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Solar Power Plant of Apartment Kertapati – A Design Study to Reduce Carbon Emission

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ABSTRACT

Energy demand in residential and housing areas in Indonesia is still predominantly reliant on fossil fuels. This dependency grows, triggering various environmental issues such as air pollution and global warming. Furthermore, energy costs in these areas are relatively high, partly due to increasing tariffs from PLN (Indonesia's state electricity company). One residential area in Palembang City with the potential for developing a Solar Power Plant (Solar PV System) is the Kertapati Rental Apartment Complex (Apartment Kertapati), located in Karya Jaya Sub-district, Kertapati District, Palembang City, South Sumatra. This area spans approximately 7 hectares and consists of a total of 300 units. Energy demand in this area is significant, particularly to support public and social facilities such as lighting, cooling systems, and various other needs. This study utilises PVsyst software, which is designed for the planning, simulation, and analysis of solar power systems. With the identified energy needs and favourable environmental conditions, this project has significant potential to deliver both economic and environmental benefits. However, this study focuses exclusively on on-grid systems for analysis and data processing.

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1. INTRODUCTION

1.1. Background

The development of Solar Power Plants (PV power plants) represents a significant effort to reduce dependence on fossil fuels, which are becoming increasingly scarce and contribute to serious environmental issues [1], [2]. As a renewable and environmentally friendly energy source, PV power plant offers a promising alternative to help meet the growing energy demands of the future [3], [4].

To address climate change and promote environmental sustainability, the Indonesian government has set a target to reduce greenhouse gas emissions by 29% by 2030 [5], [6]. One of the primary strategies to achieve this goal is the increased adoption of renewable energy sources, including the construction and use of PV power plants [7].

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1.2. Problem Statement

In Indonesia, the development of PV power plants has been gaining momentum, supported by both government initiatives and private sector investment. Residential and settlement areas have become key targets for solar energy deployment due to their high electricity consumption, particularly for lighting, cooling, and various household needs [8], [9], [10].

However, energy use in residential areas across the country continues to be dominated by fossil fuels. This reliance not only contributes to environmental degradation, such as air pollution and global warming, but also results in relatively high energy costs, especially as electricity prices from the state utility company, PLN, continue to rise [11].

1.3. Research Objective

This study explores the potential for solar energy development in Palembang, the capital of South Sumatra Province, which covers approximately 352.52 km² and is home to nearly 1.7 million residents. With a tropical climate, an average annual rainfall of 2,500 mm, and solar radiation averaging 4.67 kWh/m²/day, Palembang presents a strategic opportunity for integrating renewable energy, particularly solar photovoltaic systems. The research focuses on the Kertapati Apartments in Karya Jaya Village, Kertapati District, assessing the feasibility of installing a PV power plant to meet local energy needs. The complex spans around 7 hectares and includes 300 residential units with significant electricity demands, especially for public lighting, communal facilities, and cooling systems. By evaluating solar potential, energy consumption, and installation capacity, the study aims to provide a practical, scalable model for deploying solar energy in densely populated urban residential areas of Palembang.

1.4. Contributions

This study contributes valuable, up-to-date data and insights into the potential for solar energy utilization at the Kertapati Apartments in Palembang. It identifies strategic opportunities for solar panel installation and assesses both the technical and economic feasibility of implementing a PV power plant within the residential complex. Beyond the technical evaluation, the research offers practical policy recommendations and development strategies aimed at supporting the sustainable integration of solar energy into the apartment's infrastructure. These contributions are expected to serve as a reference for future renewable energy initiatives in similar urban residential settings.

2. METHOD

To achieve the objectives of the study, the scope of work for the PV power plant Feasibility Study at the Kertapati Apartments includes several key activities. First, it involves reviewing relevant materials to support the study process and compiling a list of necessary primary and secondary data [12], [13], [14]. Second, the study includes the preparation of data collection and preparation required for further analysis. Third, it entails the collection of data related to the potential implementation of solar panels. The main outcome of this activity is a set of technical recommendations, including components, proposed locations, and the appropriate panel capacity for the Kertapati Apartments. The study employs PVsyst software, for simulation and analysis of solar power systems.

2.1. Solar Energy Potential

Indonesia holds significant potential for solar energy due to its geographical location near the equator, which allows the country to receive abundant sunlight throughout the year. While solar energy potential varies across different regions and islands, overall, it remains highly promising [15], [16], [17]. As an archipelagic nation, Indonesia experiences average daily solar radiation ranging from 4.5 to 6.5 kWh/m² in most areas, including South Sumatra.

With a growing population, the demand for electricity in Indonesia continues to rise. In response, the government has introduced various policies and incentives to promote the adoption of PV power plants. This transition not only supports efforts to meet the increasing energy demand but also helps reduce dependence on fossil fuels and contributes to lowering greenhouse gas emissions [18], [19], [20].

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2.2. Components of PV Power Plant

The capacity of photovoltaic modules, inverters, transformers, switchgear, AC cables, and DC cables are components that must be considered in designing a solar power plant. Figure 1 shows a typical diagram of an off-grid and on-grid PV power plant system.

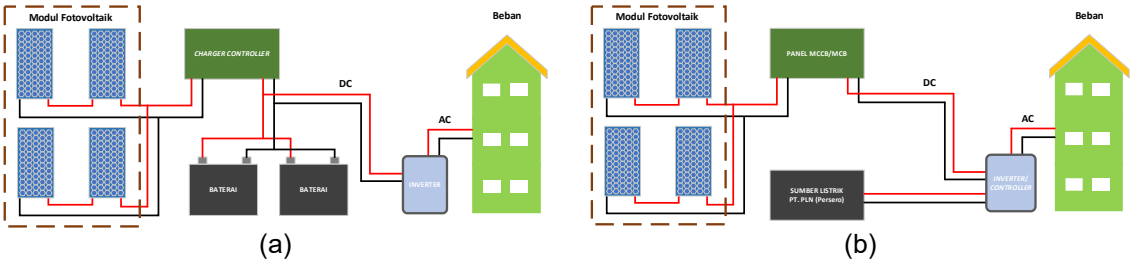
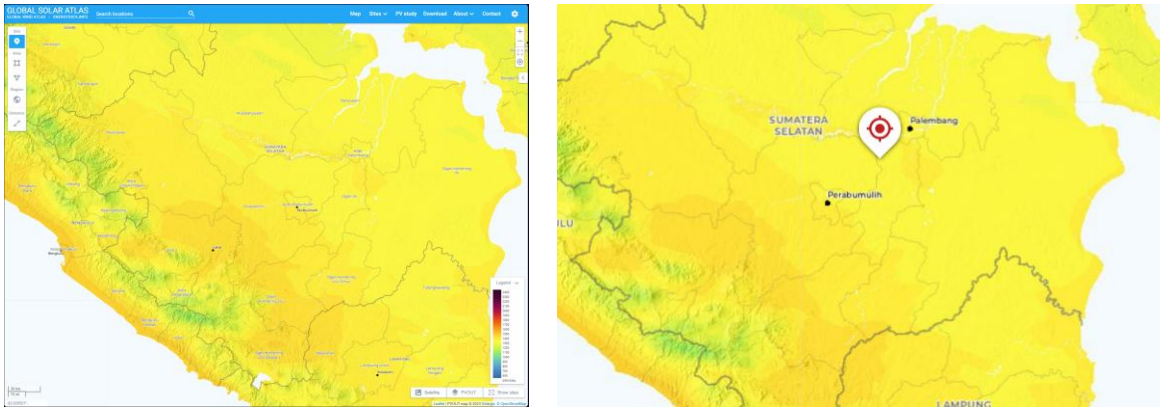


Figure 1. Block Diagram of Solar PV System (a) on-grid, and (b) off-grid

A photovoltaic power plant uses interconnected modules made of silicon-based solar cells to convert sunlight into direct current (DC) electricity. The size and layout of the array depend on available space and energy needs, with installation possible on rooftops, open land, or integrated into buildings. Support structures secure the modules and optimize their orientation for maximum sunlight. An inverter converts the DC output into alternating current (AC), sized according to the plant's capacity and load. Relays and circuit breakers are included to protect the system, ensure reliability, and maintain safety.

2.3. South Sumatra Solar Radiation Profile and Technical Feasibility

South Sumatra Province receives abundant sunlight year-round, with about 300 sunny days annually. Average daily solar radiation ranges from 4.6 kWh/m² in the west to around 5 kWh/m² in the central region, totaling 1,300–1,900 kWh/m² per year. Figure 2a illustrates the solar radiation distribution across the province, while Figure 2b highlights local weather conditions and sunlight exposure at the site, along with detailed mapping that supports the efficiency of solar PV system.



(a) (b)

Figure 2. (a) Map of solar radiation in South Sumatra Province, (b) Solar Profile at the Apartment Kertapati

2.4. Location Analysis and Power Requirement

Site analysis confirms that the Kertapati Apartment complex in Palembang is well-suited for a solar power plant, with sufficient solar exposure and flexible installation options on rooftops or open land. Local mapping and surveys reveal the site's structural suitability, as illustrated in Figure 3a and 3b, which show the general layout and available space, while Figure 3c highlights rooftop areas ideal for panel placement. The apartment's power needs are divided between public facilities (Fasus and Fasum) and residential units. For the three buildings, the total power requirement for Fasus and Fasum is 49.5 kVA (16.5 kVA per building), based on the installed PLN meter, as shown in Figure 3d.

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Figure 3. Site visit, (a) and (b) show the placement options for the PV panels in open fields available at the location. (c) Shows the placement options for the PV panels at the rooftop location. (d) A 3-phase meter

Based on billing data from the past two months and PLN's government office tariff of Rp. 1,699.53/kWh for 6.6–200 kVA, the estimated monthly energy consumption for Block A is 2,350 kWh, or about 78.33 kWh per day. This indicates substantial electricity use that must be factored into the solar power plant design. Buildings B and C each require approximately 26.67 kWh per day, and while their consumption is lower than Block A's, these figures are essential for designing a system that effectively meets the daily energy needs of all three buildings [21], [22], [23], [24].

The total power requirement for the Kertapati Apartment housing units is estimated at 390 kVA, based on 1,300 VA meters installed in each of the 300 residential units (1,300 VA × 300). This figure represents the overall capacity needed to support the daily operations and energy demands of all households, as indicated by the installed PLN meters.

2.5. Solar Profile

The solar profile describes the sunlight patterns at a specific location over time, showing how solar intensity varies daily, seasonally, and annually. This data is crucial for designing and optimising solar power systems. Key parameters of the solar profile are presented in Table 1.

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Table 1. Main parameters for characterization of solar energy profiles

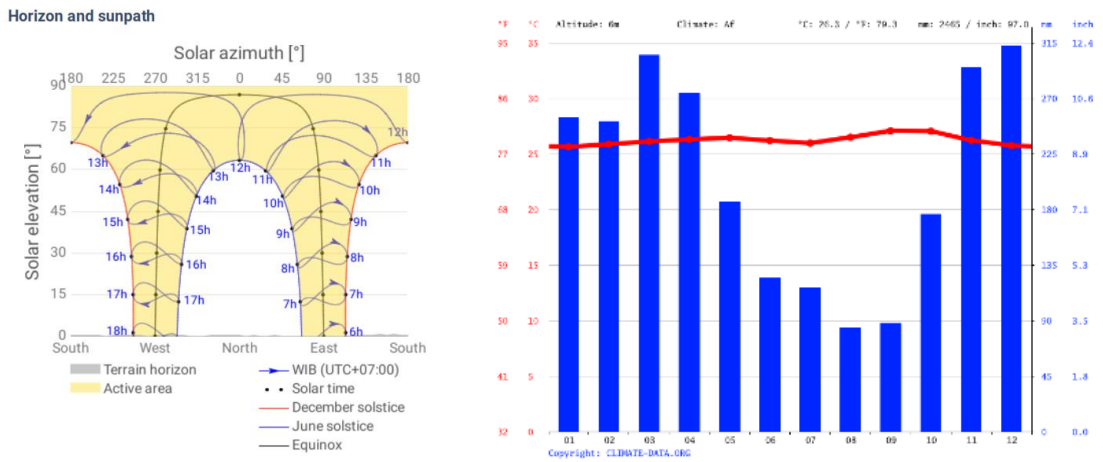
Parameter	Description
Sunlight Irradiance	It is a measure of the intensity of sunlight reaching an area in a given unit of time, to measure how much solar energy can be absorbed.
Daily Variations	A solar profile provides insight into how sunlight intensity varies in a day It involves changes in light intensity from sunrise to sunset.
Seasonal Variations	Shows how sunlight intensity changes throughout the year in relation to seasonal changes.
Shadow and Barrier Effects	Solar profiles also help identify potential shadows or obstructions that can affect the efficiency of solar panels.
Optimal Orientation and Tilt of Solar Panels	Based on the solar profile, the optimal orientation and tilt of the solar panels can be calculated to capture as much sunlight as possible.
Utilization of Energy	This information is important in understanding how efficiently a solar PV system can utilize the solar energy available at a particular location.

2.6. Horizon, Sunpath, and Climate Profile

Following a site survey and location visit, historical climate data for the Kertapati Apartment area was analysed using the GlobalAtlas tool, with results shown in Table 2. Located on the equator, the area has a tropical climate with warm temperatures year-round, ranging from 24 °C to 32 °C. It experiences high humidity, distinct wet and dry seasons, and lush vegetation. The rainy season runs from October to April, with December being the wettest month (312 mm), while the dry season lasts from May to September, with August being the driest (84 mm). A summary of the region's climate is presented in Figure 4. For optimal solar panel performance, the ideal tilt angle, based on latitude, maximises annual solar radiation, though adjustments must consider factors like dust accumulation and potential shading between panels.

Table 2. Location map results information.

Item	Acronym	Mark
PV Specific Power Output	PVOUT	1324.5 kWh / kWp
Normal Irradiation	DNI	874.1 kwH / m^2
Global Horizontal Irradiation	GHI	1669.3 kWh / m^2
Diffuse Horizontal Irradiation	DIF	986.1 kWh / m^2
Global tilted irradiation	GTI Opta	1677.3 kWh / m^2
Optimum tilt angles	OPTA	70
Water temperature	TEMP	27.1 ^{0}C
Elevation	ELE	2 m



(a) (b)

Figure 4. (a) Shows a picture of the solar irradiance path at the location, (b) Average annual climate conditions in the Apartment Kertapati area

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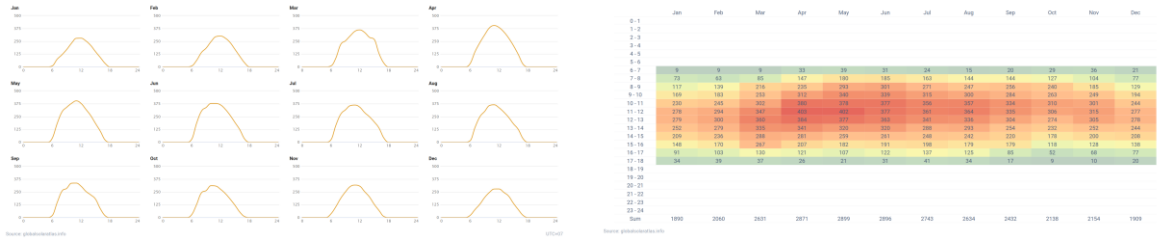
The solar profile provides insight into how sunlight intensity varies over the course of a day. It involves changes in light intensity from sunrise to sunset, as seen in Figure 5a. Furthermore, Figure 5b shows how sunlight intensity changes throughout the year in relation to seasonal changes.



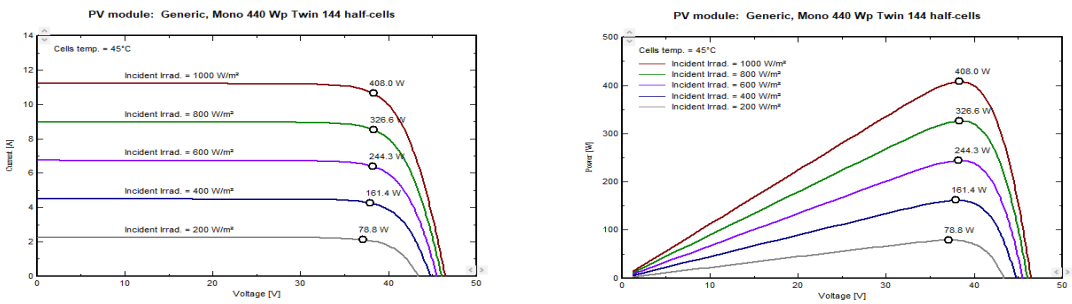
(a) (b)

Figure 5. (a) Profile of average daily solar radiation values in Apartment Kertapati.(b) Profile of monthly average solar radiation values Apartment Kertapati

3. RESULTS AND DISCUSSION

3.1. Selection of PV Power Plant Components

At the beginning of the design process, it is very important to choose the technology that will be used in the 3 x 16.5 kWp solar power plant. A simulation was carried out using PVsyst software by utilizing the solar radiation profile at the location. In this simulation environment, monocrystalline solar panels were selected, resulting in a total system production of an average of 90 MWh/year. The details of the generation can be seen in Figure 6.



(a) (b)

Figure 6. Photovoltaic module performance for Current – Voltage, and Power – Voltage

Choosing the right photovoltaic modules is essential for system efficiency and should consider factors like module performance, climate suitability, and compatibility with other components. Higher-efficiency modules offer more output but come at a higher cost, requiring a balance with budget and project goals. Table 3 lists the specifications for the selected module.

Table 3. Minimum characteristics required for photovoltaic modules

Commercial Data			
Nominal Power	≥ 400 Wp	Technology	Si-mono (minimum)
Module size	Est. 1.05 x 2.12 m2	Rough module area	Est. 2.23 m2
Rough Specifications			
Ref.temp	25 – 60oC	Ref. irradiance	1000 W/m2
Open Circuit Voltage	49.7 V	short circuit current	11.10 A
Vmpp	41.6 V	Impp	10.70 A
Pmpp	440.6 W	Isc temp. coefficient	6.3 mA/oC
One-diode Model Parameter			
Rshunt	600Ω	Io Ref	0.01 nA
Rseries	0.22Ω	Gamma	0.978

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3.2. Number of Arrays and Modules

The total number of photovoltaic modules required in the system, as well as the space required for the implementation of the PV system, will vary based on the module technology chosen for the PV system. Equation (1) is used to calculate the number of photovoltaic modules required (NPV):

$$N_{PV} = \frac{P_{design} \times 10^6}{P_m STC} \tag{1}$$

Where, is the design capacity of the power plant in MW and is the power rating of the photovoltaic modules. The number of photovoltaic modules calculated is only an estimate based on the design capacity of the power plant.

3.3. Inverter Selection

Selecting the right inverter for a solar power plant is a crucial decision that can have a significant impact on system performance and efficiency. To summarise the minimum inverter characteristic requirements, Table 4 presents important considerations for inverter selection.

Table 4. Minimum characteristics for the required Inverter

Commercial Data			
Technology	16 kHz-IGBT	Width x Height	Est. 468 mm x 613 mm
Protection	IP65	Depth	Est. 242 mm
Input Characteristic			
Operating mode	MPPT	DC Phonograph	10 kW
MPP VMax	750 V	Pmax DC	12 kW
Absolute PV Volt	900 V	Max PV Current	38 A
Output Characteristics			
Grid Voltage	400 VAC 3-Phase	Air Conditioning Pnom	9 kVA AC
Grid Frequency	50Hz	Pmax AC	10 kVA AC
		AC Inom	13 A
		Imax AC	20 A
Minimum Technical Features			
Array isolation monitoring; Internal DC and AC Switch; Output Voltage Disconnect Adjustment			

The required efficiency is shown in Figure 7. The efficiency (η) of a power converter is defined as the ratio of the useful output power (P_{out}) to the total input power (P_{in}), commonly expressed as a percentage. Equation (2) shows that efficiency as a complement of the ratio of losses to input power.

$$\eta = \left(1 - \frac{P_{loss}}{P_{in}}\right) \times 100\% \tag{2}$$

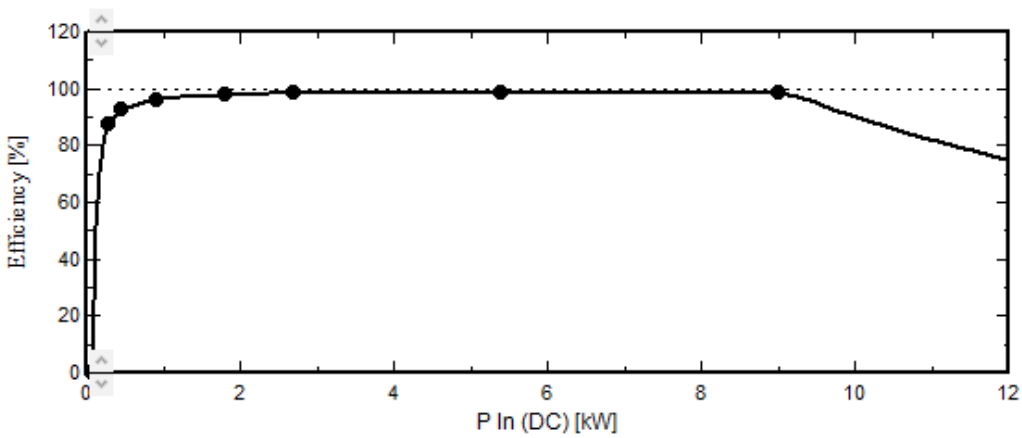

Figure 7. Required inverter efficiency curve

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At low power region, 0 kW to ≈ 1 kW, the efficiency rises very rapidly from 0%. At extremely low input power, the fixed losses (P_{fixed}) represent a significant proportion of the total input power. As P_{in} increases, P_{out} also increases, and the fixed losses become a smaller percentage of the overall power. This leads to a steep increase in efficiency from the very low value towards the peak. Equation (3) clearly illustrates this, as P_{in} increases, the P_{fixed}/P_{in} decreases significantly, driving up efficiency.

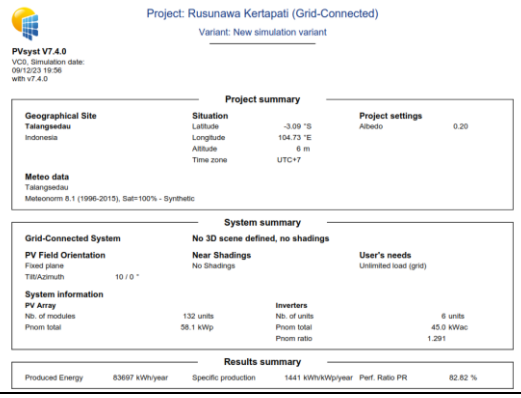
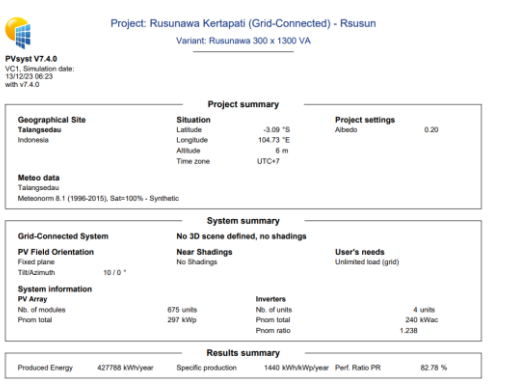
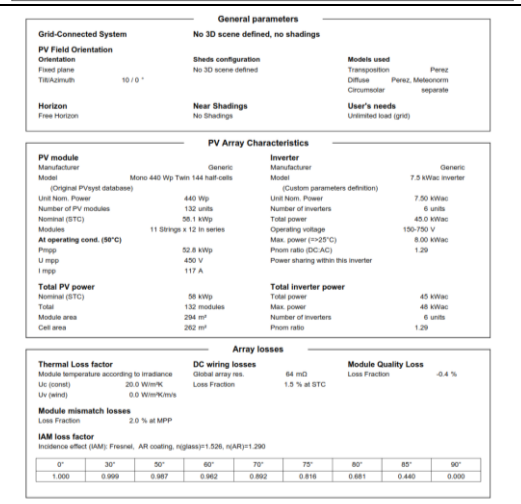
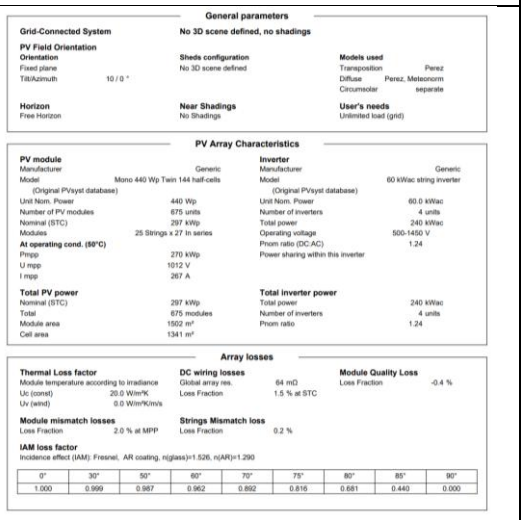
$$\eta = \left(1 - \frac{P_{fixed} + P_{variable}}{Pin}\right) \tag{3}$$

At mid to high power region the efficiency plateaus at its highest level approaching 98 – 99%. The device operates under conditions where the ratio of total losses to input power is minimized. Eventually, at high power region, above 9 kW, the efficiency begins to decline. This drop is attributable to the quadratic increase in conduction losses, I^2R, as the current levels rise with higher input power.

3.4. Technical Feasibility Study Results

The simulation results are divided into two parts, namely: (a) simulation for Public Facilities and Public Facilities, and (b) simulation for houses. Table 5 shows the results of the PVsyst software simulation.

Table 5. Simulation results

Desc.	Public Facilities and Facilities	Houses
Project Summary	 Project: Rusunawa Kertapati (Grid-Connected) Variant: New simulation variant PVsyst V7.4.0 VC0, Simulation date: 09/12/23 19:56 with v7.4.0 Project summary Geographical Site: Talangsedau, Indonesia Situation: Latitude -3.09 °S; Longitude 104.73 °E; Altitude 6 m; Time zone UTC+7 Project settings: Albedo 0.20 Meteo data: Talangsedau, Meteonorm 8.1 (1996-2015), Sat=100% - Synthetic System summary Grid-Connected System: No 3D scene defined, no shadings PV Field Orientation: Fixed plane, Tilt/Azimuth 10 / 0 ° Near Shadings: No Shadings User's needs: Unlimited load (grid) System information PV Array: Nb. of modules 132 units; Pnom total 58.1 kWp Inverters: Nb. of units 6 units; Pnom total 45.0 kWac; Pnom ratio 1.291 Results summary Produced Energy 83697 kWh/year; Specific production 1441 kWh/kWp/year; Perf. Ratio PR 82.82 %	 Project: Rusunawa Kertapati (Grid-Connected) - Rsusun Variant: Rusunawa 300 x 1300 VA PVsyst V7.4.0 VC1, Simulation date: 13/12/23 06:23 with v7.4.0 Project summary Geographical Site: Talangsedau, Indonesia Situation: Latitude -3.09 °S; Longitude 104.73 °E; Altitude 6 m; Time zone UTC+7 Project settings: Albedo 0.20 Meteo data: Talangsedau, Meteonorm 8.1 (1996-2015), Sat=100% - Synthetic System summary Grid-Connected System: No 3D scene defined, no shadings PV Field Orientation: Fixed plane, Tilt/Azimuth 10 / 0 ° Near Shadings: No Shadings User's needs: Unlimited load (grid) System information PV Array: Nb. of modules 675 units; Pnom total 297 kWp Inverters: Nb. of units 4 units; Pnom total 240 kWac; Pnom ratio 1.238 Results summary Produced Energy 427788 kWh/year; Specific production 1440 kWh/kWp/year; Perf. Ratio PR 82.78 %
General Parameters.	 General parameters Grid-Connected System: No 3D scene defined, no shadings PV Field Orientation: Fixed plane, Tilt/Azimuth 10 / 0 ° Sheds configuration: No 3D scene defined Models used: Transposition Perez; Diffuse Perez, Meteonorm; Circumsolar separate Horizon: Free Horizon Near Shadings: No Shadings User's needs: Unlimited load (grid) PV Array Characteristics PV module: Manufacturer Generic; Model Mono 440 Wp Twin 144 half-cells (Original PVsyst database); Unit Nom. Power 440 Wp; Number of PV modules 132 units; Nominal (STC) 58.1 kWp; Modules 11 Strings x 12 In series; At operating cond. (50°C): Pmpp 52.8 kWp, U mpp 450 V, I mpp 117 A Inverter: Manufacturer Generic; Model 7.5 kWac inverter (Custom parameters definition); Unit Nom. Power 7.50 kWac; Number of inverters 6 units; Total power 45.0 kWac; Operating voltage 150-750 V; Max. power (=>25°C) 8.00 kWac; Pnom ratio (DC:AC) 1.29; Power sharing within this inverter Total PV power: Nominal (STC) 58 kWp; Total 132 modules; Module area 294 m²; Cell area 262 m² Total inverter power: Total power 45 kWac; Max. power 48 kWac; Number of inverters 6 units; Pnom ratio 1.29 Array losses Thermal Loss factor: Module temperature according to irradiance; Uc (const) 20.0 W/m²K; Uv (wind) 0.0 W/m²K/m/s DC wiring losses: Global array res. 64 mΩ; Loss Fraction 1.5 % at STC Module Quality Loss: Loss Fraction -0.4 % Module mismatch losses: Loss Fraction 2.0 % at MPP IAM loss factor: Incidence effect (IAM): Fresnel, AR coating, n(glass)=1.526, n(AR)=1.290 0° 30° 50° 60° 70° 75° 80° 85° 90° 1.000 0.999 0.987 0.962 0.892 0.816 0.681 0.440 0.000	 General parameters Grid-Connected System: No 3D scene defined, no shadings PV Field Orientation: Fixed plane, Tilt/Azimuth 10 / 0 ° Sheds configuration: No 3D scene defined Models used: Transposition Perez; Diffuse Perez, Meteonorm; Circumsolar separate Horizon: Free Horizon Near Shadings: No Shadings User's needs: Unlimited load (grid) PV Array Characteristics PV module: Manufacturer Generic; Model Mono 440 Wp Twin 144 half-cells (Original PVsyst database); Unit Nom. Power 440 Wp; Number of PV modules 675 units; Nominal (STC) 297 kWp; Modules 25 Strings x 27 In series; At operating cond. (50°C): Pmpp 270 kWp, U mpp 1012 V, I mpp 267 A Inverter: Manufacturer Generic; Model 60 kWac string inverter (Original PVsyst database); Unit Nom. Power 60.0 kWac; Number of inverters 4 units; Total power 240 kWac; Operating voltage 500-1450 V; Pnom ratio (DC:AC) 1.24; Power sharing within this inverter Total PV power: Nominal (STC) 297 kWp; Total 675 modules; Module area 1502 m²; Cell area 1341 m² Total inverter power: Total power 240 kWac; Number of inverters 4 units; Pnom ratio 1.24 Array losses Thermal Loss factor: Module temperature according to irradiance; Uc (const) 20.0 W/m²K; Uv (wind) 0.0 W/m²K/m/s DC wiring losses: Global array res. 64 mΩ; Loss Fraction 1.5 % at STC Module Quality Loss: Loss Fraction -0.4 % Module mismatch losses: Loss Fraction 2.0 % at MPP Strings Mismatch loss: Loss Fraction 0.2 % IAM loss factor: Incidence effect (IAM): Fresnel, AR coating, n(glass)=1.526, n(AR)=1.290 0° 30° 50° 60° 70° 75° 80° 85° 90° 1.000 0.999 0.987 0.962 0.892 0.816 0.681 0.440 0.000

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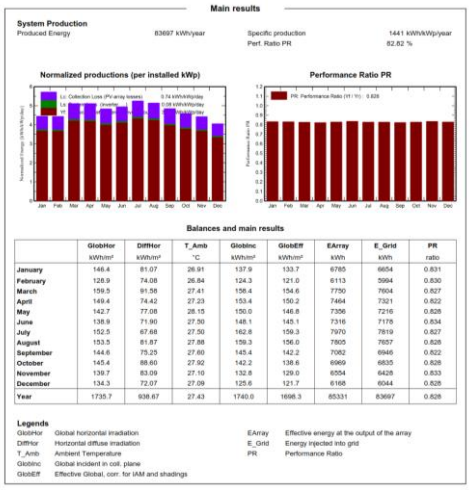
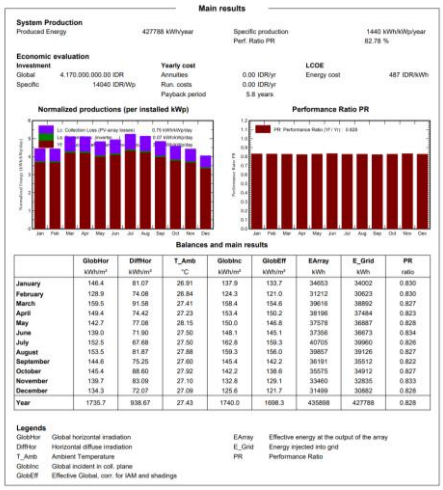
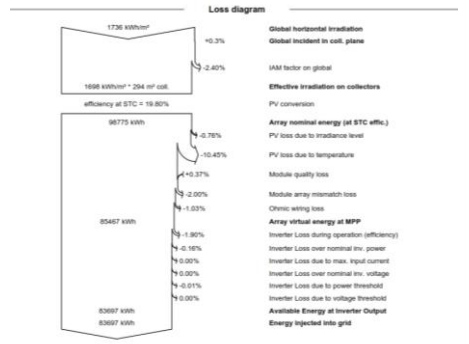
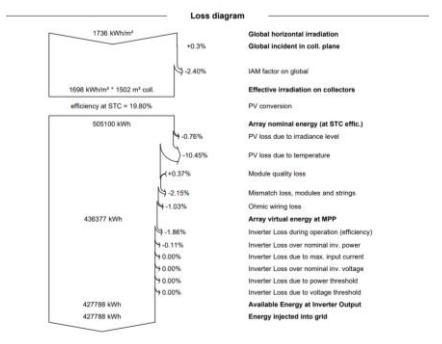
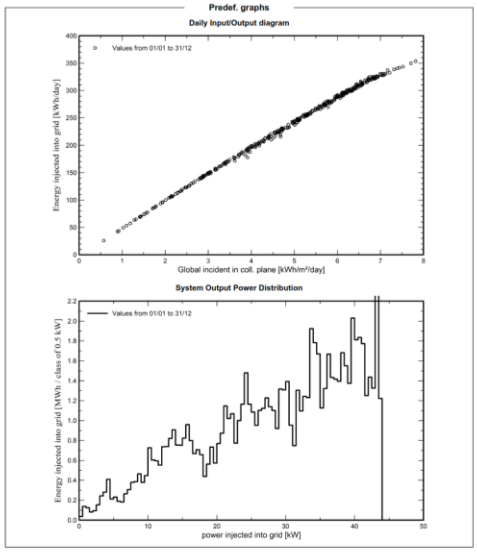
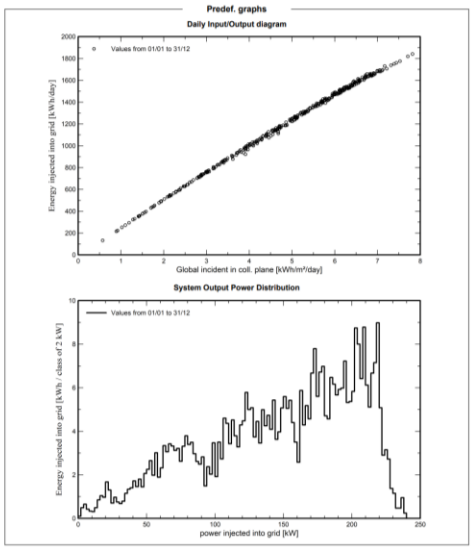
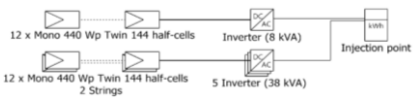
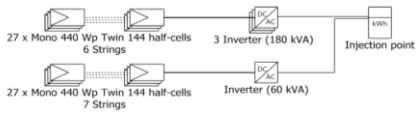
Desc.	Public Facilities and Facilities	Houses
Key Results.		
Profit and Loss Diagram.		
Daily Input/Output Chart.		
Single-line diagram.		

Figure 8 illustrates the projected reduction in CO2 emissions over time for the Kertapati Apartment solar project, showing a steady annual increase in savings throughout the PV system's 30-year lifespan. Table 6 compares CO2 emission reductions, with total savings estimated at around 1,559.6 tCO2 for public facilities and 7,629.6 tCO2 for residential units. These reductions result from replacing fossil

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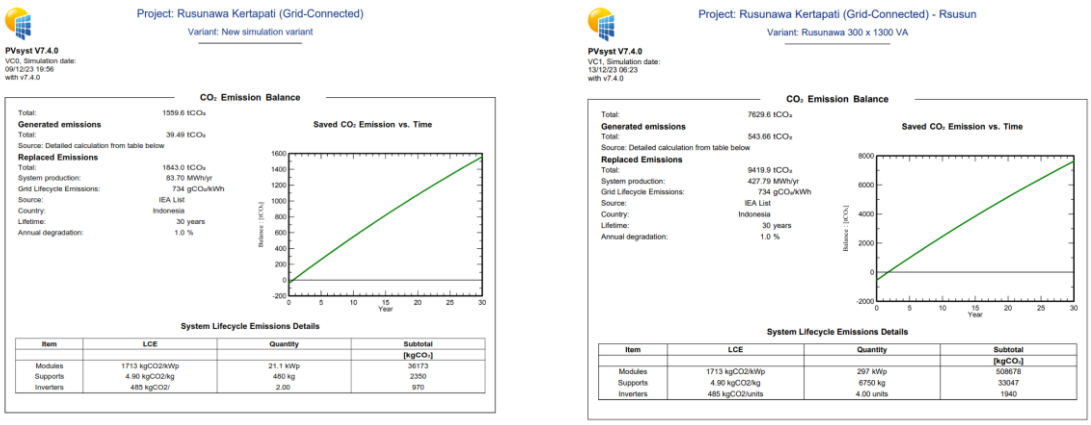
fuel-generated electricity with clean solar energy, highlighting the long-term environmental benefits of the system.



(a) (b)

Figure 8. (a) CO2 emissions for public facilities and infrastructure, and (b) CO2 Emissions from Houses

Table 6. Comparison of CO2 equilibrium for Public Facilities and Public Facilities and Houses.

Description	Unit	Public Facilities and Facilities	Houses
Total emission savings	tCO_2	1559.6	7629.6
Emissions generated during the life cycle of a solar power plant consisting of modules, supports, and inverters	tCO_2	39.49	543.66
Total emissions displaced	tCO_2	1843.0	9419.9
PV System Results	MWh/year	83.70	427.79
Replaced emissions	gCO_2/kWh	734	734

4. CONCLUSION

Based on the results of the study conducted, it was concluded that the location of Apartment Kertapati in Palembang has good potential to be a location for the placement of PV power plant. With the identified power needs and supportive environmental conditions, this project has the potential to provide significant economic and environmental benefits. However, this study only considers the on-grid system as data and analysis material. The need for off-grid analysis results requires analysis of energy storage systems such as batteries which tend to affect the price and initial investment as well as higher maintenance costs. So that the on-grid system is a more efficient and effective choice for Apartment Kertapati with the target of saving daily electricity usage costs at the location.

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