in beta:
        for s in sa:

            cosiafc = np.cos((za)*(rd))*np.cos((b)*(rd)) + np.sin((za)*(rd))*np.sin((b)*(rd))*np.cos(((az)-(s))*(rd))

            solar_received = dni*cosiafc

            total_solar_received = solar_received + dhi

            df20[b][s] = total_solar_received.sum()


    return df20



df20 = generate_items(df5['zenith_angle'], df5['Azimuth'], df5['Dni'], df20, df5[‘Dhi’])
print(df20)
# print(d)
```

```
df20.to_csv(str(Lat) + str(Loc) + '_tilt_and_surface.csv')

maxvalue = max(df20.max())

op_tilt = df20[df20 == max(df20.max())].dropna(axis=1, how='all').columns.tolist()

op_sa = df20[df20[op_tilt[0]] == maxvalue].index.values


print (filename)
print("The optimum tilt angle and azimuth angle for the solar panel to obtained the highest total solar received (a year) is:")
print(op_tilt[0], "degree tilt angle.")
print(op_sa[0], "azimuth angle of solar panel.")

print("The maximum total solar received on the solar panel in a year is: ")
print(maxvalue, "Wh/m2")
```

APPENDIX G: Python Programming Part 7: Model the optimum tilt angle in 3D Graph

```
def plottable_3d_info(df: pd.DataFrame):
    """
    Transform Pandas data into a format that's compatible with
    Matplotlib's surface and wireframe plotting.
    """
    index = df.index
    columns = df.columns

    x, y = np.meshgrid(beta, sa)
    z = np.array([[df[c][i] for c in columns] for i in index])

    # xticks = dict(ticks=np.arange(0, len(columns)/10, 5), labels=np.arange(0, len(columns)/10, 5))
    # yticks = dict(ticks=np.arange(0, len(index)/10, 10), labels=np.arange(0, len(columns)/10, 10))

    # return x, y, z, xticks, yticks
    return x, y, z

get_ipython().run_line_magic('matplotlib', 'qt')

### Transform to Matplotlib friendly format.
# x, y, z, xticks, yticks = plottable_3d_info(df20)
x, y, z = plottable_3d_info(df20)

from mpl_toolkits.mplot3d import proj3d

'-------------------------------------------------------------------------------'

fig4 = plt.figure()
axes4 = fig4.gca(projection='3d')


axes4.scatter3D(x, y, z, cmap = "hot", c = z)

axes4.set_title("Total Maximum Solar Irradiation achieved a year (Wh/m2) for each elevation and azimuth of solar panel")
axes4.set_xlabel('Elevation ')
axes4.set_ylabel('Azimuth')
```

```
axes4.set_zlabel('Total Maximum Solar \nIrradiation a year (Wh/m2)')

x2, y2, _ = proj3d.proj_transform(op_tilt[0],op_sa[0],maxvalue, axes4.get_proj())
annotate_s = 'Maximum Point ='
annotate_s += "\n"
annotate_s += r'%.1f, %.1f, %f' %(op_tilt[0], op_sa[0], maxvalue)
label = plt.annotate(
    annotate_s,
    xy = (x2, y2), xytext = (-20, 20),
    textcoords = 'offset points', ha = 'right', va = 'bottom',
    bbox = dict(boxstyle = 'round,pad=0.5', fc = 'yellow', alpha = 0.5),
    arrowprops = dict(arrowstyle = '->', connectionstyle = 'arc3,rad=0'))


from matplotlib.ticker import LinearLocator
axes4.get_xaxis().set_major_locator(LinearLocator(numticks=10))
axes4.get_yaxis().set_major_locator(LinearLocator(numticks=10))


fig4.set_size_inches(18.5, 10.5)
fig4.savefig(filename + '3d.jpg',facecolor='w')

def update_position(e):
    x2, y2, _ = proj3d.proj_transform(op_tilt[0],op_sa[0],maxvalue, axes4.get_proj())
    label.xy = x2,y2
    label.update_positions(fig4.canvas.renderer)
    fig4.canvas.draw()


fig4.canvas.mpl_connect('button_release_event', update_position)



'--------------------------------------------------------------------------------'
```

APPENDIX H: Python Programming Part 8: Estimate the Environmental Impact of the Simulation

```
'-------------------------------------------------------------------------------'
'''General Information of solar farm'''
efficiency = 16/100 #%
solar_size = 1.2*0.6 #m2 per solar panel
rated_solar_panel = 115 #w
n_solar_panel = 105000
Total_capacity = (rated_solar_panel)*(n_solar_panel) #w
Total_solar_size = n_solar_panel*solar_size #m2
Energy_output = (efficiency * maxvalue)/1000 #kwh/m2
print("The energy output with the given efficiency, number of panel and watts is:",Energy_output, "kwh/m2")




'''Presence of Carbon Dioxide'''
Land = float(input("Please enter your estimated land remove for solar farm installation.\nArea(ha):"))

co2perha = 698.36 #CO2/ha
CO2_increase = (Land*co2perha)/(Land*10000) #tCO2/m2
print("The presence of CO2 in surroundings due to deforestation is:", round(CO2_increase,6) , "tCO2/m2")



'''CO2 avoidance factor'''
location = str(input("Please enter your location of case study:\n1.Peninsular\n2.Sabah, Wilayah Persekutuan, Labuan\n3.Sarawak\nLocation:"))

if location == '1':
    CO2_avoid_factor = 0.639
elif location == '2':
    CO2_avoid_factor = 0.512
elif location == '3':
    CO2_avoid_factor = 0.364
else:
    print("Default value fixed at location 1")
    CO2_avoid_factor = 0.639

Avoided_CO2 = (Energy_output/1000)* CO2_avoid_factor
print("\nThe CO2 avoidance factor in this location is:", CO2_avoid_factor, "tCO2/MWh")
print('Avoided CO2 in tCO2/m2 is:', round(Avoided_CO2, 6), 'tCO2/m2')
```

```
'''Net Carbon DI=ioxide'''
Net_CO2 = round(CO2_increase,6) - round(Avoided_CO2, 6)
print("The net carbon dioxide is:", Net_CO2, "tCO2/m2")
if Net_CO2 < 0:
    print("Remarks: Positive Effect!\nMeans that CO2 avoidance is higher!")
elif Net_CO2 > 0:
    print("Remarks: Negative Effect!\nMeans that CO2 avoidance is lower!")
```

APPENDIX I: Python Programming Part 9: Estimate the Economic Impact of the Simulation

```
'-------------------------------------------------------------------------------'
'''Calculate the annual income'''
tariff_rate = 0.395 #(RM/kwh)
Total_income = Energy_output*Total_solar_size*tariff_rate
print("The annual income generated by the solar farm is: RM", Total_income)



'''Calculate the investment cost'''

module_price = 1.65
inverter_price = 0.33
misc_price = 0.72
install_work = 2.91
sales_tax = 6/100
Investment = Total_capacity*(module_price+inverter_price+misc_price+install_work)
Total_invest = (Investment*sales_tax) + Investment
print("\nThe total investment cost of the solar farm is: RM", Total_invest)



'''Calculate the payback period'''
interest_rate1 = 1.75/100
inflation_rate1 = 2.3/100
Real_interest1 = ((1+interest_rate1)/(1+inflation_rate1))-1
payback_p1 = (m.log(1-((Total_invest*Real_interest1)/(Total_income)))/m.log(1+Real_interest1))*-1

print("\nLow Interest Rate Case:\nThe interest rate:{}\t\tThe inflation rate:{}".format(interest_rate1,
inflation_rate1))

print("The estimated payback period of the solar farm is: ", round(payback_p1, 2), "years")



'''Calculate the payback period another case'''
print("\nHigh Interest Rate Case:")
interest_rate2 = 6/100
inflation_rate2 = 2.3/100
Real_interest2 = ((1+interest_rate2)/(1+inflation_rate2))-1
payback_p2 = (m.log(1-((Total_invest*Real_interest2)/(Total_income)))/m.log(1+Real_interest2))*-1

print("The interest rate:{}\t\tThe inflation rate:{}".format(interest_rate2, inflation_rate2))
```

```
print("The estimated payback period of the solar farm is: ", round(payback_p2, 2), "years")
```