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Correlations of System Degradation, Losses and Significant Parameters for 49 MW Large Scale Solar Plant with Real Site Data Validations

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ABSTRACT: A smooth transition towards a clean and sustainable environment will heavily rely on the continuous increase of renewable energy (RE) integration. Malaysian authorities have set targets to increase the RE capacity to 31% by the end of 2025 and achieve 40% by 2035, specifically through the power generation plan. Solar PV systems have been widely used, from industries to residential homes, because Malaysia receives a high irradiation potential of up to 5000 Wh/year. The increase in the potential of solar PV usage has allowed solar companies to provide this system regardless of its complexity and system size. However, a drop in efficiency due to system parameters within the photovoltaic (PV) system is evident over time. This study aims to analyze the relationship between solar PV system parameters and their energy performance, particularly in a tropical climate region, for a large-scale solar (LSS) plant. This project was undertaken with two objectives: First, it is to develop an optimum solar PV system by adhering to and implementing GCPV standards in Malaysia. Stage 1 will primarily focus on managing and manipulating various PV system parameters to ensure the optimum energy yield received from the plant. The system parameters analyzed are tilt angle, module technology and its effect on different temperatures, the effect of the optimizer, sizing and thermal loss. Stage 2 will then incorporate the industry data of the LSS plant by creating a Pearson's Correlation model on how energy yield is correlated against real time system parameter values obtained. An optimum tilt angle of 10°, monocrystalline module and inclusion of optimizer increases the overall energy production from 88,986 MWh/year to 89,782 MWh/year and performance ratio (PR) from 78.9% to 79.8%. The outcome of this study demonstrates the significant parameters of the PV system to maximize the energy output to the grid. This will further support the government's plan to reduce GHG emissions by 45% through the use of renewable energy, with the aim of producing up to 2.5 GW from LSS systems by 2030.

Keywords: Performance ratio; Correlation; Optimizer; Pearson; Temperature

1. Introduction

The International Renewable Energy Agency (IRENA) indicates that the global installed capacity of solar PV was 480.3 GW in 2018 and is expected to reach approximately 969 GW by 2025. Malaysia, one of the countries with a high population has become a beacon of energy usage regardless of the social or industrial activities as electricity is vital in an ever-increasing development country. At this very moment, energy use via fossil fuels has been the primary source of electricity, including coal, natural gas, and oil [1]. Research and studies have shown that electricity consumption has increased nearly threefold, and by 2050, it is expected to reach 73,000 TWh [2]. However, fossil fuel conversion into electricity tends to release significant greenhouse gas (GHG) emissions, affecting the planet's ecosystem. Renewable energy sources such as wind, hydro, solar, and biomass are setting a benchmark for providing clean and sustainable energy for the future, which will, in turn, reduce the impact on the environment [3]. Solar energy can be viewed as one of the renewable sources heavily utilized due to unlimited sources and is available for free. In terms of the business point of view, the development of solar panels that have improved cell efficiency induced lower production costs for PV panels, making them accessible from usage in power plants up to residential areas. The International Renewable

Energy Agency (IRENA) states that the global installed capacity of solar PV was 480.3 GW in 2018 and is expected to reach approximately 969 GW by 2025 [4].

Malaysia has been one of the leading countries implementing the usage of solar PV capacity drastically. This is one of the main and most important renewable sources that is fast growing as this country receives high irradiation rates ranging from 4.21 kWh/m^2 to 5.56 kWh/m^2 [5]. Solar PV system is designed to capture solar irradiation and convert it into electricity for various types of usage. PV systems can be vital compared to integration with the power grid and massive technological developments [6]. Solar to electricity generation from PV systems will generate up to 30% efficiency. Design of the PV system should be in an optimum condition to avoid an undesired drop in efficiency, which can affect the lifetime of the system. Throughout the lifetime of a PV system, efficiency will tend to drop primarily due to either environmental parameters affecting the system or the system design fault within. System parameters play a crucial role in energy losses, and identifying and correcting these components can increase the system's maximum energy output [7]. Figure 1 illustrates the total RE capacity of Malaysia in the past 10 years.

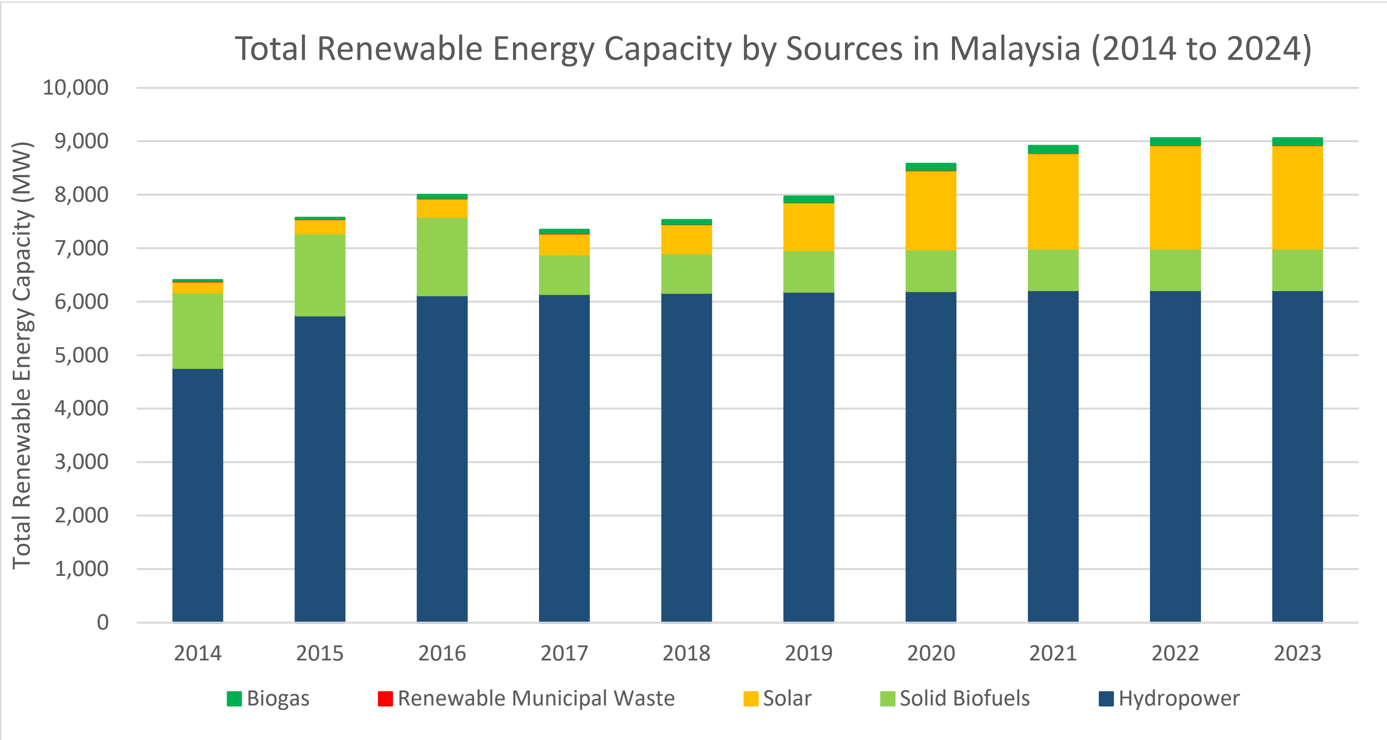

Figure 1. Total Renewable Energy Capacity for the past 10 years in Malaysia. Author's own drawing adapted from [8,9].

The main challenge often associated with this issue is the evident loss of environmental parameters, which can be mitigated and reduced through an efficient cleaning method proposal. However, the loss within the system parameters possesses a larger problem as losses take place from the edge of the PV modules up to electricity being injected into the grid. Examples of losses are thermal losses, ohmic wiring losses, auxiliaries' losses, light induced degradation (LID) losses, and panel aging losses. The National Renewable Energy Laboratory released a report in 2017 claiming that a thermal failure rate of about 5 out of 100,000 modules annually indicates higher degradation rates due to issues such as internal delamination and circuit discoloration [10]. Primary parameters often associated with system losses are PV modules, inverter configuration, DC/AC cabling units with power system and module orientation.

Large scale solar (LSS) is a centralized PV array system specifically for grid integration that consists of a power system network organized by various electronic equipment. LSS will have an installed capacity of more than 1 MW, directly connected to the grid for electricity sales. LSS are predominantly used for two key purposes: one as a utility-scale solution and the other to provide electricity via the grid to nearby residential or industrial areas. LSS are always meant to be designed as bifacial as the PV module efficiency will be at its highest because of its irradiation absorption rate across the panels. Such a design is made to maximize energy input and return on investment. Due to advancements in technology related to LSS, Malaysia has increased its efforts to build more LSS by providing financial incentives through the sale of generated electricity to the TNB grid for 21 years. Sustainable Energy Development Authority Malaysia (SEDA), which is the energy commission in Malaysia, provides schemes such as Self-Consumption (SELCO), Net-Energy Metering (NEM) and the Green Income Tax Exemption (GITE) to increase the use of energy sustainability around the country [11]. This project was achieved via the LSSPV Bidding Cycle 1 in 2017. The government aims to reduce GHG emissions by 45% by 2030 by employing renewable energy sources, particularly solar energy, with a target of producing 2.5 GW from LSS alone [12]. Table 1 shows the estimated LSS PV capacity in each state of Malaysia.

Table 1. Estimated LSS PV capacity (MW) in each state [13].

Region	Capacity Awarded (MW)	Operational Capacity (MW)	In Progress (MW)	Percentage (%)
Perlis	33.996	33.996	0	100
Kedah	355.77	194.99	160.78	55
P. Pinang	21	21	0	100
Perak	248.87	138.88	109.99	56
Kelantan	30	0	30	0
Terengganu	306.99	106.99	200	35
Pahang	209.916	79.916	130	38
Selangor	66.98	66.98	0	100
N. Sembilan	121	61	60	50
Melaka	56.8	56.8	0	100
Johor	68.99	63.99	5	93
Sabah	113.9	50	63.9	44
Total	1634.212	874.542	759.67	54

Two solar plants with installed capacities of 25 MW and 12 MW are under construction in Manjung, Perak, while another 13 MW plant will be built in Kuala Selangor, Selangor [14]. The fourth cycle of LSS stage is being conducted and constructed in Malaysia after 30 finalized bid winners were announced, with export capacity expected to range from 10 MW to 50 MW.

2. Literature Review

2.1. Malaysian Standards of GCPV

Operations of Grid-Connected Photovoltaic Systems (GCPV) will require technical assistance regardless of whether the construction is as large as LSS or for a single residential house. So, Suruhanjaya Tenaga Energy Commission Malaysia came up with standards to adhere to before beginning the GCPV commissioning to ensure that companies or vendors involved will adhere to the following protocols. The key objectives of these guidelines include explaining the procedures needed for the development of LSS and guidance required for the developers seeking connection to TNB electricity grid. MS 1837 [15], as presented in Table 2, is a document standardized for the installation of grid-connected photovoltaic (PV) system that has been revised to provide readers and developers to adhere to the standards and protocols that are needed to achieve the technical requirements in an LSS successfully. These requirements include a circuit diagram of single and multiple MPPT inverters, protection requirements since heavy electricity is flowing, cable selection, wiring identification and earthing. LSS developers will have to initially acquire the land on which the project will be constructed and acquire the direct permits related to the project. The developers will also have to manage the internal connection from PV modules to the TNB grid for network reinforcement. The primary connection includes an initial connection from the plant to TNB substation A or to the existing transmission line between substations A and B.

Table 2. Comprehensive review of MS 1837 [15].

Title	Requirements
General Requirements (installation of GCPV diagram)	Circuit diagram with single/multiple MPPT inverter, micro-inverter, and DC power optimizer.
Protection Requirements	Earth fault, lightning, over-current, and over-voltage protection.
Wiring Requirements	Wiring standards, cable selection, and system voltage.
Component Requirements	PV modules, switching devices, fuses, and inverter requirements.
Earthing	Earthing electrode
Marking Requirements	Disconnection devices, PV array, sub-array connection boxes, shutdown procedure, and fire emergency information.
Documentation	Basic circuit diagram, PV system/parts certification, PV array specifications, and PV system maintenance requirements
Commissioning	Wiring and installation integrity, short circuit current, open circuit voltage, kWh meter and commissioning records.

2.2. Connection to the Grid System

Network infrastructure is important to ensure that the TNB grid system will have the adequate capacity to accept power output from LSS. The government aims to reduce GHG emissions by 45% by 2030 through the use of renewable energy sources, particularly solar energy, with a target of generating 2.5 GW from LSS alone. This will reduce the percentage of losses with the equipment located within the system. Normally, the power from LSS will be consumed locally, regardless of whether it is for industry or residential areas. The voltage level selected for this type of project must be 132 kV, ensuring that the security of this bulk power is not compromised [16].

2.2.1. Connection 1: Connection to Existing Substation

Fixed connections to the grid are usually made via overhead transmission lines or underground cables.This connection scheme will have the ability to disconnect from TNB if the security of the grid is compromised. The grid owner will then decide on the appropriate voltage level and type of connection for the LSS. This connection is beneficial if the busbar extension for the new full bays has adequate space for construction, including room for the control relay panel in the substation building. LSS developers will have to follow TNB in accordance to construct it.

2.2.2. Connection 2: Connection to Nearest Existing Transmission Lines

A switching station will be required for the LSS developer to build if the connection is required to run by the nearby transmission lines. The connection lines of the new switching station will be loop-in-loop-out with overhead transmission lines to facilitate a new connection with the TNB as shown in Figures 2 and 3. All developments would have to follow the accordance of TNB regulations.

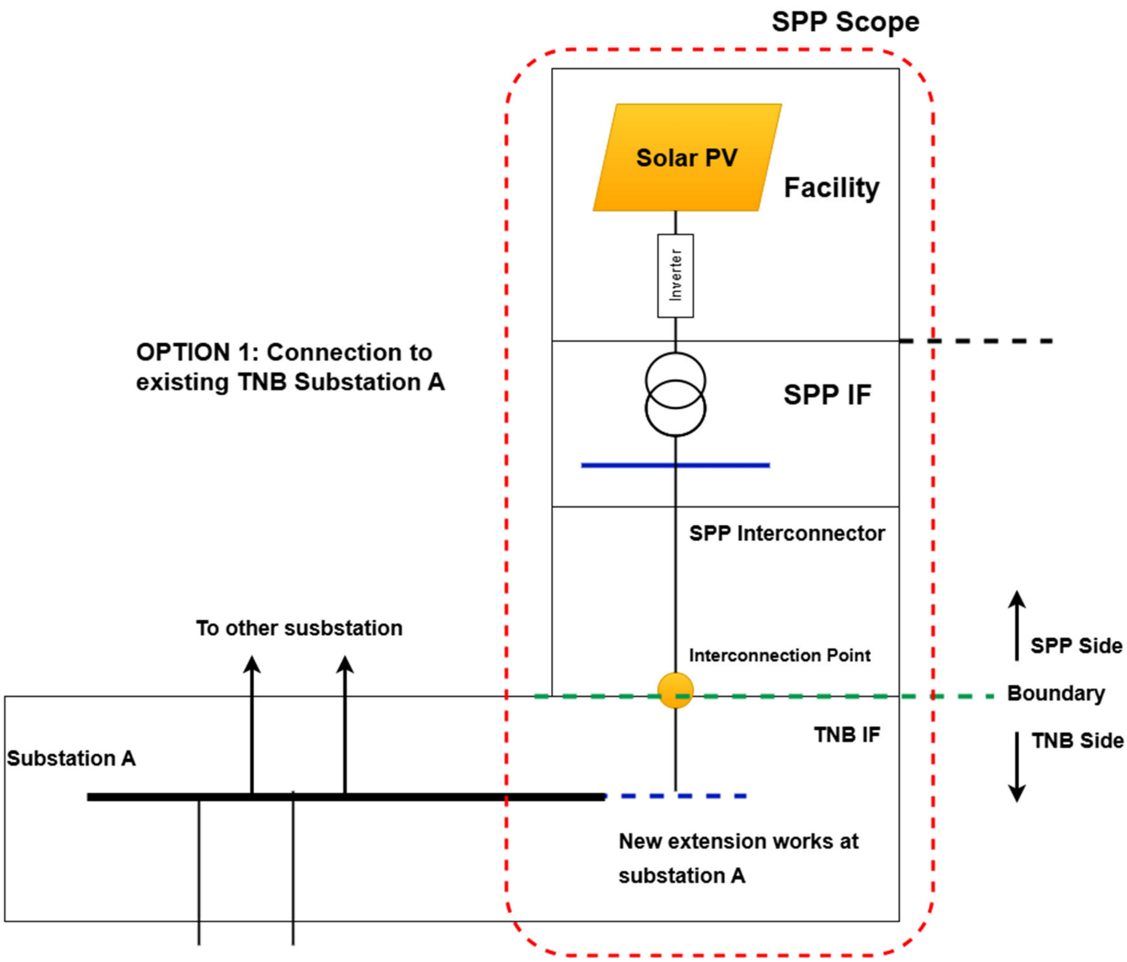

Figure 2. Connection to Existing TNB Substation. Author's own drawing adapted from [16].

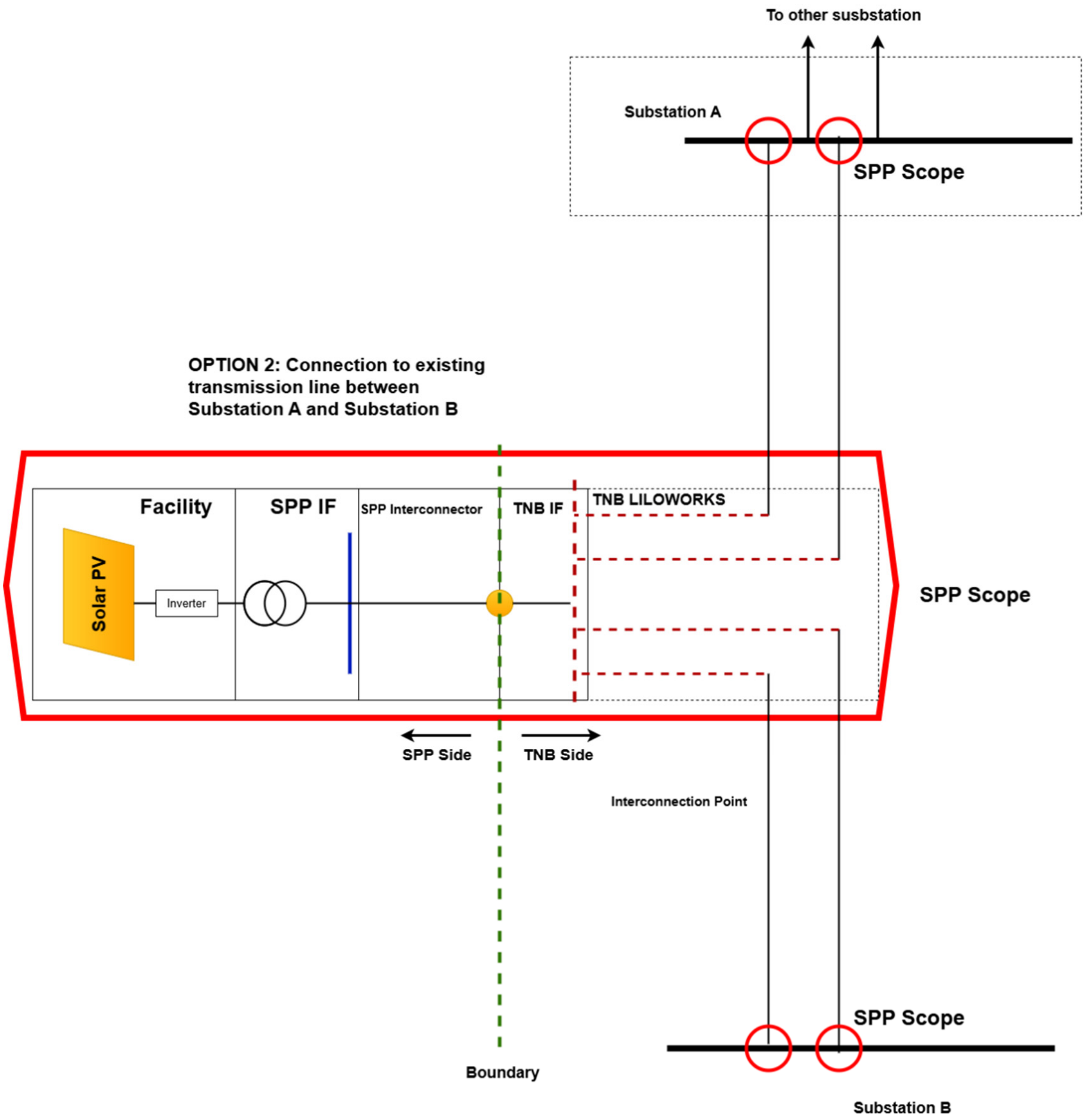

Figure 3. Connection to Existing Transmission Lines between Substations. Author's own drawing adapted from [16].

2.3. System Parameters Affecting Solar PV Performance

PV energy output generally depends on the amount of irradiation absorbed by the cells on the modules. Up towards the energy moving towards the grid, losses, regardless of environmental or system, can be found affecting the efficiency of energy output. An average system loss of about 20% is typically observed in a solar PV system annually. When solar irradiation hits the solar cells, the material absorbs the radiation and, through the photovoltaic effect, generates electricity. The inverter is used to convert DC to AC and supply it to the grid. Key components involved in a GCPV system are PV modules, bidirectional inverter, direct current (DC) bus system, alternating current (AC) bus, and DC and AC cabling connection, which can cause energy losses throughout the system's lifetime.

2.3.1. Inverter

An inverter is an essential device in any GCPV system, regardless of size and capacity. Inverter receives direct current (DC) from the PV array and changes to alternating current (AC), primarily used in building electrical loads. Inverter is the key to PV performance. If power conversion performance is affected within the GCPV, PV array power transmission to AC utility system will not be effective as losses will be apparent [17]. These losses are due to energy and heat losses associated with the electronics, magnetic and copper losses and self-consumption of inverters. An Increase in temperature due to the inverter working more power loads will cause energy levels of incident to peak around 400–700 W/m^2 causing inverter efficiency to drop at certain times and increasing the risk of component failures [18]. However, based on real-life conditions, when power conversion from DC to AC happens, an efficiency value is around 90% will be present. Studies have shown that PV inverters are often affected by failure due to components being exposed to electrical stress and high temperatures. Due to high thermal exposure, power electronic switches will cause failure to the capacitors dependent on incoming DC voltage, ripple current and ambient conditions [11]. Module-integrated inverters can be seen as the optimal ones as losses are only up to 3% and provide a higher efficiency of working power [19].

2.3.2. PV Modules

PV modules are made up of photovoltaic cells mounted in a group framework that absorbs irradiation rate and converts to direct current (DC). PV structure and material are important in managing and minimizing loss from modules. The PV atomic structure and band gap energy determine the panel efficiency. The range of PV materials includes mono-crystalline, silicon, indium phosphide and many more. The efficiency of specific PV modules, such as mono-crystalline based modules, tend to have a higher energy efficiency of about 16–22% when directly compared with poly-crystalline modules with only 14–18% [17]. However, degradation of PV modules will occur gradually within the 25-year period that manufacturers guarantee. This degradation of modules will cause energy loss as energy output towards AC will decrease gradually. Fixed mono-crystalline modules will have a 0.5% degradation rate annually. These could be due to thermal, mechanical, or electrical bases. Examples of degradation issues that lead to energy losses include potential induced degradation (PID) and mismatch losses. Potential Induced Degradation (PID) occurs when stray currents leak due to a large potential difference between the PV module frame and the module circuit, leading to degradation of the PV system. This could normally lead to power losses of up to 30% for the duration of the system. In a PV string of 30 modules and more, certain PV cells that undergo potential difference will induce electrons to leak from the cells and proceed to discharge through the modules' frame to the ground known as stray currents. This process will induce PV module's shunt resistance to drop and will cause a reduction in open circuit voltage and fill factor (FF).

Mismatch losses in an array occur when various model interconnections on an array have various voltage characteristics, causing the loss of discrepancies with modules connected in parallel or series based on stated voltage and current readings [20]. For PV systems with higher rated power, the percentage of these losses increases, typically ranging from 0.01% to 3% [21].

2.3.3. DC/AC Cabling

DC and AC cables are the primary components of a solar energy system, providing a connection from PV module cell up to TNB grid. AC and DC cables are single and double insulated, respectively. Copper wire in DC is a tinned copper wire that protect the wire from rusting and environmental hazards. Cables used in GCPV, especially plants with large capacity would have to be carefully selected as from analysis, power can be identified to be leaking from the connections regardless of PV panels, inverters, and other components [17]. Equation (1) was proposed that it is used to calculate power losses in cables depending on the location of leakage, internal wiring, array temperature or array voltage connections. The difference in size in parallel strings and cable length/dimension will induce voltage differences. The size of the conductor is important as this is determined by the capacity of the conductor carrying the current and the voltage drop.

$$P_{loss} = \frac{2\rho l p^2}{V_o S \times cos\varphi^2} \quad (1)$$

where:
P_{loss} = Power loss in the cable
ρ = Specific resistance of conductor material
l = Distance between source and load
p = Power consumption of load
V_o = Source voltage
S = Conductor cross-section
$cos\varphi$ = Power factor of load.

2.3.4. PV Array Inclination

Module orientation plays a vital role in maximizing energy output performance and minimizing losses. Orientation of the PV module absorbs the highest irradiation level when the module surface is perpendicular to the sun and must be adjusted to obtain minimal shading for maximum performance. Performance ratio (PR) can achieve energy input of up to 85% regardless of the system size and complexity with optimum angle selection. Losses in this matter can be resolved using dual axis trackers in which the performance will be optimized based on the Sun's variations. Standard rule of thumb for optimum tilt angle states that tilt angle should be like the latitude of the location on where the modules are installed [17]. However, this method is rendered useless for latitudes that are more than 45 degrees [22]. Issues such as this will cause the loss of energy due to irregularity of the irradiation received by the PV modules and thus losing energy in the process.

2.4. Pearson Correlation Model

Multiple system parameters that affect the performance of PV modules must be examined to identify the most significant factors causing the losses. A correlation between two sets of variables must be conducted to determine how a change in one variable affects the other in the opposite direction. This correlation is done to use the data of a single variable to predict the outcome of the second variable. The pearson correlation coefficient model, as shown in Equation (2), evaluates the linear relationship between two variables, commonly used in linear regression [23]. The pearson correlation formula will analyze the correlation between maximum energy output and system parameters data. The value of the Pearson correlation (*r*) ranges from −1 to 1, where 1 indicates a strong positive relationship between the two variables. −1, however, indicates a strong negative relationship stating that the two variables used do not correlate with each other or provide an adverse effect on the performance parameter [24].

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \sum(y_i - \bar{y})^2}} \tag{2}$$

where:
r = correlation coefficient
x_i = values of the *x*-variable in a sample
$\bar{x}$ = mean of the values of the *x*-variable
y_i = values of the *y*-variable in a sample
$\bar{y}$ = mean of the values of the *y*-variable.

2.5. Problem Statement and Research Gap

The rapid increase of solar energy usage in this country for the past decade has increased more than 1000 MW leading to the expected capacity plan by 2035 [25]. Past literature has been reviewed, and its findings, design parameters, and performance indicators are summarized in the Table 3. Selected literature were also analyzed to obtain the limitations and research gap in this paper. This work investigates system parameters and losses at different stages of solar system functional blocks. These factors include PV panels, inverters, PV materials, and the orientation of PV panels, all of which influence the I–V characteristics associated with energy losses in the system [14]. Detail system analysis can determine the absolute parameter contributing to the highest energy loss. Next, identify the correlation between the parameters involved and PV energy performance. The correlation model must be calculated accurately to ensure that the parameters have a positive or negative relationship with the energy performance, to be analyzed over the long term. This project aims to provide an optimum solar system design and identify system parameters that are susceptible to causing a reduction in the efficiency of solar PV panels. Stage 1 focuses on developing an optimum solar photovoltaic (PV) system by implementing the GCPV standards in Malaysia. Stage 2 investigates the system's most significant and least significant parameters that affect solar panel energy degradation. Stage 3 identifies the study of the correlation coefficient model to compute the relationship between system parameters and PV energy performance. Lastly, a comparative study will be conducted to compare the historical energy data from the large-scale solar site to system modelling results in the validation stage. The outcome of this project is the identification of key energy losses among various system parameters, along with improved solar system energy performance and plant efficiency. This work can serve as a reference model for tropical climate countries and contribute to the renewable energy mix and installed solar capacity, helping meet national energy targets by 2035.

Table 4 presents the research gap that has been identified from the literature that has been reviewed across the entire project timeline. Most system performance modelling is only considered on the parameters calculation and does not include analysis on the most and least significant parameter study. It also does not investigate the significance of the parameters, regardless of positive or negative, in which the Pearson correlation is introduced in this study.

Table 3. Findings, design parameter and performance indicators of related research.

Related Research	Findings	Design Parameters	Performance Indicators
A target-oriented performance assessment and model development of a grid-connected solar PV (GCPV) system for a commercial building in Malaysia [1]	• Performance Ratio (PR), Capacity Utilization Factor (CUF), system efficiency, Levelized Cost of Energy (LCOE) were found to be 85.4%, 14.85%, 9.15%, and 0.396 MYR/kWh, respectively. • 177 metric tons of CO_2 emissions were saved during the year after the GCPV system was installed.	• Target yield • Loss analysis • Economic analysis	• GCPV yield analysis • PR, CUF, system efficiency • System/array capture losses
Impact of energy losses due to failures on photovoltaic plant energy balance [10]	• Energy losses failure of analysed PV plants low, reaching max value of 0.96%. • Solar field energy losses are 4.26% of failure energy losses. • Due to inefficiencies, energy losses show between 22.34% and 27.58% of net energy yield.	• Energy losses calculation • Failure rate analysis	• Estimating failure rates through operation and maintenance
An integrated review of factors influencing the performance of photovoltaic panels [17]	• Panel's I–V characteristics, inverter, battery and panel efficiencies, panel material, atomic structure and band-gap energy are system factors. • Installation factors, cable characteristics, angle of inclination, mismatch effects, fixed/tracking PV mechanisms and MPPT considered. • New systems were implemented to hinder the effect of factors negatively affecting PV panels' performance.	• I-V characteristics of PV panel • Inverter efficiency • Cable characteristics • Panel orientation angle	• Performance Ratio (PR)
Effect of faults in solar panels on production rate and efficiency [20]	• Error rates grouped by deficiencies in energy balance achieved using operation/maintenance data. • The process in the system, 67,415 MW of power plant and 59,211 MW of power plant, has been obtained, resulting in a total 87.83% difference.	• Shading losses • Temperature losses • DC/Ac inverter losses • Reflection losses • Diode and mismatch losses	• Effect on panel quality and strength on production efficiency and numerical comparison
Prediction model for PV performance with correlation analysis of environmental variables [23]	• Order of significance of input variables identified by a statistical approach. • Model produces RMS error of 4.957% and a mean absolute % error of 5.468% during the measurement period.	• Correlation coefficient analysis • Linear regression models	• Analysis between power generation and variables • Model validation
Performance, energy loss, and degradation prediction of roof integrated crystalline solar PV system installed in Northern India [26]	• Analysis of capacity factor (CF), performance ratio (PR), and efficiencies. • 3-stage approach (sunlight reaching onto the PV array, sunlight into DC electricity conversion, and DC to AC electricity conversion) was used. • 92,954 kWh energy generation on annual basis from planned PV system. System estimated operate with yearly CF, PR, and energy losses as 16.72%, 77.27%, and −26.5%, respectively. • Estimated DR of PV system lie between −0.6 to −5%/yr, and possible LID is −2.5%/yr.	• Energy performance array • Degradation analysis	• PVSyst software calculations • System losses analysed
Performance study of a new photovoltaic thermoelectric utilization system based on spectral beam splitting device [27]	• Design of a novel filtered PV thermoelectric utilization system. • Improvement in total electrical and thermal efficiency • New system decreased the peak temperature of PV panels by 29.2 °C.	• PV system configuration	• Temperature • Electrical efficiency • Thermal efficiency • Power
An Overview of Factors Affecting the Performance of Solar PV Systems [28]	• Type of PV material, cell temperature, inverter • efficiency, module orientation, DC/AC cabling • influence, energy degradation	• Different PV • technologies • Degradation of PV	• Degradation rate • of modules

		• modules and • temperature	
Solar PV Performance Parameter and Recommendation for Optimization of Performance in Large Scale Grid Connected Solar PV Plant—Case Study [29]	• Performance Ratio (PR), Cumulative Utilization • Factor (CUF), contributing to the performance of solar power plants. *i.e.*, radiation, temperature, and other • climate conditions, and design parameters. • PR taken care of during plant engineering for better • performance and generation results of solar power • plant in 25 years.	• Cells operating • out of the STCs. • Voltage drops in • the dc cables and • protection diodes. • Operation voltage • out of the • maximum power • point (MPP). • Mismatch effects	• Performance • indicators after losses • calculations
Effects of soiling on photovoltaic PV modules in the Atacama Desert [30]	• Annual energy losses peaked at 39% due to high deposition rates/infrequent rainfalls • Soiling-induced annual energy losses of 7% measured in Santiago, Chile (33° S)	• Wind Influence • Humidity • Aerosol • Tilt Angle Effect • Precipitation • Cleaning Frequency	• Energy efficiency • Energy losses due to environmental parameters
Impact of soiling on energy yield of solar PV power plant and developing soiling correction factor for solar PV power forecasting [31]	• Soiling correction factor varied from −1.36% to 3.67% between June'18 and June'19 in Chennai • Correlation between module temperature/DC power; humidity/DC power; GTI/DC power varies • Highest correlation = GTI/DC power • Least correlation = wind speed/DC power • Correlation between module temperature/DC power was twice the correlation between ambient temperature/DC power	• Wind Speed • Rainfall • Humidity • GHI • Soiling Loss (%) • DC Power	• Correlation between environmental parameters and energy output
Energy analysis of utility-scale PV plant in the rain-dominated tropical monsoon climates [32]	• PV plant's average PR is 73.39, with average of 15.41% CUF over the study period. • Monsoon seasons have a more substantial influence, leading to a 35% reduction in energy generation	• Irradiance on energy output • Performance ratio and capacity factor	• Energy generation on monsoon seasons
Integration of solar energy into low-cost housing for sustainable development: case study in developing countries [33]	• Five different PV systems were developed and tested against optimal tilt angle • Optimizer integrated to increase energy yield from 0.5% to 5.3% • LCOE in Uganda ranges from $0.25–0.36/kWh and in Indonesia is $0.25–0.3/kWh • Carbon reductions were 173.894 tons and 122.742 tons in Indonesia and Uganda, respectively	• Energy yield in optimal tilt angle • PV array with suitable inverter, tilt angles and orientations	• Effect of optimizer • Overall carbon reduction • LCOE with and without optimizer
Investigation of PV System Cable Losses [34]	• Thermal losses are 5.7%, module quality losses are 3%, invertor losses are 18%, module array mismatch losses are 1%, and shading losses are 33%. • Cable losses of 1.7%, 0.6% and 0.2% for the cross-sectional areas of 1.5 mm^2, 4 mm^2 and 10 mm^2 respectively. • Different cross-sectional areas and lengths do not affect PV system performance.	• Shading losses • Thermal losses • Module mismatch losses • DC Cable losses • Effect of tilt angle	• Sizing of DC cables affecting losses • Losses breakdown for different parameters
Energy storage system design for large-scale solar PV in Malaysia: technical and environmental assessments [35]	• HOMER Pro is used to simulate power systems including various storage technologies according to solar radiation and electricity demand • Sized storage to satisfy night peak demand • 1 MWh Zinc Bromide flow battery is the best energy storage	• Daily peak average demand • Power system sizing	• Storage system sizing • Feasibility of storage to satisfy demand

Power management scheme development for large-scale solar grid integration [36]	• Malaysian LSS farm was modelled to meet a required annual energy yield of 200 GWh using PVsyst, and output data was imported to PSS SINCAL for integration of solar with IEEE-9 bus. • With the optimised allocation of capacitors, the voltage profile for all network buses was improved to be within the range of 0.94 p.u. to 1.01 p.u.	• PV array and inverter sizing • Tilt and azimuth • Reactive power demand	• Solar energy yield • Voltage profile • Reactive power supplied
Solar energy conversion systems optimization using novel Jellyfish based maximum power tracking strategy [37]	• MPPT optimising algorithms for solar energy under partially shaded conditions need to be improved to increase energy conversion efficiency. • Jellyfish optimisation based MPPT tracks the maximum power point with 5.83% error under normal conditions and 3.2% error under partially shaded conditions.	• Shading conditions • Voltage (V) • Current (A)	• Error (%)
Increasing the efficiency of PV panel with the use of PCM [38]	• Average increase of PV-PCM efficiency was from 1.1% to 2.8%. • Maximum temperature difference between PV-PCM and PV was 35.6 °C. • Higher electricity production for 7.3% in a one-year period.	• Surface Temperature of PV (°C) • Generation Efficiency (%)	• PV Output Power (kW)
A Study on Implementation of PV Tracking for Sites Proximate and Away from the Equator [39]	• A vertically oriented single-axis tracker, when optimally tilted, offers the best performance for locations near the equator. • This configuration can generate approximately 19% more energy compared to traditional fixed solar panel systems oriented toward the south.	• Tilt angle • PV tracking systems • Latitudes	• Solar energy yield
Modelling and Performance Analysis of a New PVT System, with Two Semi-Transparent PV Panels [40]	• The integration of two semi-transparent photovoltaic panels resulted in a notable improvement in electrical efficiency, increasing from 13% to 20.7%. • Specifically, STPV1 contributes an improvement of approximately 12.7%, while STPV2 adds around 7.8%.	• PV panel • Location • Temperature	• Efficiency
Analysis and design of solar PV system using Pvsyst software [41]	• A 700 kWp system design was simulated, yielding an annual energy production of 1266 MWh. • The system's performance ratio was calculated to be 0.797.	• Installed capacity • Tilt • Azimuth	• Solar energy production • Performance ratio
Optimized Power System Management Scheme for LSS PV Grid Integration in Malaysia using Reactive Power Compensation Technique [42]	• Modelling of Malaysian LSS Farm in PVsyst and integrating solar to power system using PSS/E. • The voltage profile was improved after integrating FACTS devices in the IEEE 9-bus system based on the AC contingency analysis's worse case violations (bus 8 and bus 9).	• LSS capacity • Reactive power demand.	• Voltage Profile • Reactive Power Injected
Techno-economic-environmental Analysis of Solar/hybrid/storage for Vertical Farming system: A Case study, Malaysia [43]	• Study of solar-hybrid-storage system for vertical farming under Malaysian weather conditions. • For grid-connected systems, 11.6% and 8.4% of the energy has been reduced in sites 1 and 2, respectively, after solar integration. • Performance ratios on both sites 1 and 2 were 82.22% and 82.56%, respectively.	• Design configuration	• Performance ratio • Energy yield • LCOE
This paper	• Tilt angle, module technology, optimizer, module temperature efficiency and degradation losses are parameters affecting energy yield • Pearson's determining positive/negative relationship between energy yield/ performance ratio against inverter voltage/current	• Changes in system parameters	• Energy yield/performance ratio of integrated parameters • Regression model relationship

Table 4. Research gap identified from the literature reviewed.

Research Gap
• Most system performance modelling is only considered on the parameters calculation and does not include analysis on the most and least significant parameter study.
• Correlation is carried out for environmental variables and not system parameters.
• Explanation of the significance of parameters inducing losses not observed.
• Range of parameters affecting the degradation factor was not observed.
• Correlation to determine the significant energy loss parameter not observed.
• Categorization of the most and least significant parameters influencing the PV panel performance was not observed.
• Correlation to examine parameters contributing to the largest energy losses not observed.

3. Methodology

There are a total of 186,240 units of poly-crystalline modules used in this project with 1189 units of SUN2000 string inverter. The methodology of this study will first begin to develop a more optimum solar photovoltaic (PV) system using the basis of the 49 MW LSS plant. Various system parameters of the solar system will be analyzed and reconstructed for the system to provide a higher energy yield. The design constraints analyzed here are changes in tilt angle, the effect of different module technology, module efficiency in relation to temperature, the effect of optimizer and changes in sizing. Original sizing of the plant will be initially used, changes in parameters will be conducted and the parameter that is contributing to the highest energy yield is analyzed and discussed. Results achieved will be in terms of optimal energy yield or performance ratio (PR). The performance ratio is a measure of the quality of a solar PV plant. This PR will often be interpreted in percentage and states the relationship between the theoretical and actual energy yield values from the PV plant. Figure 4 illustrates the stages of the methodology used in designing the system parameters and their variations. The steps taken in simulating the optimum PV system are as follows:

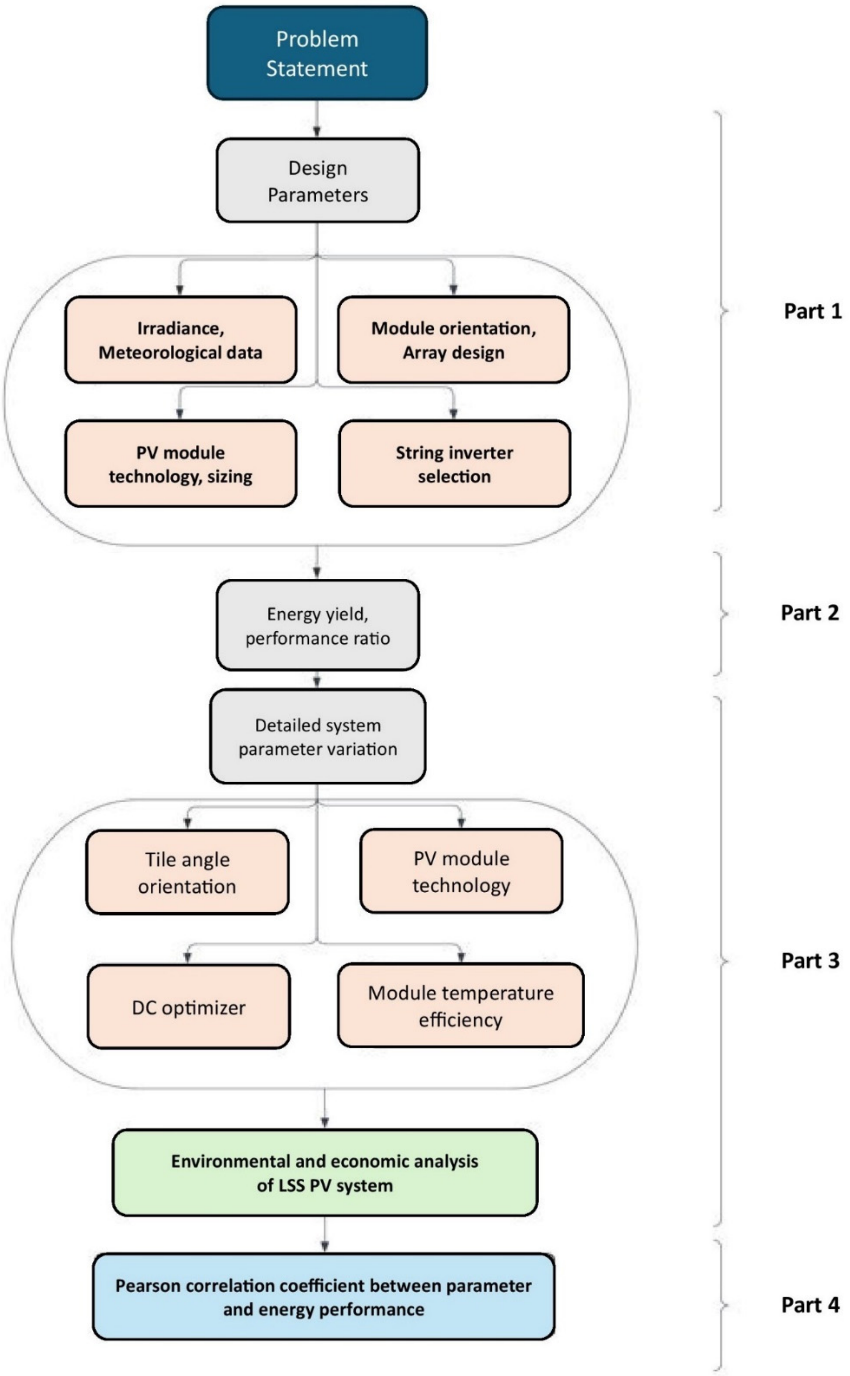

Figure 4. The key methodological stages.

Step 1: Meteorological Data at Project Location

The primary data required for this project includes the energy yield of the PV panels, as well as the reduction in efficiency due to certain parameters. Site data is processed and compared with the modelled energy system data to investigate the effect of system parameters on performance degradation. LSS location and the global horizontal irradiance (GHI) will be determined. Monthly meteorological data will be collected using the Meteonorm software in which the GHI data monthly and yearly will be tabulated. This data will be the basis for creating and simulating an optimum photovoltaic system.

Step 2: Angle Orientation

All the key parameters mentioned in this project will be analyzed using PVsyst and the real-time data obtained. These parameters are also used to compute the correlation coefficient model to analyze the parameters affecting energy degradation. Orientation angles such as tilt and azimuth are analyzed to ensure module orientation is angled so that high irradiance input can be achieved. For this study, angles of 5°, 7°, 9°, 10°, 11° and 15° were used to identify the optimal tilt angle that provides the highest energy yield or performance ratio (PR) across 12 months.

Step 3: PV Module Technology Selection

PV modules are selected based on their efficiency, which usually ranges from 17% to 24% as an optimum efficiency range used worldwide. To support the demand from the modules, module nominal power is vital as this has to be considered to ensure smooth power transition among all the panels installed in this LSS plant. PV Module specifications are normally fixed depending on the brands and manufacturers. The standard test conditions (STC) are an important benchmark and need to be analyzed for maximum voltage, maximum power, and maximum current. STC ratings are standard across all PV module industries with a fixed cell temperature of 25 °C, GHI of 1000 $\mathrm{W/m^2}$ and air mass of 1.5. Each module will contain internal specifications and as panels are arranged in an array, it is vital to obtain and simulate several specifications, such as open-circuit voltage (V_{OC}), short circuit current (I_{SC}), temperature coefficient for short-circuit current (μ_{ISC}), temperature coefficient for maximum power (μ_{Pmax}), temperature coefficient for open circuit voltage (μ_{Voc}), temperature coefficient at maximum voltage (μ_{Vmp}), and finally maximum allowable system voltage of the PV arrays. A similar PV module brand with different technology configurations will be used and compared to analyze the higher PR rate of the entire LSS plant across a year.

Step 4: Inverter Selection

Electrical components must be configured as the PV modules are laid out on the ground, as expected power and received voltage are the key components needed in choosing the optimum inverter sizing. An optimum inverter should always have an AC/DC ratio within the 1.12 to 1.25 range, and it should be directly related to energy input based on irradiance level. LSS has incorporated the usage of string inverters as there are different elevation angles and is also equipped with a maximum power point tracker (MPPT). MPPT is vital in this situation as this could reduce mismatch losses of the PV array. The specifications that must be analyzed to select an optimum inverter are the available nominal PV power, nominal MPP voltage, maximum and minimum MPP voltages and maximum input voltage of inverter. To ensure that the output voltage of the PV module array does not exceed the allowable input voltage range of the inverter, the input voltage limit of the inverter's MPPT is crucial.

The project is conducted in two stages. Firstly, the energy system will be developed to estimate the energy yield obtained by PV module arrays. PV modules, along with the array, will be configured with a suitable inverter and an appropriate orientation angle. Once initial energy estimation is conducted, system parameters will be investigated, such as tilt angle, module technology, DC optimizer, efficiency of module temperature, and degradation losses, to identify the suitable system parameter that will provide optimum energy yield. The second stage will be using inverter data such as smart logger data, to analyze the relationship between the power meter, energy yield and performance ratio (PR) by creating a regression model. This model will further quantify whether the relationship between these two parameters is positive or negative because that is occurring on the performance ratio of the LSS plant.

Step 5: Detailed Losses in LSS Plant PV System

Losses in any solar photovoltaic (PV) system are important to be addressed as this plays a very important role in analyzing the energy losses that occur throughout the life of the PV system. For this LSS plant, the detailed losses are set as and are stated in detail in the Table 5.

Table 5. Types of losses in LSS energy system modelling [44].

Losses	Value
Field Thermal Loss Factor	29.0 W/m^2K
Ohmic Losses for the Array	1.50% in STC
Module Mismatch Losses	2.0%
Light Induced Degradation (LID)	2.0%
Soiling Loss	3.4%/year
PV Module Degradation (Ageing)	Average degradation factor of 0.8%/year. Mismatch degradation factor of 1.49%/year. Mismatch for 25 years: 5.12%.

Step 6: Economical and Environmental Analysis

Levelized Cost of Energy (LCOE) is the key information that can be calculated using the initial capital expenditure (CAPEX) of installation costs alongside operating costs (OPEX). Key inputs required include initial costing, feed-in tariff (FiT), financial parameters, investment, and charges such as study analysis, land costs, and external components. Main economic inputs that are vital are Net Present Value (NPV), Return on Investment (ROI), and payback period can be obtained in this investigation. Technical specifications and system designs are presented in Tables 6 and 7.

$$\mathrm{NPV} = \sum_{t=1}^{n} \frac{R_t}{(1+i)^t} \tag{3}$$

R_t = Net balance for year *t*.
i = Discount rate for specific system
n = System lifetime.

Return on Investment (ROI) is the ratio of net profit from CAPEX to the total investment in the project. ROI is deemed to be successful if it provides positive value.

$$\mathrm{ROI} = \frac{Net\ profit\ at\ the\ end\ of\ project\ life\ cycle}{Total\ Investment} \tag{4}$$

Table 6. Five different module technologies used in this study.

Technical Specifications of System	Module 1	Module 2	Module 3	Module 4	Module 5
Model	JAM60	JAP72	JAP72	JAP72	JAP60
Technology	Monocrystalline	Monocrystalline	Polycrystalline	Polycrystalline	EFG
Max Power Point	330.2 W	325.2 W	325.2 W	320.0 W	275.0 W
Module Efficiency	20.01%	18.59%	17.67%	18.29%	16.35%
V_{mp}	33.75 V	37.39 V	37.09 V	37.28 V	31.22 V
V_{oc}	41.30 V	46.38 V	45.85 V	46.12 V	37.01 V
I_{sc}	10.32 A	9.17 A	9.01 A	9.09 A	9.29 A
I_{mp}	9.78 A	8.62 A	8.46 A	8.54 A	8.80 A
Dimension (mm)	1657 × 996	1960 × 991	1730 × 990	1960 × 991	1689 × 996
Temperature Coefficient of Isc	+0.051%/°C	+0.058%/°C	+0.058%/°C	+0.058%/°C	+0.058%/°C
Temperature Coefficient of Voc	−0.289%/°C	−0.330%/°C	−0.330%/°C	−0.330%/°C	−0.330%/°C
Temperature Coefficient of Pmax	−0.350%/°C	−0.400%/°C	−0.400%/°C	−0.400%/°C	−0.400%/°C

Table 7. System design specifications before optimization.

Specifications	Value
Tilt	7°
Transposition Model	Perez
Soiling	3.4%
PV Module	Si-Poly
PV Modules in Series	20
PV Modules in Parallel	9311 strings
Total Module Area	361,745 m^2
Array Global Power (Nominal STC)	60,528 kWp
Inverter	SUN2000-42kTL
No of Inverters	1189
Operating Voltage	200–1000 V
Unit Nominal Power	42.0 kWac
Produced Energy	85,065 MWh/year
Specific Production	1405 kWh/kWp/year
Performance Ratio (PR)	80.76%

Step 7: Correlation Coefficient Model and System Optimization

Correlation model will be used to compute the relationship between two variables. For this project, one of the system parameters versus energy efficiency yield will be measured to identify which is heavily affecting efficiency. Next is the optimization of the solar PV system. Development of solar PV system using real site information, compare and validate using system modelling results.

4. Results and Discussions

4.1. Effect of Tilt Angle on Energy Yield and Performance Ratio (PR)

The first design parameter to be investigated is the tilt angle which served as one of the significant parameters affecting the energy performance of the PV modules. Angles of 5°, 7°, 9°, 10°, 11° and 15° were used to identify the optimum tilt angle for this project. Based on Figure 5, a tilt angle of 10° is observed to provide the highest performance ratio (PR) of 79.2% for the plant. Measured tilt angles provided a performance ratio (PR) ranging from 70% to 80%. The range of tilt angles initially selected aims to maximize energy production and provide an easy cleaning method for the PV panels. Although the performance ratio is slightly lower than the original specifications, the energy produced was higher. Table 8 shows the PR value for each tilt angle calculated. Consideration of the tilt angle will not only depend on the PR value, but also on factors such as cleaning methods, energy yield, and installation challenges in uneven terrain.

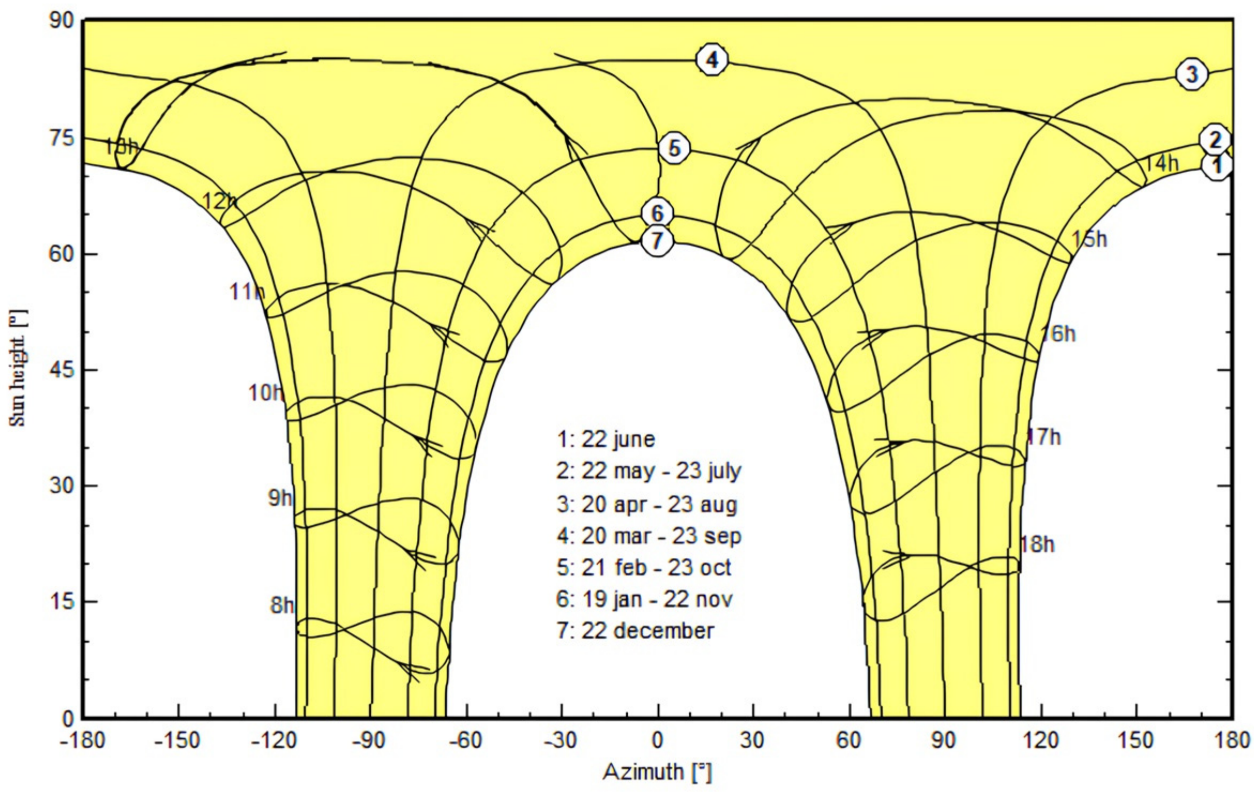

Figure 5. Sun path diagram at the location of the plant.

Table 8. Various tilt angles with performance ratio and energy production.

Tilt Angle (°)	Performance Ratio (%)	Energy Production (MWh/yr)
5°	78.3	87,977
7°	78.6	88,078
9°	78.9	88,259
10°	79.2	88,986
11°	79.0	88,773
15°	78.8	88,175

4.2. Effect of PV Module Technology on Energy Yield and Performance Ratio (PR)

PV module technology is important in aiding module performance, thus providing a higher energy yield. Different technologies will have a range of panel efficiency and designed nominal power to provide expected power output. Three different module technologies with five different configurations were used, along with their nominal power, efficiency, performance ratio, and total energy system production, as listed in Table 9. All the modules were repeated, and a selection of efficient modules was chosen for this study. As shown in Figures 6–8, PV monocrystalline modules exhibit a higher efficiency rate compared to the other two technologies tested. Monocrystalline modules have higher efficiency because they contain lower light induced degradation (LID) effect by about 2% annually. LID is caused by a high potential difference between the crystalline cells (semiconductor material) and external parts of the module, such as the module frame, which can be made of aluminum or glass. The stated difference will cause negative and positive ions to migrate out of crystalline cells known as leakage of current. Monocrystalline modules are also efficient in warm weather even though the efficiency rate drops and ambient temperature increases. Figure 9 indicates the comparison of the performance ratio between the 3-module technology.

Table 9. Summary of PV module technology used.

PV Module Technology	Nominal Power (Wp)	Panel Efficiency (%)	PR (%)	Energy Production (MWh/yr)
Si-Mono	325	19.89	79.2	88,986
Si-Mono	330	20.01	80.05	90,560
Si-Poly	315	19.23	79.0	88,289
Si-Poly	325	19.76	79.4	89,231
Si-EFG	275	18.5	78.3	88,180

The coloured one shows highest energy production.

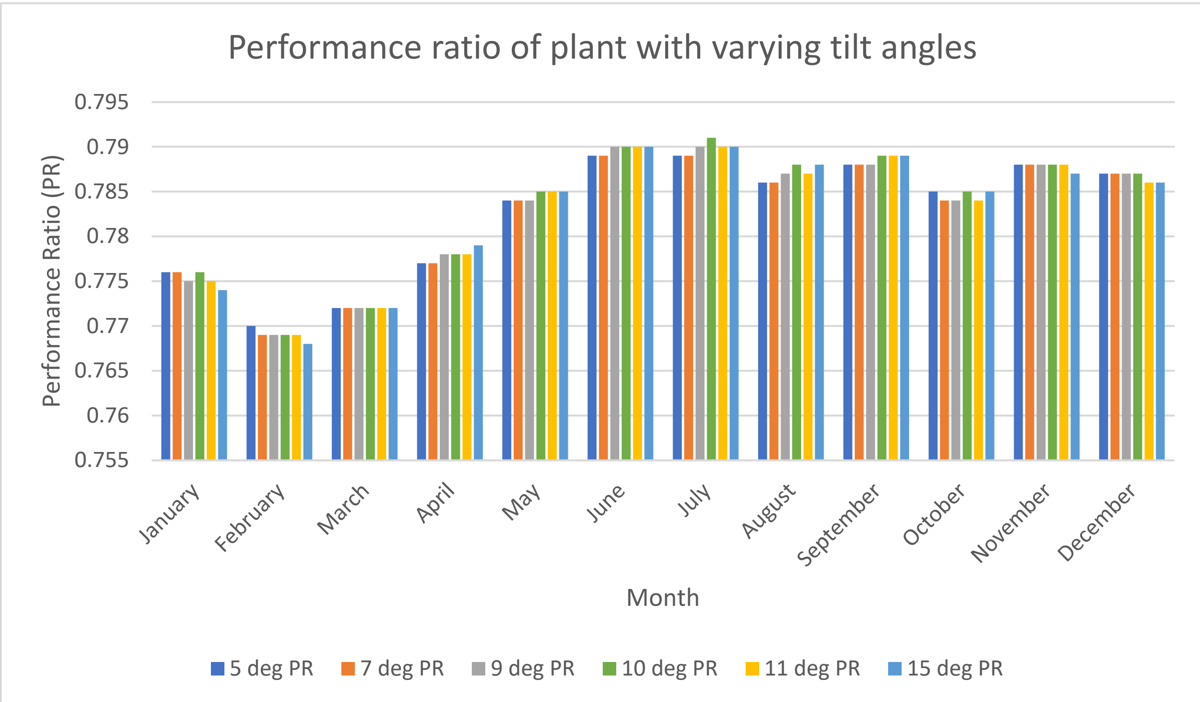

Figure 6. Performance ratio of plant with varying tilt angles.

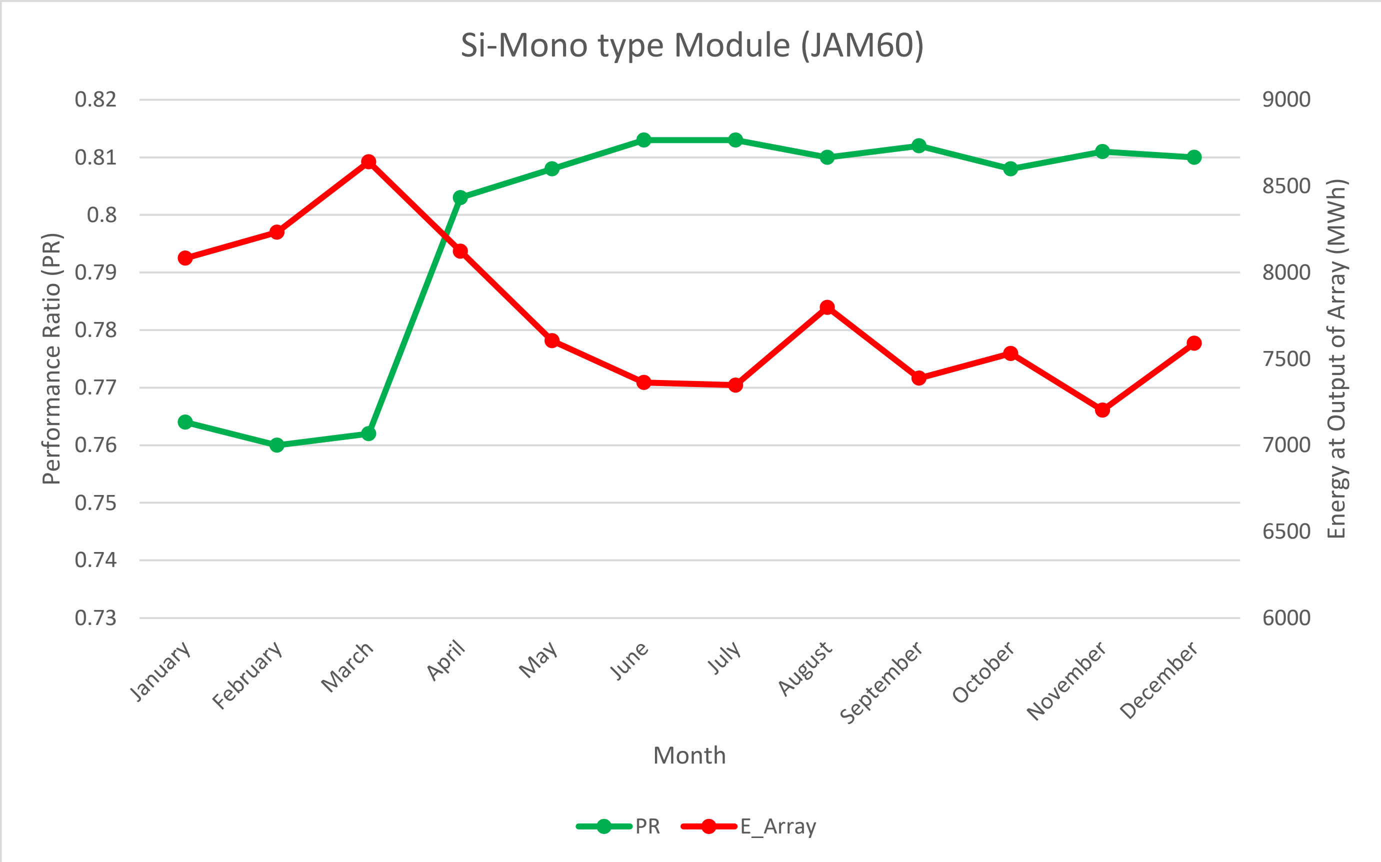

Figure 7. Performance ratio and energy yield of monocrystalline module.

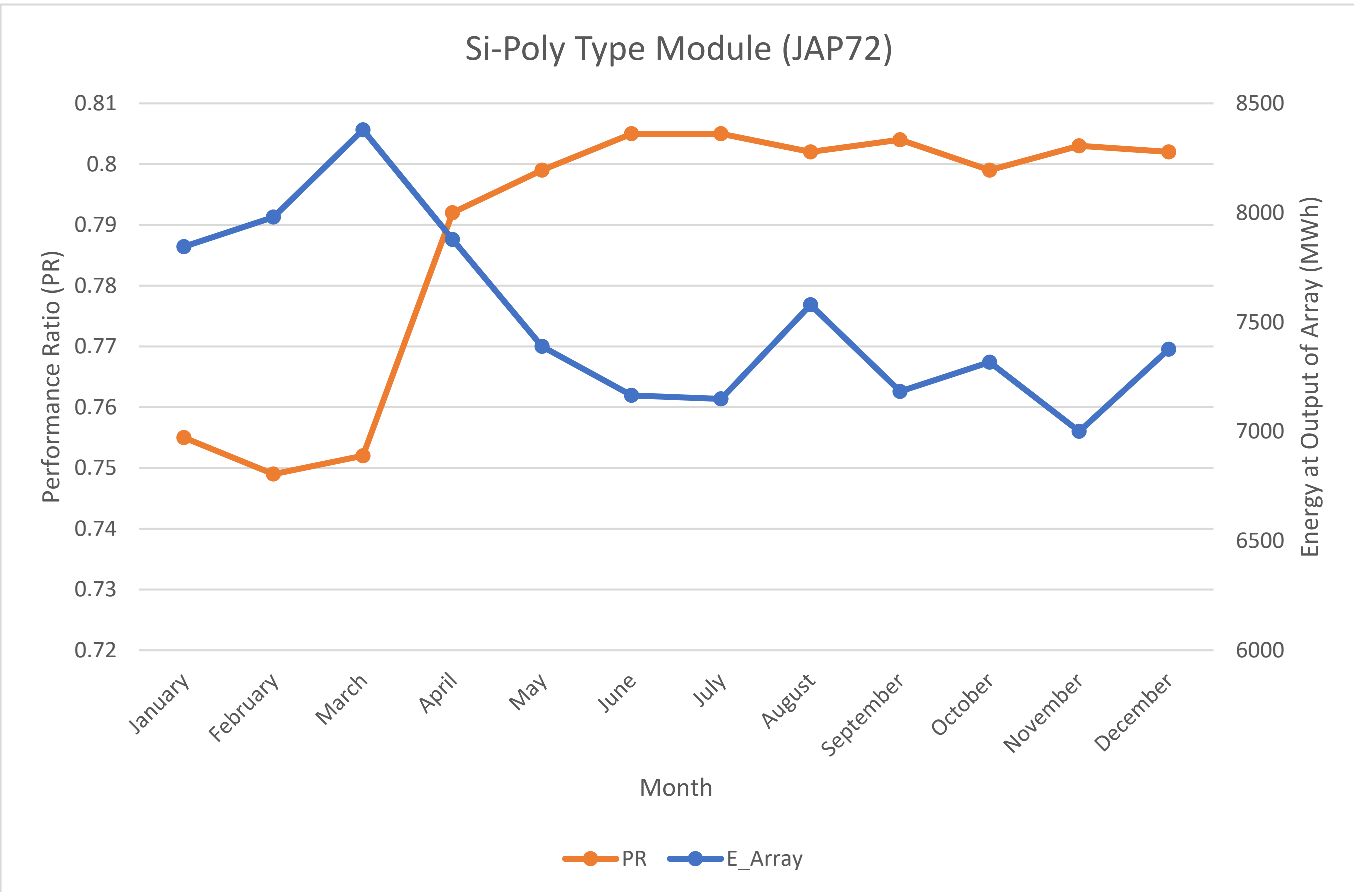

Figure 8. Performance ratio and energy yield of polycrystalline module.

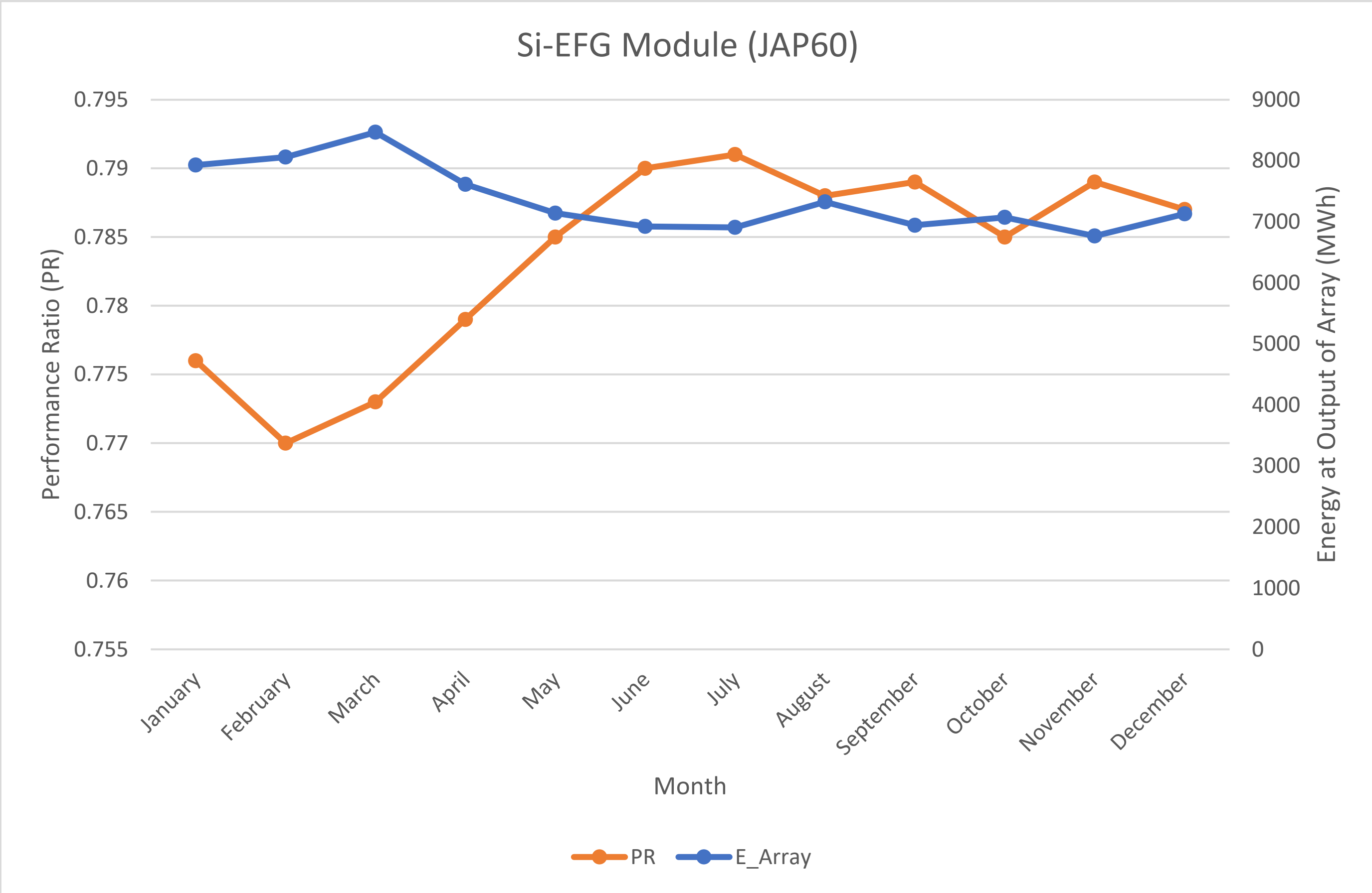

Figure 9. Performance ratio and energy yield of EFG module.

4.3. Effect of Optimizer on Energy Yield and Performance Ratio (PR)

Optimizer is purely used to increase PV system design and production and helps in supporting monitoring and optimizing overall PV system. Installed optimizer receives direct current (DC) energy from solar irradiance, regulates module output and subsequently sends energy to inverter for direct current (DC) to alternating current (AC). PV array's overall energy output will increase by using an optimizer as this will track the maximum power point tracking (MPPT) value of individual modules of the PV system. With this tracking system, the modules can increase DC power efficiency from the solar cells to the inverter system. In terms of monitoring, optimizers will allow performance-monitoring for individual modules for quick maintenance. These optimizers can mitigate degradation rate, mismatch losses and partial shading. Using the previously optimized tilt angle of 10° and monocrystalline module technology, further work was conducted by adding an optimizer to the system. The P401 WorldWide optimizer was used with an expected power output of 400 W. As a result, annual energy production increased from 88,986 MWh/year to 89,782 MWh/year, and the performance ratio (PR) improved from 78.9% to 79.8%. Figure 10 below shows the effect of with and without an optimizer on the plant's performance ratio (PR).

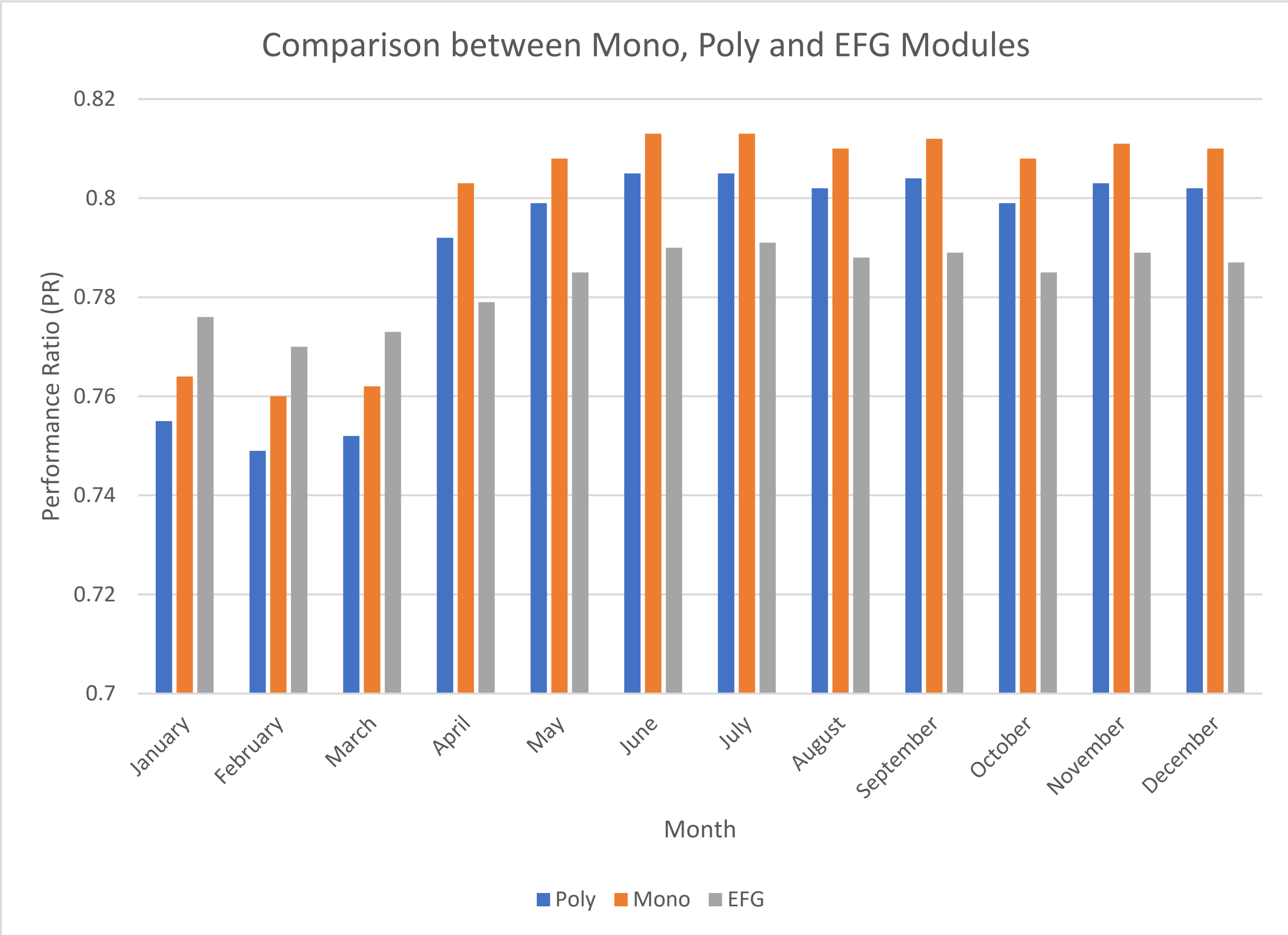

Figure 10. Performance ratio and energy yield comparison of mono, poly and EFG modules.

4.4. Effect of Module Efficiency in Respect to Irradiance and Ambient Temperature

Each module, regardless of its brand and specifications, has efficiency levels depending solely on irradiance levels and ambient temperature that affects the cell temperature subsequently. Two PV modules with different technologies are used to understand and identify which efficiency rate works for the modules up to a specific irradiance level. Figures 11 and 12 indicate monocrystalline modules tend to have a higher efficiency rate than the polycrystalline modules as the former tends to work efficiently in higher temperatures than the latter. However, for both modules, it can be noticed that the efficiency curve tends to take a dip as soon as it passes the irradiance level of 1000 W/m^2 which indicates that regardless of cell temperature, modules can only accept energy input up to a certain level to maintain an efficiency rate high for maximum energy capture to be injected into grid. Therefore, maintenance and cooling systems are often retrofitted onto array modules to keep the module cells cool for maximum efficiency.

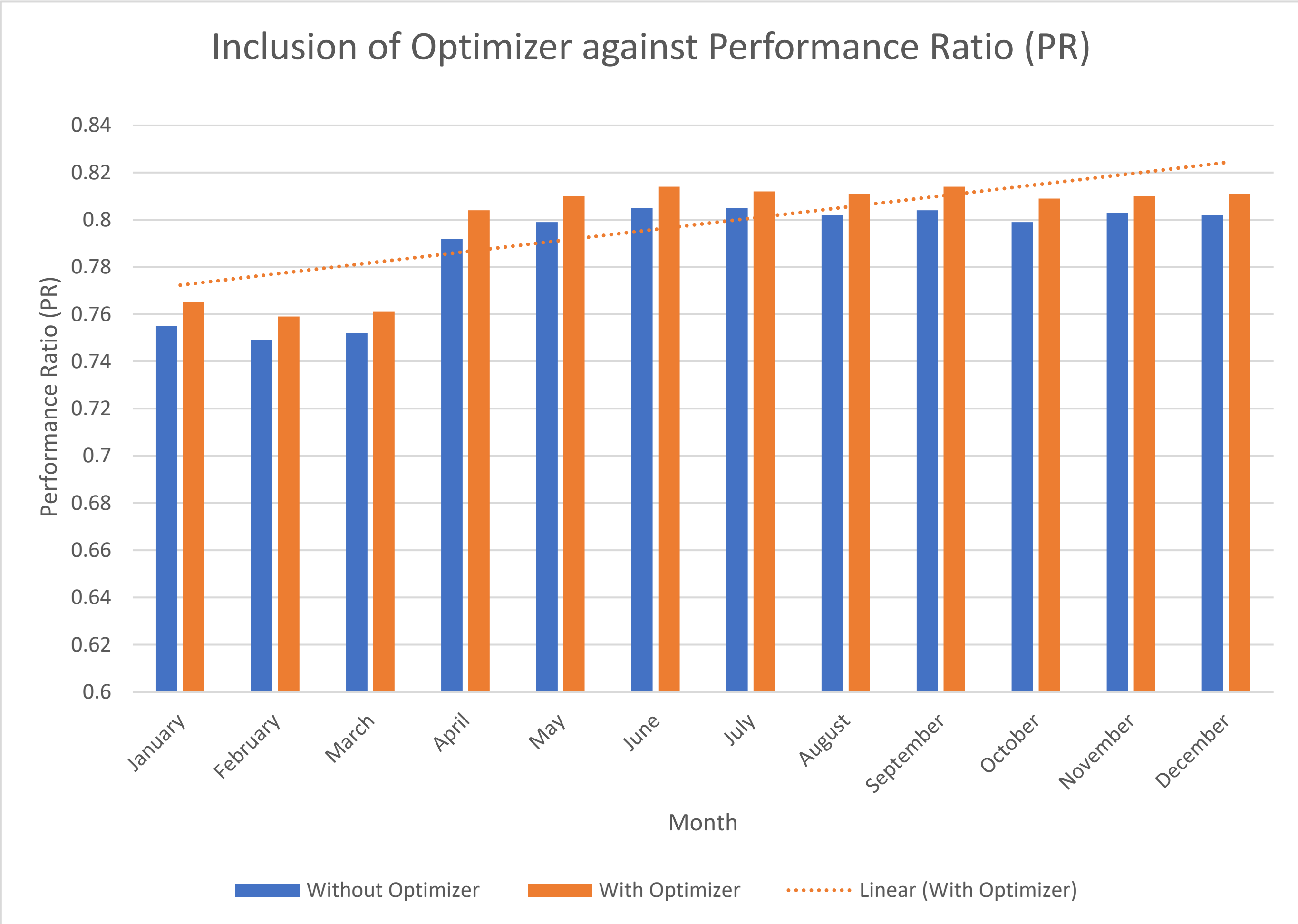

Figure 11. Performance ratio comparison with and without optimizer.

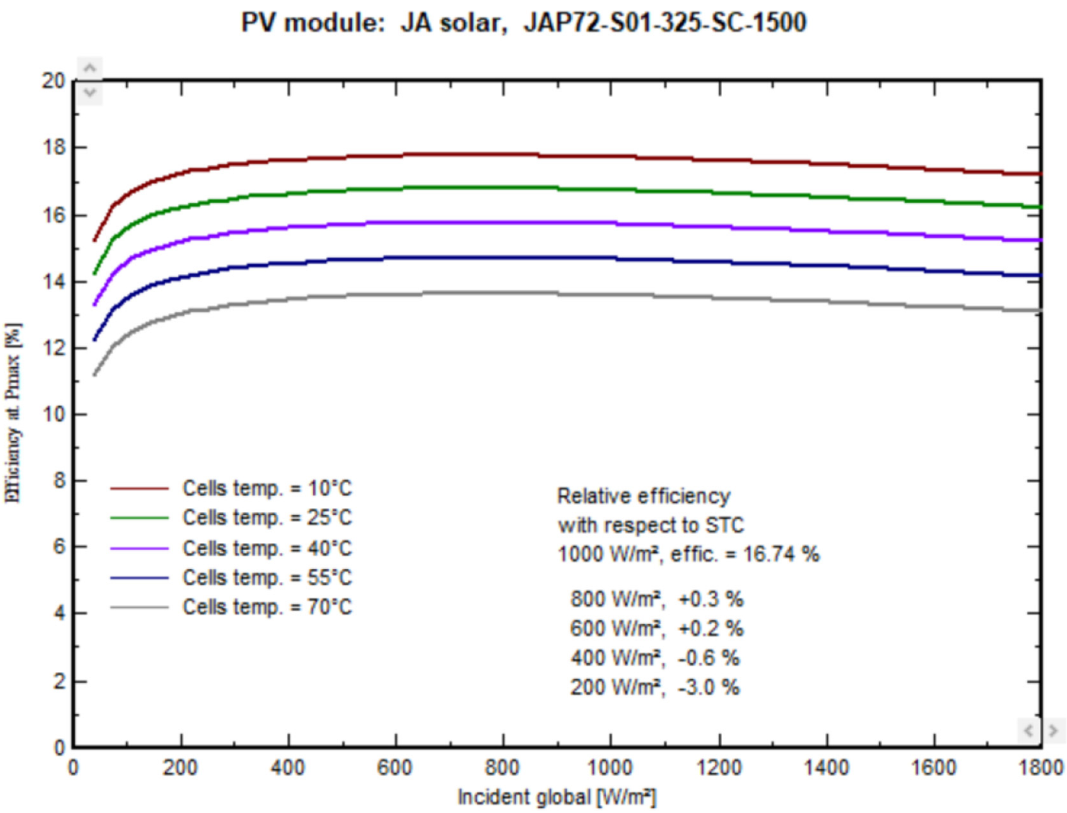

Figure 12. Efficiency against GHI for polycrystalline modules [44].

4.5. Economic and Environmental Analysis

An economic standpoint is vital in any project to ensure it runs smoothly and remains sustainable throughout the entire project timeline as shown in Table 10. It has a total estimated cost of RM 306.25 million. Levelized Cost of Energy (LCOE) is the cost of power produced by solar energy over the entire lifetime of the PV system. LCOE is vital to estimate renewable energy feasibility, which is compared to other sources of electricity and is now very competitive when compared with other energy sources such as wind, coal and gas. LCOE for this project was found to be 0.174 MYR/kWh with a payback period of 6.4 years, as it is calculated with a feed-in-tariff (FiT) of 0.470 MYR/kWh. The return on investment (ROI) was calculated to be 220.1%. Environmental concerns in this project were also addressed with the carbon balance of PV system calculated based on the Environmental Impact Assessment (EIA) of Malaysia and lifecycle emissions calculated. Total carbon dioxide emissions saved over the expected 30-year project lifecycle are 1,244,342.34 tons, based on the usage of the solar PV plant system.

Table 10. Economic project data for the LSS plant.

Economic Project Data		
Energy Generation	90,560	MWh/year
Annual Degradation Factor	0.53	%
CAPEX	245.9 million	MYR
OPEX	368,333	MYR
Installation Costs	28 million	MYR
Financing		
Loan Interest	6	%
Loan Term	21	Years
Initial Investment	61.5 million	MYR
Electricity Sale		
Feed-in-Tariff (FiT)	0.470	MYR/kWh
LCOE	0.174	MYR/kWh
Payback Period	6.4	Years
Net Present Value (NPV)	541.3 million	MYR
Return on Investment (ROI)	220.1	%

4.6. Pearson Correlation Coefficient on System Parameter against Energy Performance

The correlation model was conducted to analyze the relationship between data retrieved from external systems, such as the smart logger and the energy yield production of the large-scale solar plant. From the industry data retrieved, the LSS plant is split into 24 individual zones, each with its own smart logger and the data for each zone was recovered. Zones 1, 5, 10, 15, and 20 were selected as they were located far apart, which will enable us to obtain measurements from different sections of the plant. Figures 13–17 shows the correlation model and the relationship between smart logger data and energy yield production. Zone 20 contains the highest positive relationship between smart logger data and total grid energy data as it contains efficient system parameters inducing in positive relationship.

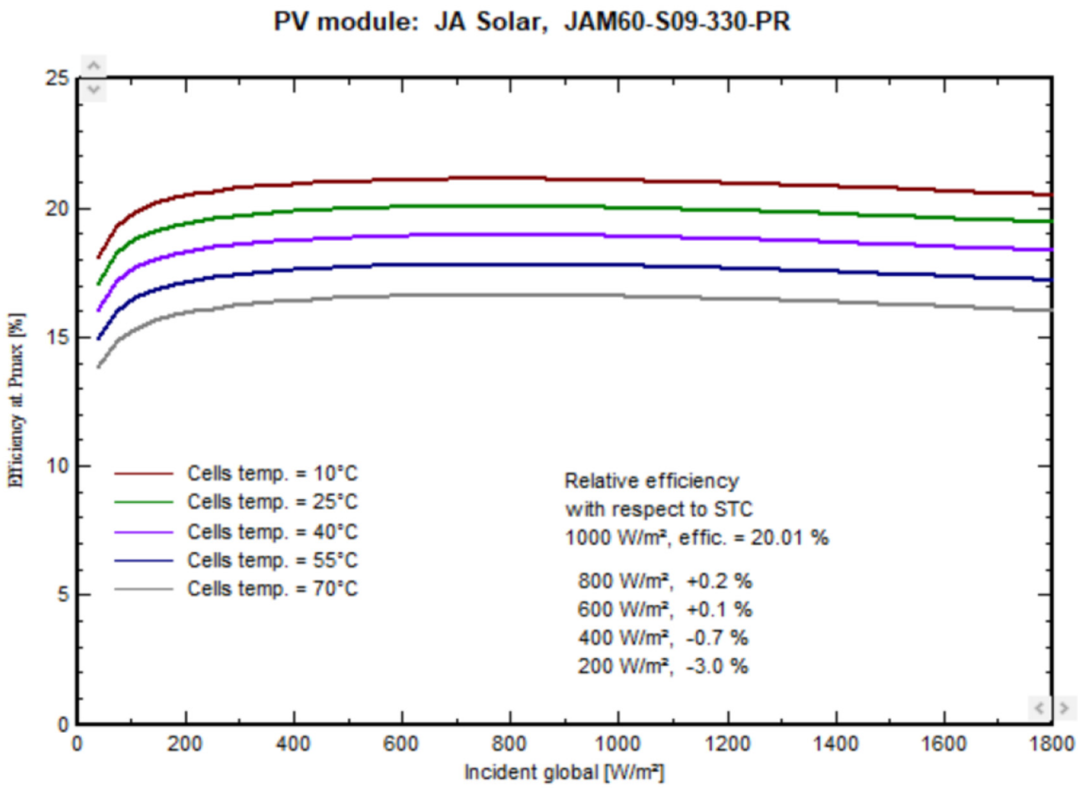

Figure 13. Efficiency against GHI for monocrystalline modules [44].

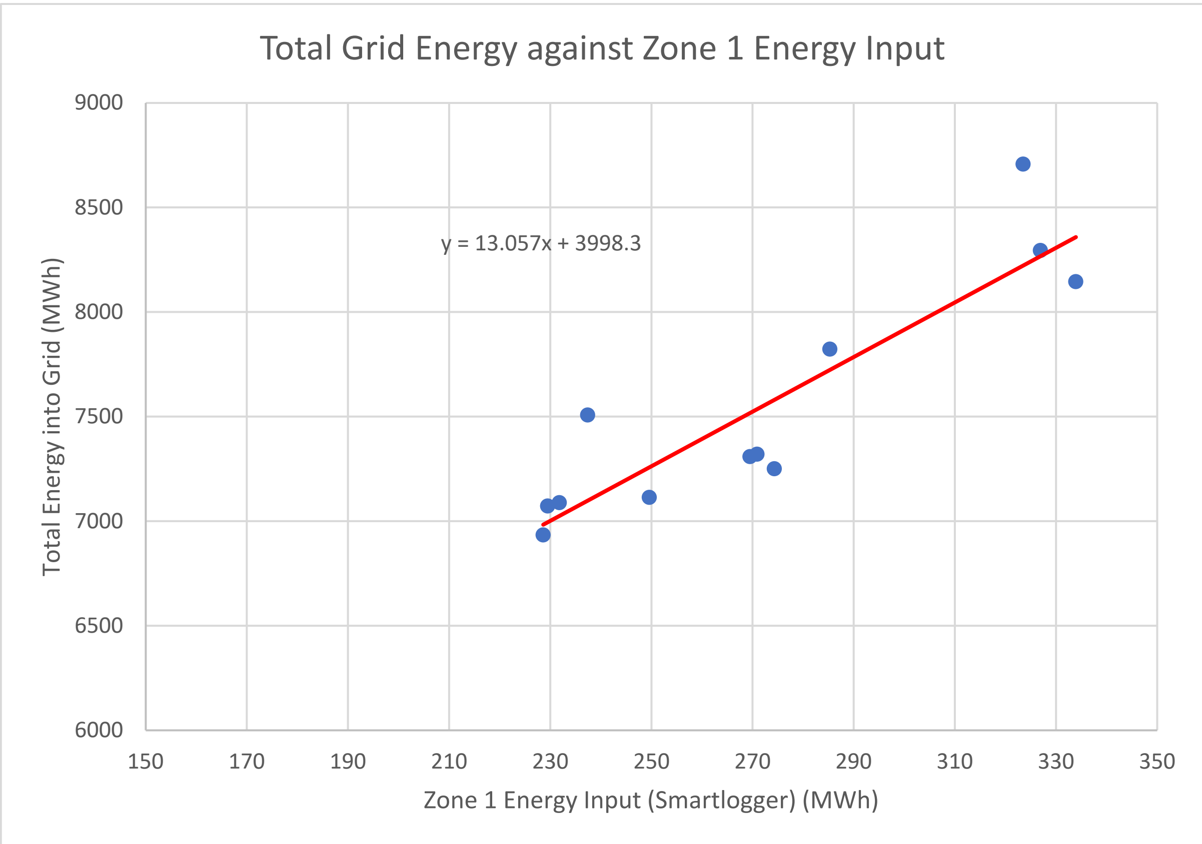

Figure 14. Total grid energy against zone 1 energy input.

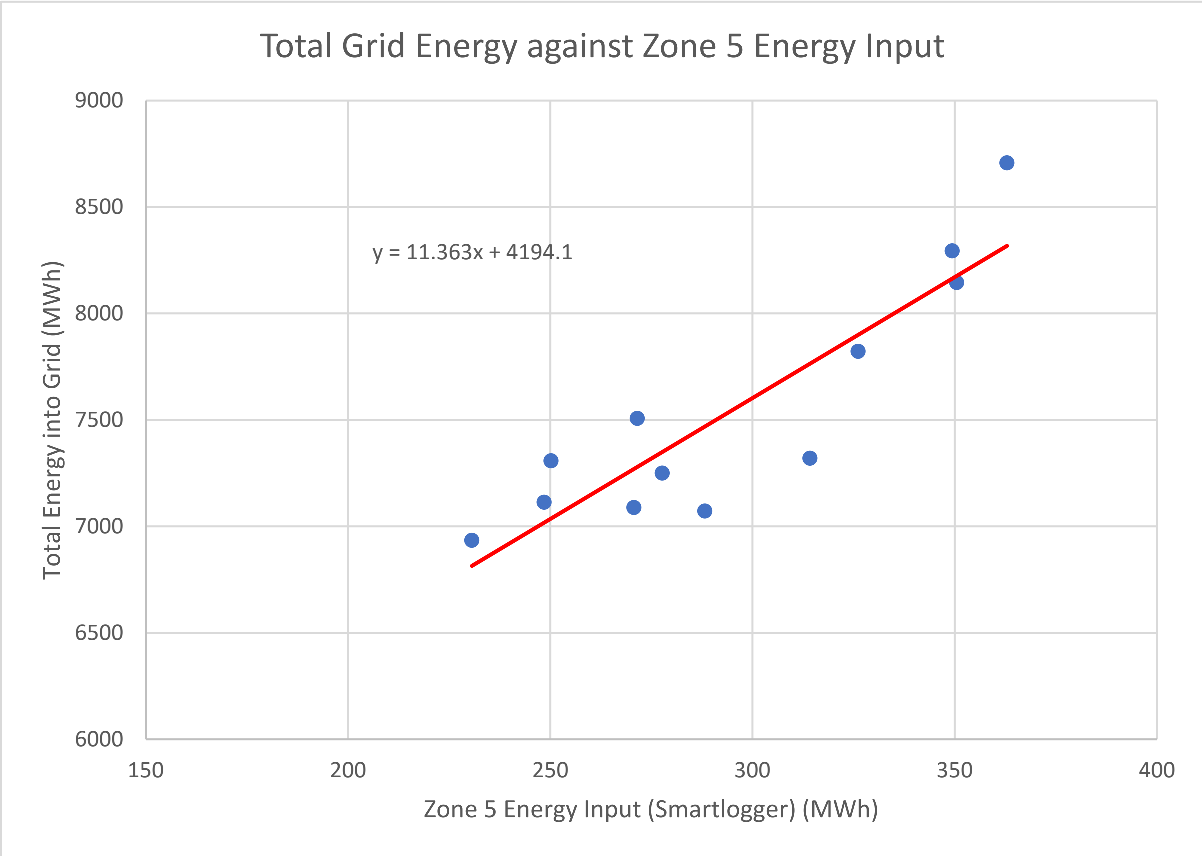

Figure 15. Total grid energy against zone 5 energy input.

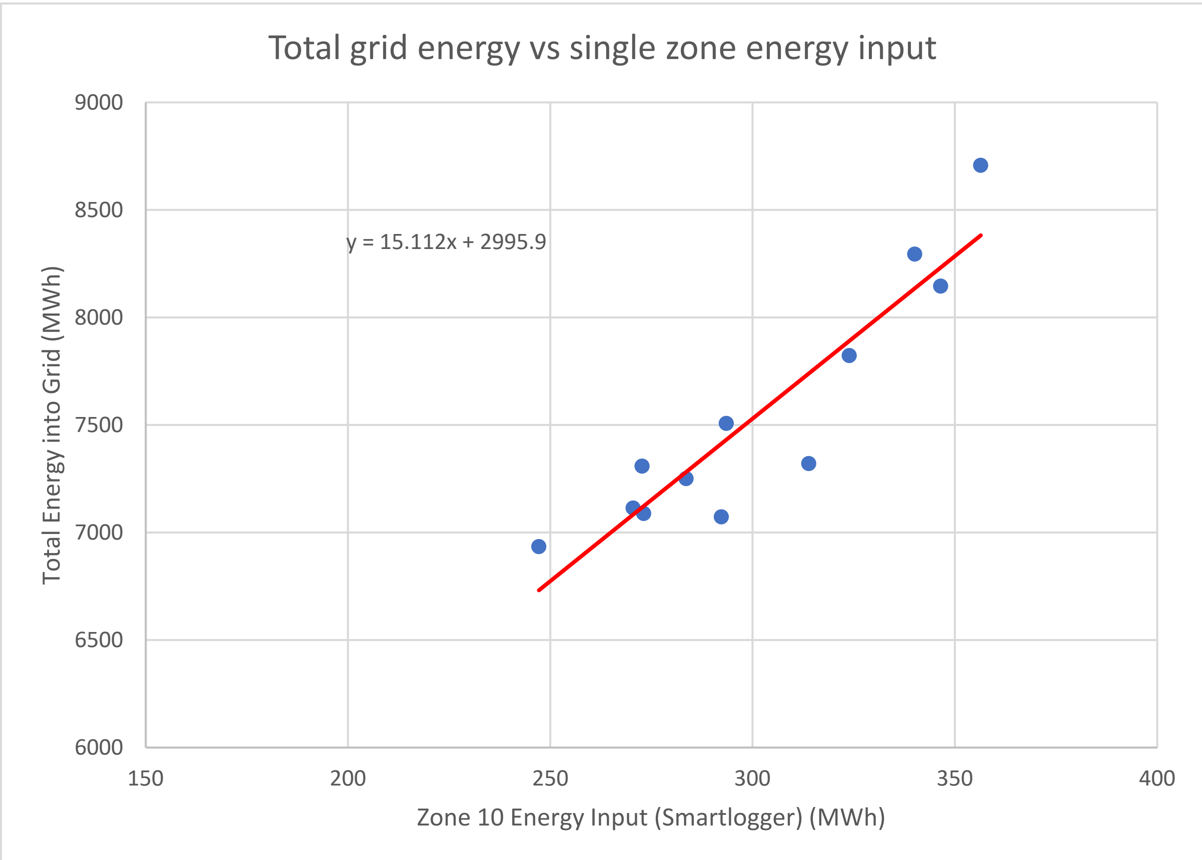

Figure 16. Total grid energy versus selected zone's energy input.

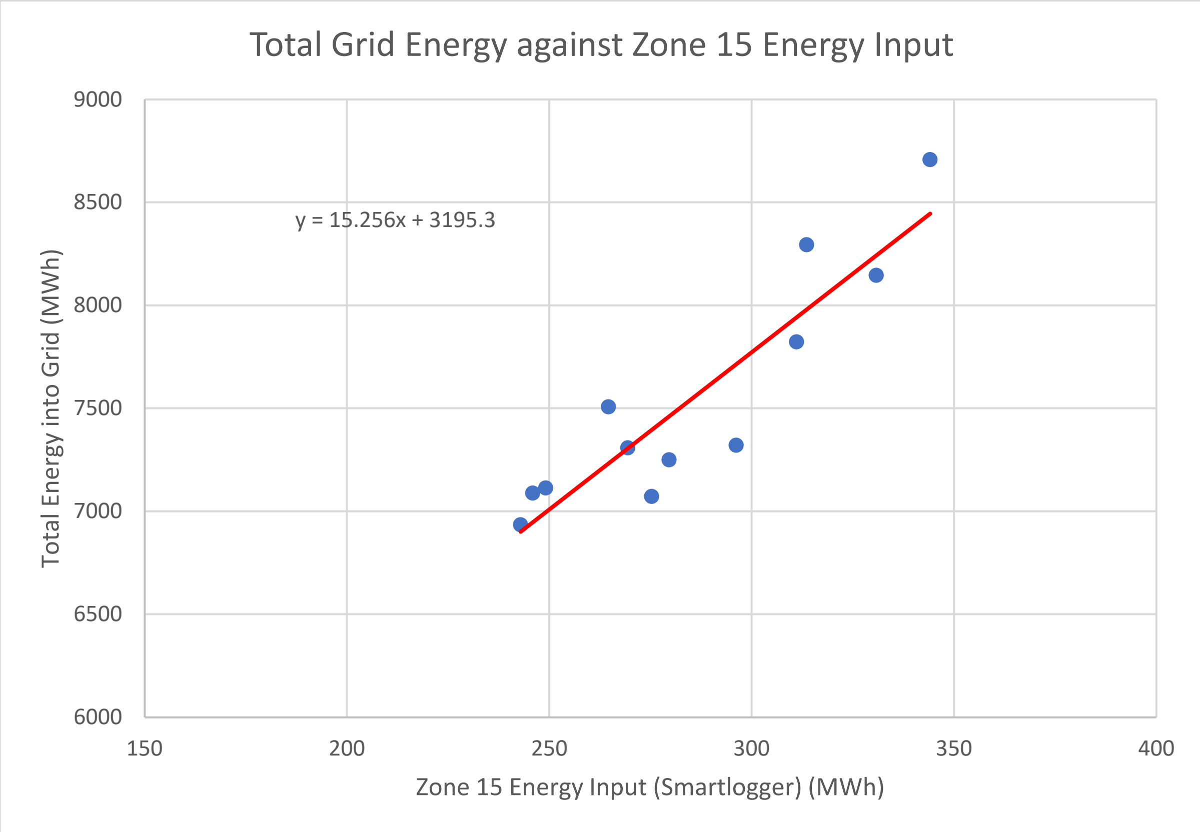

Figure 17. Total grid energy against zone 15 energy input.

4.6.1. Validation: Pearson Correlation Model and Indexes

The system performance is validated using the Pearson correlation model as shown in Table 11. It is observed that Zone A to E exhibit similar correlation coefficient values ranging from 0.878 to 0.915. The values of A range from 2995.9 to 4194.1, whereas B ranges from 11.363 to 15.256. Zone E shows the highest correlation coefficient value. Zone A to E represents Zones 1, 5, 10, 15, and 20 that are geographically apart. This is to ensure the data selected truly reflects the system conditions. Zone E (Zone 20) demonstrated the highest positive relationship between smart logger data and total grid energy data. It is consistent with the correlation coefficient on system parameters against energy performance from the data retrieved from the external system, such as the smart logger and the energy yield production of the large-scale solar plant.

Table 11. Correlation relationship between zones and total energy in 5 individual zones.

Zone	Equation	A, B	Correlation Coefficient Value
A	$y = 13.057x + 3998.3$	3998.3, 13.057	0.895
B	$y = 11.363x + 4194.1$	4194.1, 11.363	0.878
C	$y = 15.112x + 2995.9$	2995.9, 15.112	0.915
D	$y = 15.256x + 3195.3$	3195.3, 15.256	0.891
E	$y = 14.576x + 3154.9$	3154.9, 14.576	0.905

4.6.2. Validation: Site Data and Modelled Energy System Output for Selected Key Parameters

Once system parameters are adjusted to provide an optimum and efficient energy yield performance, these values are compared with the original real-time data received from the industry. Table 12 shows the changes in data comparison that were carried out to indicate the difference in the increase in energy yield production and performance ratio (PR). It shows the differences and similarities in both design specifications. In terms of performance data, it is different as meteorological data plays a role as both designs took place in different timelines. Different modules and tilt angles were used in the latest modelling, contributing to the difference in energy yield production. Figures 18–20 indicate the difference that can be achieved when industry and study data are compared against each other. The industry data has been extracted via MMF and Smart Logger sensors attached to 20 individual zones within the plant, providing real-time data with a 1-min time step. Validation can be further concluded by providing a better system parameter to maximize energy production annually.

Table 12. Validation and comparative studies between site data and output of the modelled energy system.

Specifications	Site Data	Modelling Output
Tilt Angle	7°	10°
Weather Data	Meteornorm	Meteonorm
Transposition Model	Perez	Perez
Soiling	3.4%	3.4%
PV Module	Si-Poly	Si-Mono
Max Power Point	325.0 W	325.0 W
Inverter	SUN2000-42kTL	SUN2000-42kTL
Inclusion of Optimizer	No	Yes (P401 WorldWide)
Energy Production	85,065 MWh/year	90,560 MWh/year
Performance Ratio	80.76%	80.05%

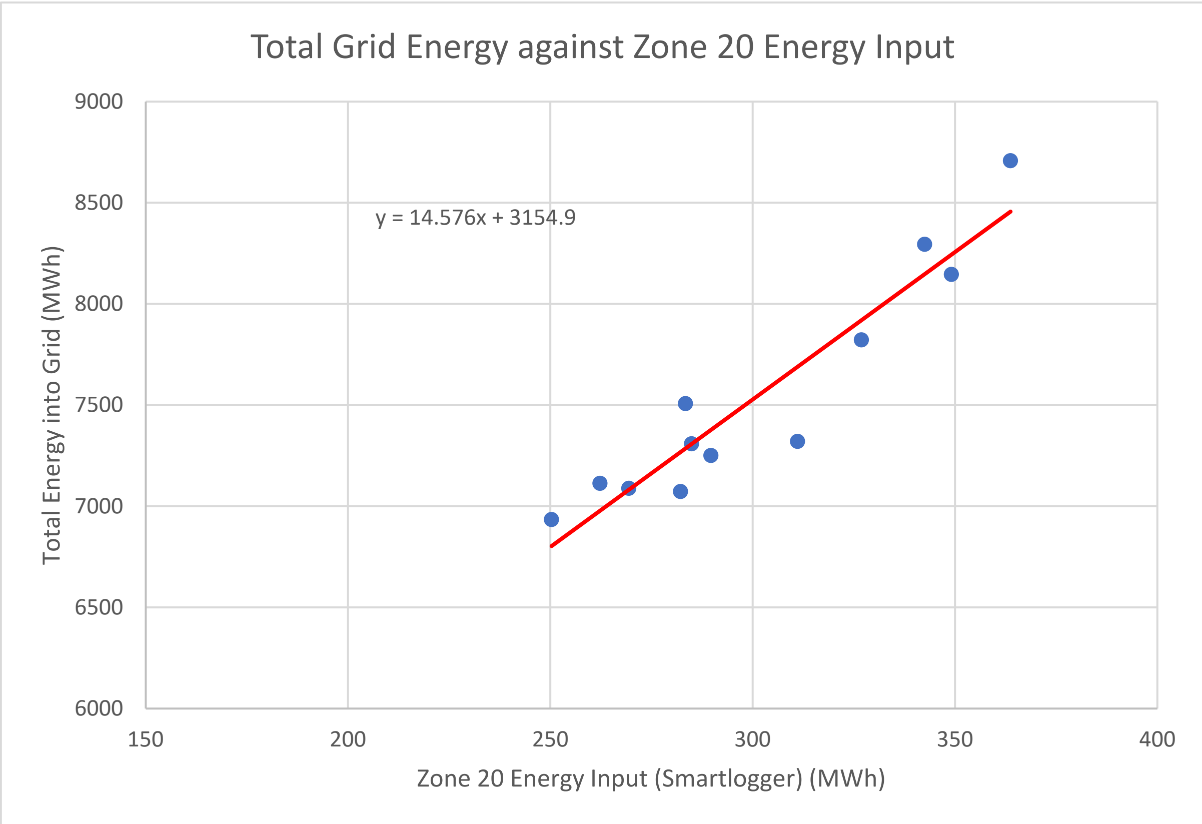

Figure 18. Total grid energy against zone 20 energy input.

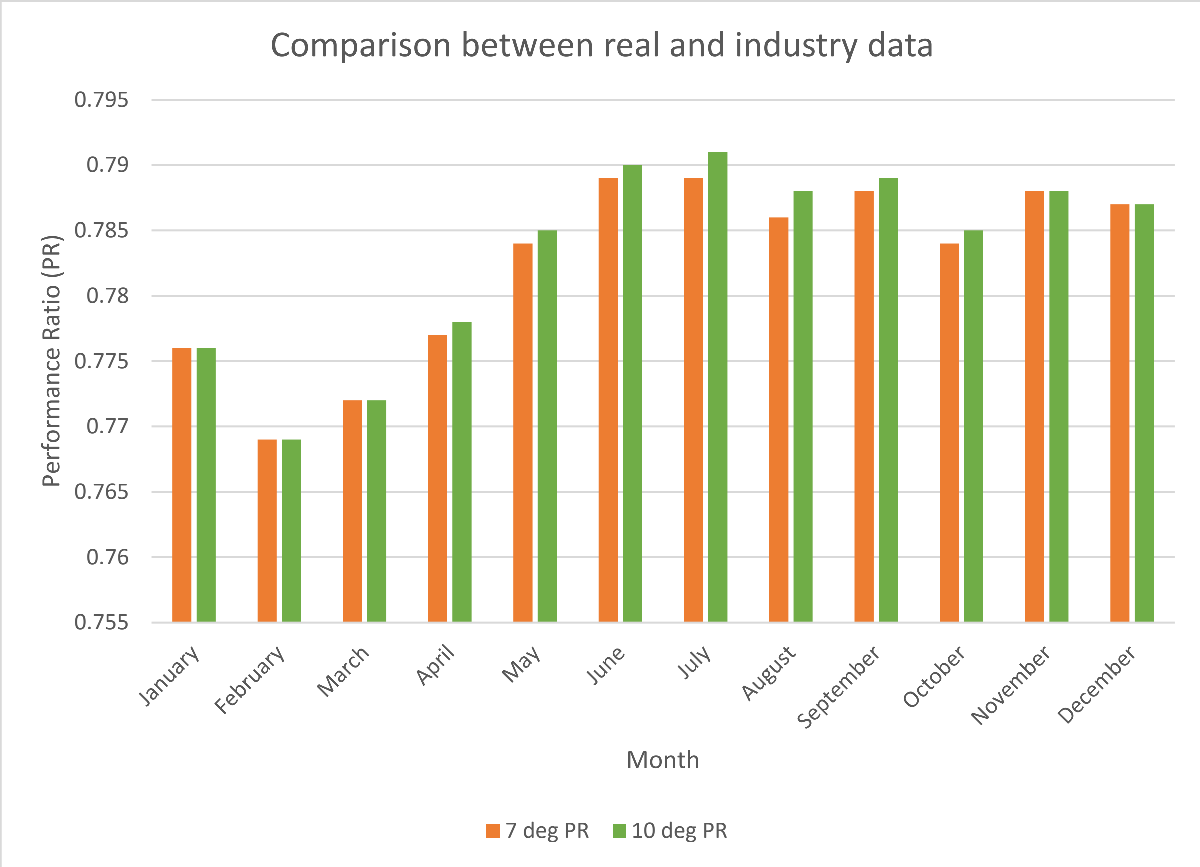

Figure 19. Comparison between final two tilt angles.

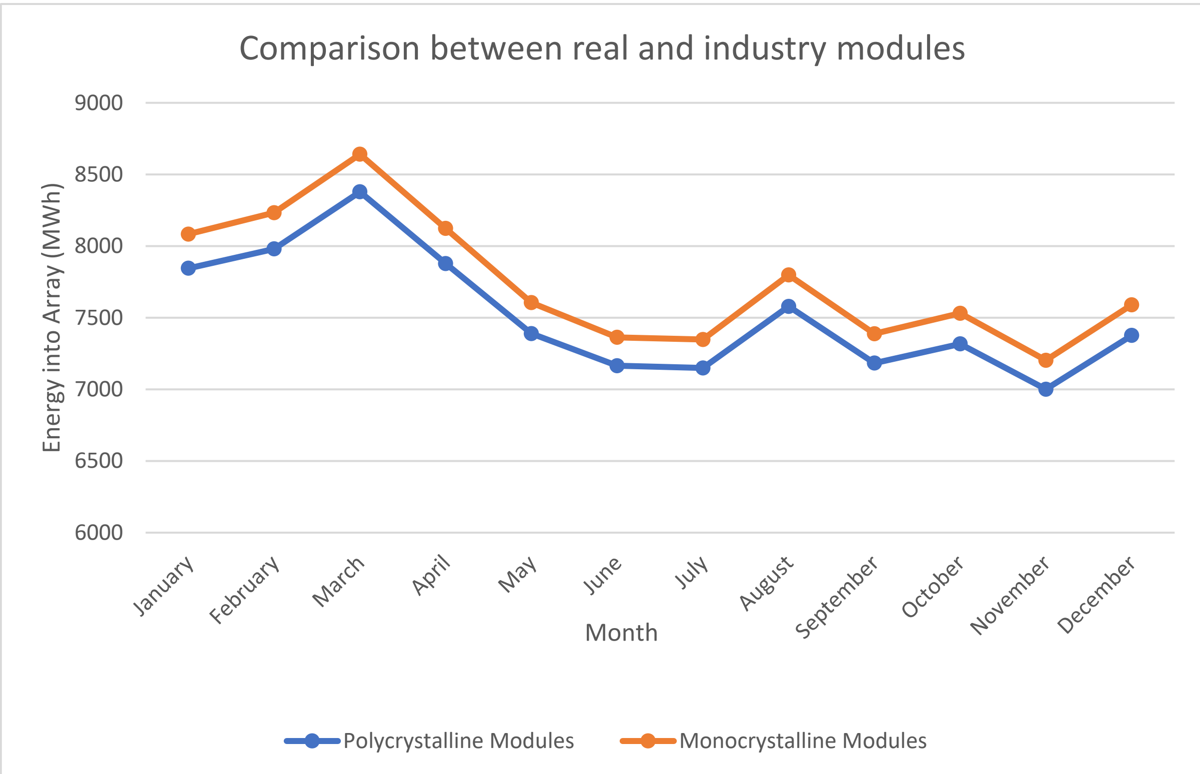

Figure 20. Comparison between final 2 modules.

5. Conclusions

The Malaysian government plans to increase its renewable energy (RE) capacity to 31% by the end of 2025 and aims to achieve 40% by 2035 through energy generation planning [45]. This will align exactly with the government initiative of reducing GHG emissions by 45% by the year 2030 by increasing the use of renewable energy sources with a primary target to produce up to 2.5 GW of solar energy via LSS specifically to boost sustainable development goals. Solar PV systems have been widely used, from industries to residential homes, because Malaysia receives a high irradiation potential of up to 5000 Wh/year. The drop in efficiency of the solar PV system became evident over time due to the degradation rate within system parameters, which induced more losses than the environmental factors affecting the system.

The work identified the significant system parameters affecting the performance and losses. It also investigated possible optimization to enhance the energy yield. Based on a study conducted for the photovoltaic system, tilt angle, effect of module technology, inclusion of optimizer and effect of module efficiency on different temperatures are the parameters investigated for optimum system performance. An optimum tilt angle of 10°, monocrystalline module and inclusion of optimizer increases the overall energy production from 88,986 MWh/year to 89,782 MWh/year and PR from 78.9% to 79.8%. Economic and environmental evaluations were also conducted to assess the cost of energy required for the system to operate annually. The Levelized Cost of Energy (LCOE) was found to be 0.178 MYR/kWh, with carbon emissions savings of 1,244,342.34 tons. Based on these findings, validation was conducted, and a comparison was made using real-time industry data and system data studied. Adjusting several system parameters would improve energy production and performance ratio (PR), extending the system's lifespan and increasing renewable energy (RE) capacity over a longer period, further supporting the government's initiative to increase RE capacity and reduce GHG emissions. More detailed system parameters must be analyzed to reduce internal losses such as thermal, ohmic, auxiliary, and aging losses. Advancements in technology will provide a pathway to minimize these losses and improve panel efficiency over a longer lifespan.

Author Contributions

Writing–Original Draft Preparation, L.S.; Writing–Review & Editing, Y.I.G.; Methodology, L.S.; Software, L.S.; Formal Analysis, L.S.; Supervision, Y.I.G.; Project Administration, Y.I.G.

Ethics Statement

Not applicable.

Informed Consent Statement

Not applicable.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

List of Nomenclature

AC	Alternating Current	p	Power consumption of load
CAPEX	Capital Expenditure	P_{loss}	Power loss in the cable
CF	Capacity Factor	PID	Potential Induced Degradation
CO_2	Carbon Dioxide	PR	Performance Ratio
$cos\varphi$	Power factor of load	PV	Photovoltaic
CUF	Capacity Utilization Factor	PVSyst	Photovoltaic Software
DC	Direct Current	r	correlation coefficient
DR	Degradation Rate	RE	Renewable Energy
EIA	Environmental Impact Assessment	RES	Renewable Energy Sources
FF	Fill Factor	ROI	Return on Investment
FiT	Feed-in Tariff	RMS	Root Mean Square
GHI	Global Horizontal Irradiance	S	Conductor cross-section
GITE	Green Income Tax Exemption	SC	Short Circuit Current
GCPV	Grid-Connected Photovoltaic	SELCO	Self-Consumption
GHG	Greenhouse Gas	SEDA	Sustainable Energy Development Authority
HOMER	Hybrid Optimization of Multiple Electric Renewables	STC	Standard Test Conditions
IEC	International Electrotechnical Commission	TNB	Tenaga Nasional Berhad

IRENA	International Renewable Energy Agency	μ_{ISC}	Temperature Coefficient for Short-Circuit Current
l	Distance between source and load	μ_{Pmax}	Temperature Coefficient for Maximum Power
LCOE	Levelized Cost of Energy	μ_{Voc}	Temperature Coefficient for Open-Circuit Voltage
LID	Light Induced Degradation	μ_{Vmp}	Temperature Coefficient for Maximum Voltage
LSS	Large Scale Solar	V_o	Source voltage
MPPT	Maximum Power Point Tracking	ρ	Specific resistance of conductor material
MS	Malaysian Standards	x_i	values of the *x*-variable in a sample
MYR	Malaysian Ringgit	$\bar{x}$	mean of the values of the *x*-variable
NEM	Net-Energy Metering	y_i	values of the *y*-variable in a sample
NPV	Net Present Value	$\bar{y}$	mean of the values of the *y*-variable

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