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Feasibility Design: Case Study of Rooftop PV System for Pharmaceutical Company

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ABSTRACT

According to 2019 data, solar energy represents the most significant potential for renewable energy (RE), totalling 207.8 GW. This has propelled the use of solar renewable energy across all industrial sectors, emphasizing ecologically sustainable energy derived from photovoltaic (PV) technology. This context has propelled the design and empirical evaluation of a grid tied rooftop PV system for the load of an Air Handling Unit (AHU) at a corporation. This study delineates various PV roof-top design methodologies, encompassing K2 base system simulation, solar energy potential (kWh/m^2/day), available area, component generation capacity, and an analysis of the Levelized Cost of Energy (LCOE), Net Present Cost (NPC), and PV contributions to the RE and PLN grid sources utilizing Homer software. The modelling and analytical results produced an average solar energy of 4.81 kW/m²/day. The usable area encompasses 3,140 m², accommodating 1,324 panels capable of producing 52.6 kWp of energy to meet the existing electricity demand of 5,808 kW/day. The total energy produced is 756,389 kWh, with a renewable share of 33.5%. The NPC value is Rp43,680,200,000.00, the LCOE is Rp1,050.30, the reduction value is 5.8%, and the running cost is Rp2,013,450,000. In contrast to the electricity provided by Grid at 2,119,920 kWh/year, the PV contribution is 1,502,835 kWh/year, resulting in a 29% reduction in emissions.

Keywords: Air Handling Unit, Levelized Cost of Energy, Net Present Cost, Photovoltaic, Renewable Energy.

Introduction

At the end of 2023, total installed electricity capacity increased by 0.34% from the previous year. This data aims to offer a comparative analysis of the contributions of various power plant types to the nation's total electricity producing capacity[1]. The coal-fired power plant possesses the highest capacity at 20,439.90 MW, constituting 28.01% of the total installed capacity. This signifies that coal-fired power plants continue to prevail in electricity generation in Indonesia. The gas-fired combined cycle power plant ranks second, possessing a capacity of 12,089.10 MW, equating to 16.57%. Gas-fired power plants play a crucial role in electricity generation, employing natural gas as its fuel source. The diesel power plant, with a capacity of 3,521.21 MW (4.83%), signifies a modest yet significant contribution, particularly in areas with restricted access to extensive infrastructure. The gas engine power plant, with a capacity of 2,071.31 MW (2.84%), contributes a little share while nonetheless assisting in energy provision during peak demand periods. The hydroelectric power plant, with a capacity of 3,142.85 MW (4.31%), serves as a notable renewable energy source, but smaller than coal and gas-fired power plants. The capacity of micro-hydropower and hybrid micro-hydropower plants is a mere 454.27 MW (0.62%), signifying that the micro-hydropower potential in Indonesia remains underdeveloped. The gas power plant, with a capacity of 2,763.97 MW (3.79%), provides a significant

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contribution, albeit less than that of gas-fired combined cycle power plant due to restricted gas availability. The geothermal power plant, with a capacity of 579.26 MW (0.79%), demonstrates a limited contribution from geothermal energy, considering Indonesia's considerable potential. The solar power plant, possessing a capacity of 33.32 MW (0.04%), constitutes a negligible portion of the overall installed capacity, indicating the nascent phase of solar energy development, albeit its considerable potential inside the country. The wind power plant and biomass have minimal capacities, with wind energy at 33.32 MW and Biomass unreported, signifying that both renewable sources possess little installed capacity in Indonesia[2], [3].

It is anticipated that a corporation can actively contribute to mitigating air pollution and enhancing the utilization of renewable energy. This study will delineate a model and design for a solar system intended to promote sustainable energy, encompassing a techno-economic analysis of rooftop PV systems. The design and analysis of this rooftop PV system are grounded in prior research and analyses conducted by many researchers in different locales. Certain studies cited in the design and analysis of this research involve modelling PV systems in a campus setting, incorporating optimization and various factors essential for the sustainability of rooftop PV systems for critical loads necessitating backup[4], [5]. The decrease in energy expenses is a primary benefit of utilizing rooftop PV systems. By reallocating a substantial percentage of a building's energy requirements from traditional power grids to solar energy, property owners can markedly decrease their electricity expenses[6]. As per[7], rooftop PV systems can diminish electricity expenses by as much as 70% in certain areas with significant solar radiation potential. Rooftop PV systems promote the utilization of renewable energy, which is more environmentally sustainable. The utilization of solar power for electricity generation diminishes CO_2 emissions from fossil fuel-based power plants. A study by[8] demonstrated that the installation of rooftop PV systems in urban environments can decrease CO_2 emissions by 2 to 3 tons per year for each system, contingent upon its capacity and location[9], [10]. Energy Independence and Security: Rooftop PV systems allow buildings to become more energy independent. By generating their own electricity, buildings reduce their dependence on external power supplies. This is particularly important for energy security, especially in the face of global energy price fluctuations and energy crises. [11]estimates that the adoption of rooftop PV systems in commercial and residential buildings can improve energy security. Increase property value: Buildings with rooftop PV systems tend to have higher market values. Consumers and investors increasingly prioritize properties with green features and energy efficiency. A study by [12]found that buildings with renewable energy systems, including rooftop PV, experienced significant increases in market value, approximately 5% to 10% higher than similar properties without renewable energy systems. Energy storage potential (Batteries)[13]: With advances in battery technology, rooftop PV systems allow building owners to store excess energy produced during the day for use at night or in the event of a power outage. The use of energy storage systems can improve the overall utility of rooftop PV systems[14]. According to [15], energy storage systems can increase the efficiency of rooftop PV systems by as much as 30%, especially in areas that experience regular power outages.

This project seeks to investigate and develop effective energy management technologies and systems, including the K2Base system and Homer Pro, to improve the performance and efficiency of rooftop PV systems. This entails evaluating the viability of solar energy as a power source for the PV system of a pharmaceutical company, considering its geographical location and coordinates, and designing a rooftop PV system utilizing the K2Base System to ascertain the attainable capacity based on the specified load in this analysis. Conducting a rooftop PV system analysis based on simulations using Homer Pro software to obtain techno-economic values and determine the amount of investment based on time for the next 25 years. This work is structured into five chapters, beginning with Chapter I: Introduction, which outlines the research background and the aims to be attained in this study. Chapter II: Research Methods features a block diagram for planning within the research flow diagram that delineates the design process utilizing supporting software. Chapter IV: Results and Discussion elucidates the energy

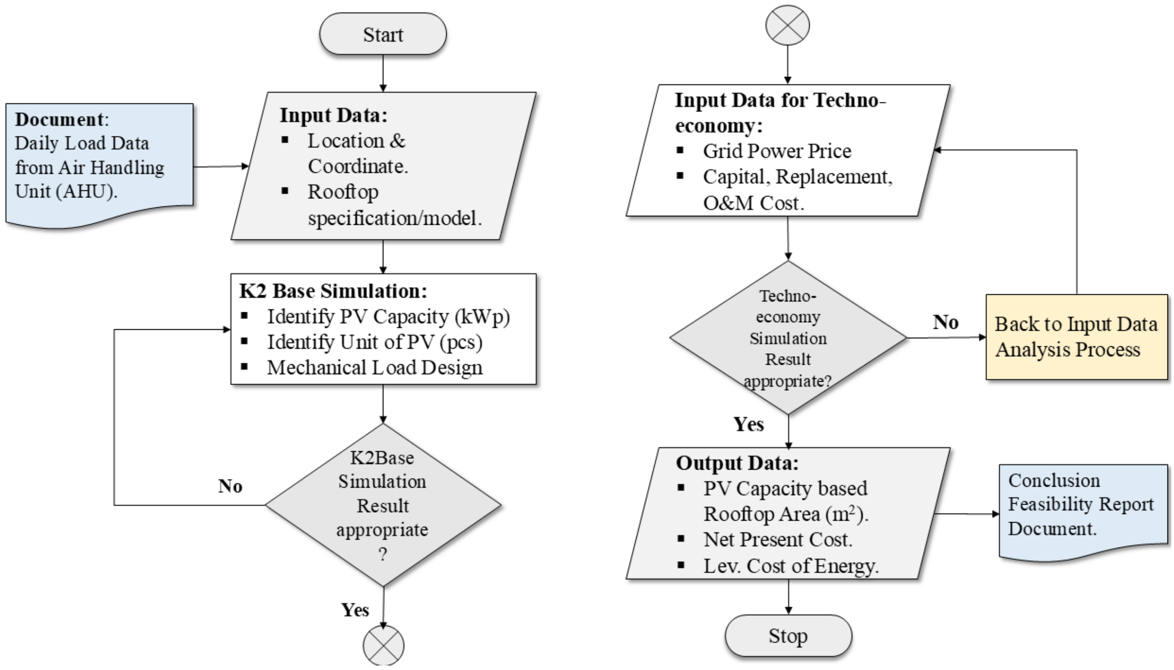

Figure 1. Research Methodology Flowchart

potential, assesses the load capacity of the pharmaceutical company during the operation of the AHU system, calculates capacity, and presents optimization scenarios for economic value in the rooftop PV system. Chapter V, Conclusions, ultimately concludes the thesis by presenting the inferences derived from the research findings and suggestions for subsequent studies.

Methods

The research method is presented systematically in Figure 1. The diagram above illustrates the research methodology used to analyze electricity consumption and its impact on carbon emissions. This flowchart outlines the steps involved in the research process, from data collection to the final report preparation. Figure 1 delineates a systematic approach for executing research on the technical and economic evaluation of PV systems in buildings. The process initiates with data collecting and concludes with the final report creation, incorporating numerous studies and calculations to assure the proposed system's efficiency and economic viability, while also contributing to the reduction of carbon emissions. This method is crucial for elucidating how solar power systems can diminish dependence on fossil energy sources and foster sustainable development, while also addressing their technical and economic dimensions.

Figure 1 shows the research procedure commences with the preliminary stage of collecting data on the rise in power use and its relationship with carbon emissions. This signifies that the research aims to elucidate the correlation between power usage and its environmental repercussions, particularly carbon emissions. The subsequent phase is the literature review. At this juncture, the researcher performs a literature study to compile existing information and studies pertaining to energy usage and its environmental impacts. This step is essential for comprehending the theoretical framework and acquiring pertinent information about the subject under investigation. Upon examining the literature, the researcher identifies the research domain. This entails determining the suitable place for the investigation and delineating the load within that area. Furthermore, the area's requirements must be taken into account to guarantee the pertinence of the data gathered. Assessment of capacity predicated on spatial dimensions. At this stage, the researcher determines the required capacity for the area under investigation, contingent upon its dimensions. The K2Base System determines this capacity, assisting the researcher in evaluating the suitable capacity

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for the power plant or energy producing system in the specified region. Authentication Upon calculating the capacity, the subsequent step is to evaluate the appropriateness of the design input in relation to the study objectives. A verification is performed to confirm that the design is pertinent and feasible for implementation. Upon verification of the design's accuracy, the subsequent phase will commence. If not, the researcher must amend the design. Upon verification of the design, the researcher advances to ascertain the specs and pricing of the components utilized in the system. This encompasses the selection of materials and components, in addition to the calculation of their associated costs. This phase guarantees that all essential components adhere to the budget and complete the specified requirements. Techno-economic evaluation with HOMER Pro. The researcher conducts a techno-economic evaluation utilizing Homer Pro software. Homer Pro is utilized to efficiently examine diverse designs of power plants, taking into account cost, profitability, and technical performance. This analysis enables the researcher to evaluate the viability of the system design about performance and cost[16], [17].

The design simulation will be assessed at this point. The researcher evaluates the adequacy and optimality of the simulation results. Should the simulation outcomes be good, the process advances to the subsequent phase. Nevertheless, if the outcomes are suboptimal or misaligned with the objectives, the researcher must scrutinize any discrepancies and modify the simulation to guarantee its optimization. Upon optimizing the simulation, the researcher proceeds to the final stage of report preparation. The report will encompass the research findings, including a review of the system's capacity, expenses, and performance. The document will encompass recommendations for subsequent actions and findings pertaining to the efficacy of solar power systems in buildings and their capacity to diminish carbon emissions. Upon the completion of the report and the finalization of all analyses, the research is deemed complete. The researcher will offer recommendations derived from the research findings for the use of solar power systems in diverse buildings or locations.

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Location Meteo-data and Solar Energy Potential

The location used in the design of the rooftop PV system at the pharmaceutical company is at coordinates -6°51' 43.32“, 107° 29' 45.73”. The table 1 provided shows meteorological data for each month, including the Clarity Index, Daily Radiation, Average Wind Speed, and Daily Temperature in Indonesia. This data is very useful in renewable energy analysis, particularly for evaluating the use of solar energy, as well as for planning the application of renewable energy source.

There is an inverse relationship between wind speed and solar radiation in some months. For instance, in July, wind speed is higher compared to other months, but solar radiation is not at its peak. This indicates that while wind energy potential may peak, solar energy has its own distinct seasonal pattern of availability. Based on radiation and clearness index data, September emerges as the month with the highest solar energy potential, while January shows the lowest. Therefore, months with high clearness and radiation should be optimally utilized for solar power generation. High temperatures in certain months, like October, may decrease the efficiency of PV systems but can be mitigated by utilizing appropriate technology in solar power systems. The peak clarity index value was recorded in July (0.558),

Table 1. Meteo-data at Existing Location

Month	Clearness Index	Daily Radiation (kWh/m^2/d)	Average Wind (m/s)	Daily Temperature (°C)
Jan	0.390	4.18	3.84	23.34
Feb	0.394	4.25	3.92	23.27
Mar	0.454	4.77	3.19	23.66
Apr	0.493	4.82	2.63	23.95
May	0.529	4.74	2.64	23.91
Jun	0.539	4.58	2.88	23.27
Jul	0.558	4.86	3.06	22.76
Aug	0.555	5.24	3.13	22.83
Sep	0.545	5.56	2.92	23.69
Oct	0.500	5.32	2.60	24.35
Nov	0.449	4.80	2.49	24.27
Dec	0.435	4.63	3.29	23.73
Average	0.49	4.81	3.00	23.59

while the lowest was observed in January (0.390). This suggests that during specific months, such as July, Indonesia experiences a clearer atmosphere conducive to enhanced solar power generating efficiency. Daily radiation denotes the quantity of solar energy received per square meter each day, quantified in kWh/m²/d. This is the primary metric for assessing solar energy potential. The maximum daily radiation is recorded in September at 5,560 kWh/m²/d, while the minimum occurs in January at 4,180 kWh/m²/d. This radiation intensifies during specific months, signifying intervals with elevated potential for solar power production. The maximum temperature was documented in October (24.35°C) and the minimum in July (22.76°C). Temperature fluctuations can impact the efficacy of renewable energy systems, particularly in HVAC (Heating, Ventilation, and Air Conditioning) applications.

Determining Total Load Power

Since the company requires controlled air quality in its production areas, a fully operational Heating, Ventilation, and Air Conditioning (HVAC) system is necessary to maintain air quality. As a result, the power consumption of the HVAC system is very high, as it must operate 24 hours a day, every day. Table 2 presents the AHU components and the requisite load capacity for a pharmaceutical industry, with a survey duration spanning from August 5 to September 4, 2024. The load levels recorded over one hour were subsequently averaged to represent the load values for one month. The aggregate energy consumption of all AHU units is 5808 kWh daily. This statistic is a crucial indicator of the electrical energy demands for the building's HVAC system. The energy consumption per AHU unit significantly fluctuates, from 2.50 kW/h (AHU B1) to 32.89 kW/h (AHU G11). The unit with the greatest energy demand (AHU G11) accounts for 789.36 kWh daily, or approximately 13.6% of the overall AHU energy usage. Multiple primary units (e.g., AHU G1, G7, G11, and G5) exhibit significant energy use, varying from 333 kWh to 800 kWh daily. Emphasizing energy efficiency in these units will significantly diminish the overall energy consumption of the HVAC system. The pharmaceutical company where the research was done operates 23 AHUs and a SCADA system that monitors the HVAC system's operation, functioning continuously with a total energy consumption of 242 kW per hour. Consequently, if the AHU functions continuously for 24 hours, the cumulative energy consumption in a daily amount to 5808 kW. The unit exhibiting the highest energy consumption is AHU G11, with a power rating of 32.89 kW per hour or 789.36 kW per day, while the unit with the second highest energy consumption is AHU B1, with a power rating of 2.5 kW per hour or 60 kW per day. Overall, Table 2 presents a comprehensive analysis of energy use across different AHU units within the HVAC system.

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Table 2. Existing Load Power based on Survey

Comp. Load	Hour Energy (kW/h)	Tot. Daily Power (kW/day)
AHU B1	2,50	60,00
AHU B2	7,31	175,44
AHU B3A	3,85	92,40
AHU B3B	4,67	112,08
AHU G1.1	3,90	93,60
AHU G1	16,64	399,36
AHU G2	11,90	285,60
AHU G2A	4,88	117,12
AHU G2B	5,32	127,68
AHU G3	12,50	300,00
AHU G6	13,88	333,12
AHU G7	16,40	393,60
PAC G9A	9,55	229,20
AHU G11	32,89	789,36
AHU G12	10,00	240,00
AHU G1A	12,39	297,36
AHU G4	7,49	179,76
AHU G5	13,90	333,60
AHU G8	3,10	74,40
AHU G9	9,86	236,64
AHU FA01	9,26	222,24
AHU FA02	9,55	229,20
AHU FA03	9,26	222,24
SCADA SYST.	11,00	264,00

Table 3. K2 Base Simulation Parameter

Rooftop Parameter Specifications	Info.
Rooftop type	Gable
Building Height Estimation	15.00 m
Roof Pitch Option	15°
Roof Pitch Direction	186.3°
Calculated Surface Area (m^2)	3,140.74
Roof Covering Option	Trapezoid
Fastening Methods Option	Cover
Fastening Grid Option	Crest Grid

The predominant energy consumption originates from few primary units; thus, enhancing the efficiency of these units will yield the most significant benefits in energy conservation and operational cost reduction. The operation of 24 hours daily underscores the necessity for enhanced time management and regulation to maximize energy efficiency. The integration of control technologies and energy efficiency measures can diminish consumption and carbon emissions, hence advancing the building's sustainability objectives.

Rooftop PV System Simulation

After determining the location, the first step is to input the coordinate data via a map to ensure that the area is suitable[18]. Once the location has been determined, the input type is selected based on the zone, indicating that the design is based on specific parameters in a particular region. In the Terrain Category section, which classifies environments based on ground surface roughness or wind resistance levels affecting structural design when calculating wind loads according to environmental conditions, this rooftop PV system's design is located in an industrial area and is therefore classified as Category IV Urban Area[19].

Table 3 contains the main parameters used in the K2 Base model simulation related to a building's rooftop specifications. Accurate simulation results that correspond to the actual conditions of the building being simulated depend on these parameters. Table 3 shows that the gable roof type has a slope of 15°, a relatively conservative and common choice for commercial or industrial buildings. Compared to steeper roof slopes, a gentler slope can reduce material costs and facilitate construction. However, it can affect the speed of rainwater flow, so drainage design must consider this factor. With an estimated height of 15 meters, this is considered a medium- to high-rise building, so wind exposure and dynamic loads are important factors. With a roof area of 3,140.74 m², precise calculations are required for the roofing system and fastening to ensure stability. Using trapezoidal roofing panels and the "roof cover" and "crest grid" fastening methods demonstrates a focus on roof strength and durability.

The Crest Grid fastening pattern typically provides good load distribution and resistance to strong winds, which is important for buildings of this height. The 186.3° roof slope direction toward the south will affect natural lighting, roof heating from sunlight, and potential exposure to seasonal winds.

Table 4. K2 Base Simulation of Rooftop Characteristics

Characteristics Roofing	Information
Crest Distance Estimation	200.0 mm
Crest Width Assumption	25.00 mm
Crest Height Assumption	25.00 mm
Sheet Material Option	aluminum
Sheet Quality Option	165 N/mm^2
Sheet Thickness Estimation	1.000 mm

Table 5. K2 Base Simulation of Load Option

Characteristics Loads	Pressure (kN/m^2)
Wind Load Velocity Press.	0.01
Snow Load on Roof	0.00
Exceptional Snow Load on Roof	0.00

Table 4 lists the main technical characteristics of the materials and dimensions of the roof used in the K2 Base model simulation. This information is important for determining the structural and mechanical performance of the roof in more detail. Comparison and Implications Profile Dimensions vs. Material A crest distance of 200 mm with a crest width and height of 25 mm indicates a fairly deep and wide trapezoidal profile, which enhances the structural stiffness of the sheet despite its relatively thin 1 mm thickness. This compensates for the thinness with a shape that strengthens the sheet's load-bearing capacity. The use of aluminum compared to steel or other materials offers advantages such as lighter weight and corrosion resistance, making it suitable for wet or corrosive environments. However, its tensile strength (165 N/mm²) is somewhat lower than that of steel, so the profile dimensions and thickness must be optimized to sustain loads. Material Thickness and Quality The 1 mm thickness is relatively thin for roofing applications, so it requires a profile with sufficiently large crest dimensions to ensure rigidity and durability. The tensile strength of 165 N/mm² shows that the material meets general structural requirements for light to medium roofing applications. This table shows the technical roofing characteristics focused on lightweight aluminum material combined with an optimized trapezoidal profile design through crest distance, width, and height dimensions. This combination aims to produce a roofing sheet that is strong and durable yet lightweight, supporting the K2 Base simulation model which prioritizes structural efficiency and material durability.

Table 5 shows the snow load for this rooftop PV system is 0.00 kN/m², as the study area has a tropical climate and does not experience snow. For environmental considerations, it is classified as normal terrain, as the soil and environmental conditions are considered standard, with no significant geotechnical risks, such as steep slopes or soft soil. Next, determine the area to be used. In the rooftop PV system design by marking it. The dimensions of the marked area will then be displayed automatically: 51.41 m × 59.01 m. After marking the area to be used in the design, determine the type of roof. In this case, it is a gable roof. The building is then 15 m high, with a roof slope of 15° and an orientation of 186.3°. The previously marked area has a surface area of 3,140.74 m². The roof specification uses a trapezoidal or corrugated roof. The installation method to be used in the design is a roof cover, with the mounting attached directly to the roof. The panels are mounted in a crest or wave peak configuration. Since a crest configuration is to be implemented, the following characteristics must be known: the distance between waves is 200 mm; the width of each wave is 25 mm; and the height of each wave is also 25 mm. The roof covering material is aluminium with a strength of 165 N/mm² and a thickness of 1 mm.

PV System Techno-economy Parameter Simulation

The techno-economic analysis is designed based on applicable guidelines and standards. This includes taking into account the capacity of the system's components, as well as capital costs, replacement costs and operation and maintenance (O&M) costs[16], [20]. These factors are used to determine the subscription price for PV users to connect to the grid. This paper presents a design for a grid-connected rooftop PV system in which the load is supplied by the grid and the PV system simultaneously. The energy harvested by the rooftop PV panels will first be converted using an inverter and stored in batteries before being supplied to the load. Figure 2 presented simulation flowchart outlines a comprehensive methodology for designing and optimizing an integrated PV system, incorporating technical, economic, and environmental considerations.

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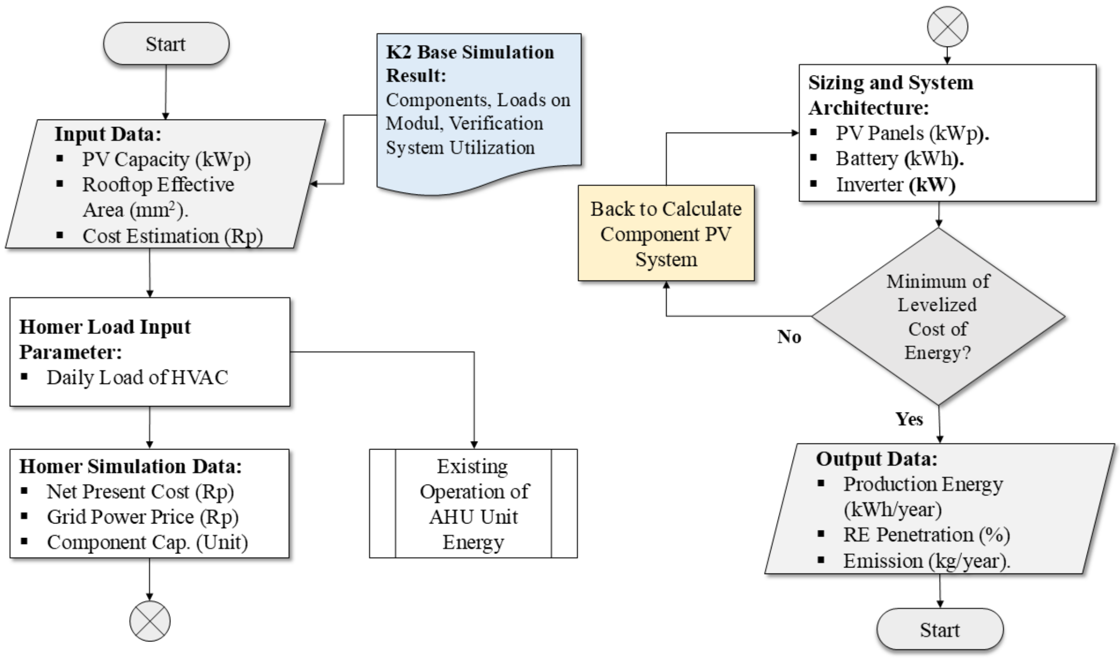

Figure 2. Flowchart of Techno-economy Simulation Output Analysis

The process initiates with the collection of primary input data, including PV capacity (kWp), effective rooftop area (mm²), and cost estimation (IDR). These parameters serve as the foundation for evaluating system feasibility within spatial and financial constraints. Subsequently, results from the K2 Base Simulation are employed to verify system components, module loads, and system utilization. This stage acts as an initial validation to ensure consistency between theoretical designs and operational limitations. If verification criteria are unmet, the workflow reverts to the PV System Component Calculation phase, where system architecture comprising PV panels (kWp), battery storage (kWh), and inverters (kW) is refined through sizing analysis. Optimization criteria focus on minimizing the LCOE as the primary economic indicator. An iterative process is conducted until the LCOE reaches its minimum value, reflecting long-term cost efficiency. Annual simulation periods integrate temporal variability to ensure system resilience against load fluctuations and environmental conditions. Output data encompasses annual energy production (kWh/year), renewable energy (RE) penetration (%), and carbon emissions (kg/year). These metrics quantify environmental impacts and the system's contribution to sustainable energy transitions. Integration with the HOMER simulation tool enhances the analysis through specific input parameters such as HVAC daily load profiles, NPC, grid electricity prices (IDR), and component capacities. This enables a holistic evaluation of interactions between the PV system, grid infrastructure, and operational units like Air Handling Units (AHUs). Comparative analysis with Existing AHU Unit Energy Operations provides insights into efficiency improvements and emission reductions relative to conventional systems. This approach addresses technical challenges in PV system design while aligning economic objectives (LCOE minimization) with sustainability goals (emission reduction). The proposed simulation framework serves as a reference model for renewable energy development in urban areas characterized by land constraints and complex energy demands. Its integration of multi-criteria optimization and temporal dynamics positions it as a robust tool for advancing low-carbon energy systems in diverse operational contexts.

Table 6. Economic Simulation Parameter

No	Parameter Setting	Information
1	Nominal Discount Rate	5.98 %
2	Expected Inflation Rate	3.50 %
3	Project Lifetime	25 Year

Table 7. PV Component Net Present Cost Simulation Parameter

System Comp.	Cap. Cost Million (IDR)	Replac. Million (IDR)	O&M Million (IDR)
PV LG Electronics	3.699	0.00	0.5
EnerSys Battery	1,5022	1,5022	0.00
Pure Wave Inverter	3.750	3.750	0.00

Table 6 illustrates the nominal discount rate in an economic setting with an average reference interest rate of 5.98%, an average inflation rate of 3.50%, a real discount rate of 2.40%, and an economic project duration of 25 years. Table 7 presents NPC simulation parameters for key components of a PV system, including capital, replacement, operations and maintenance (O&M) costs, and component lifespans. The analysis covers three primary components: PV LG Electronics panels, EnerSys Battery, and Pure Wave Inverter, each with distinct cost profiles and operational lifetimes. PV LG Electronics Panels exhibit a capital cost of 3.699 million IDR with no replacement cost over the 25-year simulation period, indicating their long operational lifespan. However, annual O&M costs amount to 0.5 million IDR, reflecting ongoing maintenance requirements. EnerSys Battery requires a high initial capital investment of 15,022 million IDR, with an identical replacement cost after 15 years. The absence of O&M costs suggests minimal maintenance needs, but the shorter lifespan necessitates one replacement within the 25-year period. Pure Wave Inverter shares a capital and replacement cost of 3.750 million IDR, with no O&M costs and a 15-year lifespan, similarly requiring one replacement during the simulation timeframe.

PV Component Capacity

Use equation (1) to determine the battery capacity to be used[21].

$$C_{Ah} = \frac{E_{tot} \times Autonom_{day}}{V_{DC} \times DoD} \qquad (1)$$

Battery capacity is determined by comparing the total load multiplied by the number of autonomous days to the nominal battery voltage multiplied by the depth of discharge.

Use Eq. (2) to determine the battery capacity to be used.

$$P_{inv} = \frac{130}{100} \times E_d \qquad (2)$$

The power capacity value of an inverter is equal to the inverter rating divided by 100 and multiplied by the load power requirement. The inverter rating is 25-30% greater than the load power requirement for protection purposes.

Results and Discussions

Figure 4 illustrates a hybrid power system configuration with input from the electrical grid (PLN) and a renewable energy source (PV panels) connected through an inverter and supported by a battery storage system. Homer will simulate the operation of this system to determine the optimization of energy use, efficiency, cost, and reliability in meeting electrical load requirements, taking into account energy production from solar panels and battery capacity. The energy consumption is listed as 5808 kWh/day and the peak power is 443.64 kW. These are important values for determining daily energy requirements and peak loads.

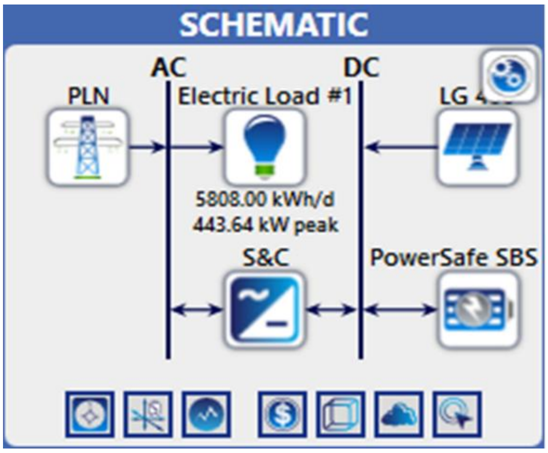

Figure 4. Schematic of PV System Simulation using Homer.pro

The photovoltaic system was designed through iterative simulations. For the solar panel configuration, following simulation using the K2 Base System with the LG400N2W-A5 panel type, which yielded a total power output of 529.6 kWp, the same panel type was subsequently specified in Homer Pro for system optimization and validation. This approach ensured alignment between theoretical modeling and practical feasibility, minimizing performance discrepancies.

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Table 8. K2 Base per-Unit Capacity Output

Comp.	Manufacture	Capacity (per-Unit)
PV Panel	LG Electronics.	400 Wp
Battery	EnerSys Power Safe.	12V/875 Ah
Inverter	S&C Pure Wave SMS-250.	50kW

Table 9. K2 Base Simulation Output

Qty (Unit)	Total Capacity	Eff. (%)	Time (Years)
1,324	529.6 kWp	13.0	25
152	1.596 kWh	97.0	15
14	689 kW	97.5	15

Table 8 – 9 shows the total system capacity of 529.6 kWp is calculated based on the multiplication of the power per panel (400 Wp) by the number of panels (1,324 units). Under optimal irradiation conditions, this system has the potential to generate approximately 700–800 MWh per year, depending on geographical and environmental factors. Use equation (1). After obtaining the battery capacity value, proceed with the configuration by determining the battery type and inputting the appropriate capacity data for the PV system design. The PV system has a battery capacity of 132,400 Ah. It uses EnerSys PowerSafe SBS 780 batteries, which have a maximum value of 875 Ah each. A total of 152 batteries are used in the system.
Total electrical energy production in software is a composite metric that delineates the technological efficacy of the hybrid system under design. The software computes total electrical energy production through a sequence of processes, including load modelling, wherein daily or hourly electrical load inputs are simulated based on real consumption patterns or estimates. System component simulation for energy production from solar panels, wind turbines, diesel generators, or alternative sources is determined by local climatic data (solar radiation, wind velocity), device efficiency, and installed capacity. The function of the Energy Management algorithm dispatch method is to control the distribution of energy among generators, storage systems, and loads. This plan establishes the precedence for utilizing renewable energy, storage solutions, or backup generators, as well as the total accumulated output.

Table 10. Production Simulation Result

Comp.	Production (kWh/yr)	Contribution (%)
PV System	746,389	33.2
Grid Purchases	1,502,835	66.8
Total	2,249,224	100

Table 11. Production Simulation Result

Comp.	Production (kWh/yr)	Contribution (%)
AC Load	2,119,920	95.0
DC Load	0	0.0
Grid Sales	110,592	4.96

As shown in Table 10, the energy system in this study combines PV sources with grid electricity purchases to meet the annual energy demand of 2,249,224 kWh. The PV system generates 746,389 kWh/year, accounting for 33.2% of the total energy production. Meanwhile, grid purchases amount to 1,502,835 kWh per year, accounting for the remaining 66.8%.
Based on the energy consumption simulation results in Table 11, the AC Primary Load dominates energy usage, contributing 95% (2,119,920 kWh/year), while the DC Primary Load shows no contribution (0 kWh/year). Additionally, the system sells excess energy to the grid (Grid Sales) amounting to 110,592 kWh/year or 4.96% of the total energy consumption. The total annual energy consumption of the system is 2,230,512 kWh, with an excess production of approximately 18,712 kWh/year (derived from the difference between total production of 2,249,224 kWh and consumption of 2,230,512 kWh). The high proportion of AC Primary Load (95%) indicates that the majority of energy is used for alternating current devices, such as cooling systems, lighting, or industrial machinery. This reflects the system's reliance on conventional AC-based infrastructure. The absence of DC Primary Load highlights a lack of integration with direct current devices, despite renewable energy sources like solar panels inherently producing DC power. This underscores an opportunity to enhance efficiency by adopting DC-compatible appliances that align with renewable energy systems. Although there is an excess energy production of 18,712 kWh/year, only 110,592

kWh/year is sold back to the grid. This disparity may stem from technical limitations, such as grid capacity constraints, or policy barriers that discourage energy feed-in. Energy losses during transmission or conversion processes could also contribute to this gap. The total energy production (2,249,224 kWh/year) marginally exceeds consumption (2,230,512 kWh/year), indicating that the system operates near its capacity limit. This makes it vulnerable to demand fluctuations or disruptions in energy production.

Based on equation (1), determine the capacity of the battery to be used, after obtaining the value of the battery capacity, then configure it by determining the type of battery along with the appropriate capacity data input for the PV design. The battery capacity for the P V system is 132,400Ah using EnerSys PowerSafe SBS 780 batteries with a maximum value of 875Ah per battery, so the number used in the system is 152 pcs. Based on equation (2), it is determined that the inverter capacity to be used with the inverter value has 25% - 30% more than the load power for protection. The inverter capacity that can be used is 689kW.

Table 11 shows the maximum simulation per optimization is 60 which means that each optimization iteration will include up to 60 simulations to get the best solution. System design precision is 0.01 which indicates that the level of design precision is evaluated with high accuracy. For NPC precision is 0.01 which indicates that the calculation of the total cost of the system over its lifetime is carried out with precise calculations. Focus factor worth 50 optimization value is done with a high level of accuracy.

Maximum renewable penetration is >55% for the maximum percentage of new renewable energy contribution in total energy production. In Battery Autonomy of Less Than for 2 hours which allows the sidesain system to not depend on the battery for 2 hours. The Grid power price is the price set at 1,115 IDR/kWh and the Grid Emission value generated by the grid is 800g/kWh. The following are the results of the rooftop PV design optimization. Based on the rooftop PV system optimization simulation, the Homer pro system proposes the addition of new renewable energy consisting of 530 kW of solar panels as well as adding 1 battery and a converter with a capacity of 689kW.

Table 11. Grid Optimization

Parameter	Input
Maximal Simulation per Optimization	60
System Design precision	0.01
NPC precision	0.01
Focus Factor	50
Max. RE Penetration.	>55%
Battery Autonomy of less than	2 Hours
Grid Power Price/kWh	IDR1,115

Table 12. PV Rating Output

Parameter	Info.
Rated Capacity	530 kW
Mean Output	85.2 kW
Mean Output per Day	2,045 kWh/d
Capacity Factor	16.1%
Total Production	746,389 kWh/yr
Hours of Operation	4,430 h/yr

Table 13. Battery Rating Output

Parameter	Info.
Storage Wear Cost	907 IDR/kWh
Nominal Capacity	10.5 kWh
Usable Nominal Capacity	7.35 kWh
Lifetime Throughput	11,212 kWh
Expected Life	5.59 year
Energy In	2,028 kWh/yr
Energy Out	1,974 kWh/yr
Storage Depletion	7.35 kWh/yr
Losses	61.0 kWh/yr
Annual Throughput	2,005 kWh/yr

Table 14. Inverter Rating Output

Parameter	Info.
Capacity	689 kW
Mean Output	83.1 kW
Capacity Factor	12.1 %
Hours of Operation	4,712 h/yr
Energy Out	727,677 kWh/yr
Energy In	746,336 kWh/yr
Losses	18,658 kWh/yr

Based on table 12, the energy output produced specifically by solar panels with a total energy produced of 746.389kWh with a total operating time of 4,430 hours per year. The installed energy of 530kW has an average output of 85.2kW or an average output per day of about 2,045kWh with a capacity factor of 16.1%.

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Table 13 shows the number of batteries used is 1 string (see calculation results). The cost of using battery storage is 907 IDR/kWh. The nominal capacity value is 10.5kWh and the usable capacity is 7.35kWh. Then for the energy that the battery can deliver during its lifetime of 11,212kWh with an expected life of 5.59 years. The battery in this system has a total incoming energy of 2,028kWh/year and a total outgoing energy of 1,974kWh/year with energy lost due to the battery discharge process of 7.35kWh/year and a total energy loss in storage of 61kWh/year. Then the energy actually processed by the battery is 2,005kWh/year.

Table 14 shows the output results of the inverter where the inverter capacity used is 689kW with an average output value of 83.1kW. with an operating time of 4,712 hours per year, the energy entering the inverter is 746.336kWh per year and the energy released from the inverter is 727.677kWh per year with a loss value due to energy lost during the conversion process of 18.658kWh/year.

After analyzing the optimization of the system and analyzing the energy produced in each component, the next step is to analyze the economic value of the PV system. Based on the simulation results in Table 15, the total Net Present Cost is 43.6 billion IDR which is the total cost used to build a rooftop PV system. The Levelized Cost of Energy value is 1,050.30 IDR/kWh for the average cost of energy production per kWh. And an Operating Cost value of 2.01 billion IDR for the total operational costs including system maintenance for the next 25 years. Based on simulation analysis using HOMER, the renewable penetration (RP) level of the proposed hybrid system reaches 33.5%, indicating that the proposed renewable energy source (rooftop PV) is able to support part of the electricity demand. A high RP value indicates reduced dependence on fossil energy sources, thus supporting environmental sustainability and energy security. System optimization through the addition of battery storage capacity, setting efficient dispatch strategies, and utilizing dump loads are expected to increase the contribution of renewable energy. However, there is a large area available for PV system utilization, so the RP has not reached 100%. Further explore combinations of other RE sources to improve system stability while maximizing renewable penetration.

Table 15. Techno-economy Simulation Result

Assessment Criteria	Cost (IDR)
Total Net Present Cost	43.6 billion
Levelized Cost of Energy	0,0015 million
Operating Cost	2.01 billion

Table 16. Emissions in PV System

Emission	Grid without PV (kg/year)	Grid with PV (kg/year)
Carbon Dioxide	1,695,936	1,202,268
Sulfur Dioxide	5,809	4,118
Nitrogen Oxides	2,841	2,014

Furthermore, the analysis of emissions generated by the PV system and emissions generated by the grid without PV. Based on the data in the table, the value of emissions generated in the grid system decreased in PV produced carbon dioxide of 1,202,268 kg / year while in the grid system of 1,695,936 kg / year, for sulfur dioxide in PV of 4,118 kg / year and for nitrogen oxides in PV of 2,014 kg / year and on the grid 2,841 kg / year. The PV system has a reduction in emissions from all components of about 29.35%.

Conclusions

Based on simulation data and analysis of rooftop PV system design, among others, the potential for renewable energy in the pharmaceutical company area based on Solar GHI Resourcce produces an average energy of 4.81 kW/m^2/day, wind speed of 3.05 m / s and an average temperature of 23.59 C. Based on actual load data in pharmaceutical companies for AHU operations, a total load of 5808 kW is obtained in a day. The simulation results of the K2 Base System, the usable area is 3,140.74m2 with the type of LG Electronics Inc module (LG400N2W-A5) can be installed 1324 pcs modules after adjusting obstacles in the area so that the energy that can be generated is 529.6 kWp. Furthermore, the researchers continued the analysis using the simulation results of the K2 Base System because it is most suitable for the conditions in the research area, so that the power is fulfilled around 33.5% of the load requirements. Analysis and modeling of PV systems in pharmaceutical companies can be implemented based on data obtained from the results of simulations that have been carried out, both from PV design with the results of energy that can be generated of 746,389 kWh / year with a Renewable Fraction value of 33.5%, an NPC value of 43.68 million IDR and an LCOE of 1,050.30 IDR with a reduction value of 5.8% from the Grid price of 1,115 IDR and an operating cost value of 2.01 million IDR. Based on the Homer simulation results for the PV system and the amount of electricity purchased by the grid on the PV system of 1,502,835 kWh / year with a value of 1,675 million IDR and for 2.1 million IDR / kWh / year with a value of 2.36 billion IDR there is a reduction in power supplied by the grid by 29.1%. As well as with the emissions generated in the PV system Carbon Dioxide 1,202,268 kg / year, Sulfur Dioxide 4,118 kg / year and Nitrogen Oxides 2,841 kg / year while for the grid produces Carbon Dioxide emissions 1,695,936 kg / year, Sulfur Dioxide 5,809 kg / year and Nitrogen Oxides 2,841 kg / year so that the reduction in emissions obtained by implementing PV systems on grid is approximately 29%.

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Conflicts of Interest

The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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