Feasibility study and simulation of a 4 MW solar power plant design using PVSyst in Oefafi Village, Kupang, Indonesia

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ABSTRACT

Indonesia has a vast amount of potential for renewable energy, with many places still experiencing inaccessibility and inadequacy to electricity. One of the places, Kupang in East Nusa Tenggara, suffers a deficit of 4 MW at night along with a blackout despite the implementation of the Oelpuah Solar Power Plant that can produce 5 MW. Thus, this study presents a feasibility study and simulation of additional solar power plant implementation using PVSyst based on geospatial analysis by ArcGIS to point down the desired location, namely Oefafi. The results produce 7,212,139 kWh/year (almost 20 MWh/day using 6,552 modules of Jinkosolar 610 Wp JKM-610N-78HL4-BDV, 274 units of Growatt 12KTL3-X inverters, and 2000 BYD B-Box PRO 2.5 1,024 V 5,200 Ah battery. The losses of the systems mostly come from temperature loss in PV. The total installation cost is 51 billion IDR with a payback period of 8.3 years, NPV of 6.6 billion IDR, and IRR of 10.62% for an electricity tariff of 1,000 IDR/kWh. The amount of greenhouses saved accounts for 134,110.3 tCO_2. This will help in filling the 4MW deficit while also potentially providing to other unsupplied regions. Future research may use other software for comparison and give better explanations.

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1. INTRODUCTION

Humans have relied on energy significantly since long ago. One of the energies that has been used most for human activities is electricity. Countries in the world use this energy for everyday life. The last decade of energy consumption shows an increase annually, linear to human dependency. Fossil fuels are one of the energy sources that are dominantly used since it is relatively cheaper than other sources. From the 1800s to 2021, consumption showed an increase while its reserves reduced tremendously [1]. The process of producing fossil fuels also causes environmental problems. These include acid rain, global warming, climate change, pollution, and others [2], [3]. Moreover, today's issues show that countries faced the fossil fuel crisis while still needing to rely on it, including Indonesia which shows the dominance for electricity, gas, and coal [4].

On top of that, the Ministry of Energy (ESDM) stated that the reserves of gas in Indonesia will last 22 years and coal for 65 years [4]. This shows that the reserves may not be used by future generations since they cannot last for a century. Hence, an alternative is proposed, which is using renewable energy. Renewable energy is considered more environmentally friendly than fossil fuels since it can reduce greenhouse gas emissions that contribute to climate change mitigation and other issues [5]-[7]. Examples of this energy are solar energy, wind energy, geothermal energy, hydropower, and bioenergy.

Renewable energy serves as the source of electricity supply with its advantages including the availability, fossil fuels usage reduction to minimize environmental impact, and technology development [5], [8], [9]. Yet, several drawbacks act as a limitation upon applying this energy, including lower efficiency compared to fossil fuels, unpredictability and volatility of the availability, as well as the presence of reserves when deficiency occurs [5], [9]. Thus, countering this situation requires careful consideration and specific planning in the research and design phase.

One of the techniques to execute this phase is to utilize energy models for decision-making purposes, namely simulation [10]. This method gives solutions to physical outputs based on virtual replication, linking theories, and experimental investigation using known parameters [11]. This creates opportunities to analyze estimated losses by cost, time, quality, and environmental impact. The most popular source of renewable energy, solar, has been studied using the help of simulations [12], [13]. This energy comes from the sun's irradiation, which can be converted to heat, electricity, and other energy forms using conversion technology [14]. The advantage of this energy is that aside from being used to generate electricity mainly, its operation and maintenance do not produce pollution. However, the disadvantages include high investment costs, being weather dependent, space occupation, as well as the possibility of negative consequences to animals [14]-[19]. Not to mention, the conversion mechanism starts from the sunlight that reaches the PV cell made from semiconductors, which produce electricity from the photons' absorption that moves the electrons. The electricity outcome is in the form of direct current, which then enters inverters to be turned into alternating current. This form will be used for end users (house and industry) for appliance purposes. Additional systems such as electronic power and storage systems can be used for better conversion efficiency as well as storing unused energy. As such, it is important to see the performance of solar energy installation based on the models of modules, storage systems, trackers, DC/DC converters, and inverters. Hence, it may contribute to giving suggestions based on the simulation results to show the possibility of physical world performance.

Some software that provides the facility for solar energy models includes PVSyst, RETScreen, HOMER, and MATLAB. One of the common software that gives an overall analytical test in designated locations for the whole solar system is PVSyst [7]. In contrast to other software, PVSyst provides in-depth analysis results ranging from the size to the output of the PV system [20]. The product can be considered accurate, with a mean bias error (MBE) value of about 1–2% [20]. Many studies have relied on PVSyst, which varies from grid-connected to off-grid, showing the capability of analysis features provided by this software [20], [21]. The study in solar power plant design in Pekanbaru has shown the results of above 23 MWh using more than 40,000 units of Longi Solar modules (415 Wp) based on PVSyst simulation [20]. Another study uses a PVSyst simulation of 5 MWp, which compares to the real generation that shows higher estimation in system efficiency by 0.12% and PR lower by 0.60%, indicating the accuracy and potential as a dependable tool [21].

Moving back, Indonesia’s renewable energy potential is not fully maximized, as shown in Table 1. Knowing that it will help supply energy to underdeveloped areas [5]. This research is specified to analyze Kupang potential which is located in East Nusa Tenggar (Nusa Tenggara Timur or NTT), Indonesia. Currently, it is known that electricity crises and regular blackouts regularly occur due to natural disasters [22]. Moreover, *Perusahaan Listrik Negara* (PLN) or National Energy Company data had shown that only about 94.04% of the whole villages in NTT have access to electricity, with the rest of 215 villages out of reach [22]. Ironically, the potential of renewable energy in NTT is relatively high, with 10,188 MW for wind energy followed by solar energy at 7,272 MW and ocean energy at 5,355 MW [22], [23]. To fulfill the need for electricity supply, governments built a solar energy power plant in this area called Oelpuah Power Plant with an output of 5 MW with a total of 22,008 PLTS modules with one producing 230 Wp from National Energy Council spread over an area of 7.5 hectares in Oelpuah Village, 20 kilometers from Oelamasi, the capital city of Kupang Regency, NTT [24].

Table 1. Indonesia's potential and installed capacity for renewable energy in 2021 [22]

NRE commodity	Total potential 2021 (GW)	Power plant capacity (GW)	Utilization (%)
Tidal	17.9	-	-
Geothermal	23.9	2.3	9.6%
Bioenergy	56.9	2.3	4.0%
Wind	154.9	0.2	0.1%
Hydro	95.0	6.6	6.9%
Solar	3,294.4	0.2	0.01%
Total	3,643	11.2	0.3%

The electricity from this solar power plant acts as a solution for shifting blackouts during the day around Kupang City and the district [23]. Yet, a deficit of 4 megawatts (MW) still occurs at night in the Kupang Branch 3. According to Jupiter, field officer of PLTS Oelpuah, the 5 MW electricity was not supplied all at once but was carried out in stages. The production of plants is highly dependent on solar energy in which in cloudy weather the production is limited to 2 MW. In addition, the temperature in the system should not be below 20 degrees Celsius and exceed 35 degrees Celsius, with the ideal range from 25-35 degrees Celsius. If the heat coming from the sun reaches beyond the limit, losses can occur. The energy obtained is sold to PT PLN at approximately Rp 3,450/kWh with a contract period of 20 years. PLN then distributes it to end users.

Moreover, although several literatures have discussed the solar power implementation in this region as shown in [24] that elaborate the PR obtained ranges from 0.7-0.9 and [25] which discuss the potential location in Oelnasi, it lacks the in-depth analysis. Following the information, it is crucial to make a better analysis and consideration upon building a new communal solar power plant to cope with the deficit and blackout problems. Thus, this research uses PVSyst to carry out simulations for additional solar power plants based on several considerations and location selection with high potential that avoids natural disaster areas. This research will use additional software, namely ArcGIS, to help in narrowing the designated best location for solar power plant installation purposes. In accordance with the information, it is crucial to make an analysis and consideration upon building a new communal solar power plant to cope with the deficit and blackout problems. Thus, this research uses PVSyst to carry out simulations for 4 MW solar power plants based on several considerations based on the specific location selection with high potential that avoids natural disaster areas. This research will use additional software, namely ArcGIS, to help in narrowing the designated best location for solar power plant installation purposes.

2. METHOD

The design procedure of the solar power plant in this research is based on simulations using PVSyst software, with the assistance of ArcGIS to aid in selecting the optimal location. The stages involved are outlined as follows. The first stage is problem identification, where the issue addressed in this study is the electricity deficit and blackouts in Kupang. Although the Oelpuah solar power plant is already in operation, it has not been able to meet the electricity demand fully, highlighting the need for additional power generation capacity. Next is the literature review, which involves reviewing studies related to the use of PVSyst in solar power plant design. This review provides a technical foundation for the research and helps understand different approaches and results from previous studies.

Following this, location selection is carried out. This step includes analyzing geospatial information such as solar irradiation, potential geohazards or natural disaster risks, and thermal conditions. By using ArcGIS and secondary data from various sources, the analysis helps narrow down the best location for the new solar power plant. The fourth step is finalizing the selected area. After considering all the relevant factors, the most suitable location for the power plant is confirmed. The next stage is data collection, where technical information regarding components necessary for the installation is gathered. This includes specifications of solar panels, inverters, and other equipment required for the solar power plant design. Once the data is collected, data processing takes place through the design and simulation of the power plant using PVSyst. This allows for a thorough analysis of the plant’s performance and its potential energy output. Finally, the results are analyzed, and conclusions are drawn. The results from the simulation are evaluated to determine the feasibility, efficiency, and potential impact of the planned solar power plant. Further details on the data collection and processing stages will be elaborated in the subsequent sections of this research.

2.1. Location selection

In this section, thorough studies are for the selection of location and solar power plant parameters. First of all, based on the problem that has been identified, Kupang has been chosen as the location to be used to implement a solar power plant. In this case, careful planning for location determination is made using ArcGIS. First of all, data from Dukcapil is obtained to set the village classification area in Kupang. Then, using the data from Global Solar Atlas, solar irradiation can be obtained in the determined area. Finally, the data of Landsat 8 operational land imager (OLI) and thermal infrared sensor (TIRS), which consists of spectral bands with spatial resolution of 30 m (band 1-7 and 9), 15 m (band 8), and 100 m (band 10 and 11) are also used, specified in Table 2. From this data obtained, analysis can be made by importing the village classification and solar irradiation data, specifically in June 2024, as shown in Figure 1.

From Figure 1, it can be seen that areas that are colored red show great potential since the solar radiation is high, above 140 W/m^2. However, usually high solar radiation may indicate high temperatures in the area. Thus, band 10 is imported to see the temperature condition, as shown in Figure 2. As narrowed down, the red parts are mainly located in Oelnasi Village, thus, this should be avoided. To its left side are

Oelpuah Village and Oefafi Village, with similar solar radiation which can be selected as alternatives. Thus, further analysis can be done. By adding layers for urban areas using bands 7-6-4, the representation of the land can be shown in Figure 3.

Table 2. Band combination

Band combination	Landsat 8
Natural Color	4-3-2
False Color (urban)	7-6-4
Color Infrared (Vegetation)	5-4-3
Agriculture	6-5-2
Atmospheric Penetration	7-6-5
Healthy Vegetation	5-6-2
Land/Water	5-6-4
Natural With Atmospheric Removal	7-5-3
Shortwave Infrared	7-5-4
Vegetation Analysis	6-5-4

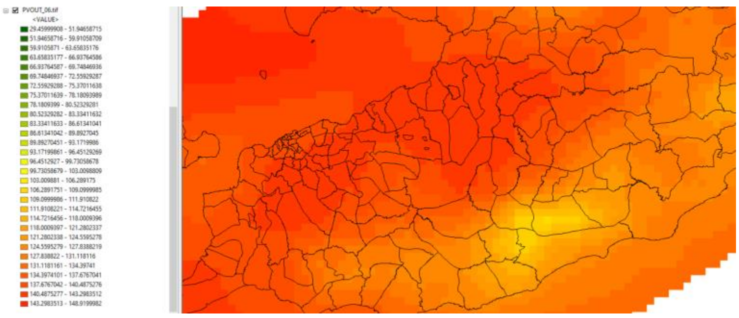


Figure 1. Solar irradiation in June 2024 for Kupang Region

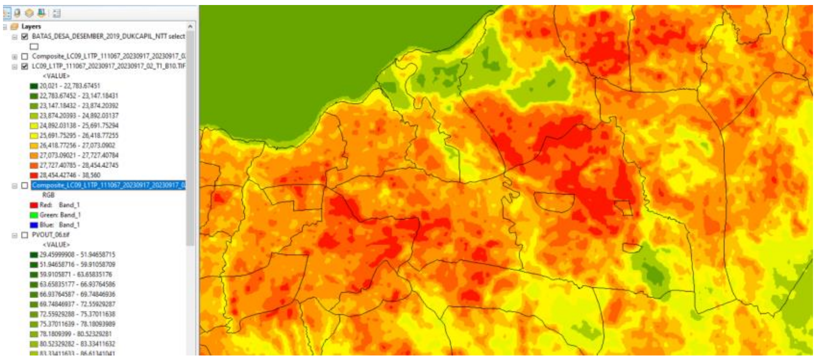


Figure 2. Thermal condition for Kupang Region

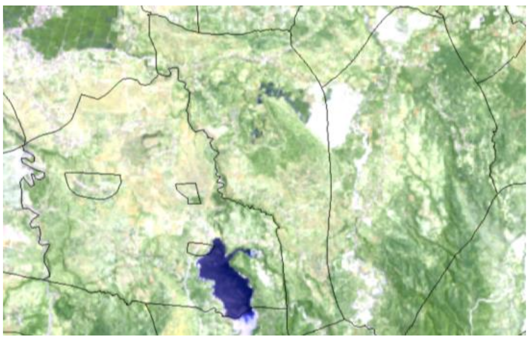
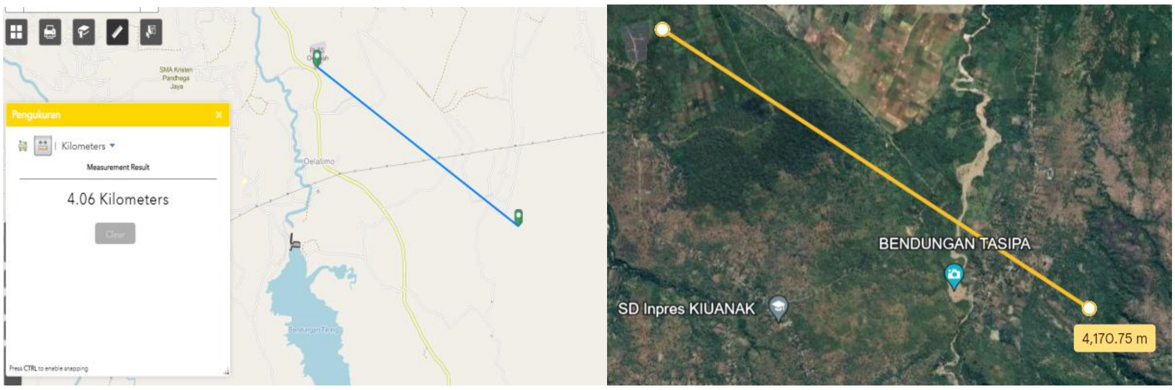


Figure 3. Oelnasi, Oelpuah, and Oefafi Village (urban color) from left to right

From this, even further analysis can be made with data from geohazard potential in Kupang from Badan Penanggulangan Bencana Daerah Kupang [26]. Based on the report that shows risks of hazards in the area, the selected villages have a low potential for earthquakes, the least potential for tsunami and landslide, low potential for floods, intermediate potential for drought, as well as low potential for extreme weather and multi-natural disasters [26]-[29]. Thus, generally, both villages are considered well-suited for solar power selection. Finally, Figure 4 is the location of the utility grid which is considered based on the geoportal map in Figure 4(a) and Google Earth map data in Figure 4(b). As shown in Figure 4, the nearest grid is from the Oelpuah Solar Power Plant, around 4 km.



(a) (b)

Figure 4. Oelpuah solar power plant distance from selected area view from (a) Geoportal Map and (b) Google Map

Thus, the finalized area lies around Oefafi village which is determined for solar power plant installation. This village is located in the highlands with an area of 20.37 km^2 with around 2,473 people living in (578 families), mostly with the age range of 15-30 based on Dukcapil data. The problem in this village is mostly due to drought, in which local people suffer from a lack of usable water for their daily activities which An imperative action regarding suitable dam and water pump installation must be executed. Thus, it is hoped that the planned solar power plant can help both Oelpuah village with deficit problems and Oefafi village with water pump operation.

2.2. Data collection

This study will assess the most suitable solar power plant system based on the main components which are the solar cells and inverters. Inverters are an important component that converts DC supply from PV to AC supply while also behaving as safety measures in response to voltage, current, and frequency that may go beyond the limit. In this case, the solar power plant is designed to be connected to the utility grid along with the installation of storage systems for locals to access electricity if a deficit occurs. Thus, the solar power plant parameters for modules, inverters, and batteries can be described in Tables 3-5.

Table 3. PV module mono silicone jinkosolar, JKM-610N-78HL4-BDV

Parameters	Value	Parameters	Value
G Reference Condition	1,000 W/m^2	Tref	25 °C
Short Circuit Current (Isc)	14.03 A	Open circuit Voc	55.31 V
Max Power Point (Impp)	13.88 A	Vmpp	45.60 V
Temperature Coefficient	6.5 mA/°C	Length	2,465 mm
Nominal Power	610 Wp	Width	1,134 mm

Table 4. PV inverter–growatt MOD 12KTL3-X

Parameters	Value	Parameters	Value
Minimum MPP Voltage	140 V	Frequency	50-60 Hz
Min. Voltage for PNom	235 V	Nominal AC Power	12 kW
Maximum current per MPPT	26 A	Depth	178 mm
Nominal MPP Voltage	580 V	Height	387 mm
Maximum MPP Voltage	1,000 V	Width	425 mm

Table 5. Lithium-ion, LFP Battery BYD B Box PRO 2.5

Parameters	Value	Parameters	Value
Nominal Voltage	51.2 V	Maximum Charging Current	50.0 A
Capacity at C10	52 Ah	Maximum Discharging Current	100.0 A
Internal resistance at ref. temperature	21.12 mΩ	Weight	79 Kg
Reference Temperature	20.0 ℃	Depth	510 mm
Coulombic efficiency	95.3 %	Height	883 mm
Charge Cut-Off Voltage	60.8 V	Width	600 mm
Discharge Cut-Off Voltage	32.0 V		

The PV module used in this design is the JinkoSolar Mono Silicone JKM-610N-78HL4-BDV, which has a nominal power of 610 Wp. It operates under standard conditions with a reference irradiance of 1,000 W/m² and a temperature of 25 °C. The module's short circuit current (Isc) is 14.03 A, while its maximum power point current (Impp) is 13.88 A at a voltage (Vmpp) of 45.60 V. The physical dimensions of the module are 2,465 mm in length and 1134 mm in width.

The inverter selected is the Growatt MOD 12KTL3-X, with a nominal MPP voltage of 580 V and a maximum input voltage of 1,000 V. This inverter supports a frequency range of 50-60 Hz and a maximum current per MPPT of 26 A. The physical dimensions of the inverter include a height of 387 mm, a width of 425 mm, and a depth of 178 mm, with a nominal AC power of 12 kW, making it a compact and efficient solution for the system.

For energy storage, the system uses the BYD B Box PRO 2.5 Lithium-ion battery. It has a nominal voltage of 51.2 V and a capacity of 52 Ah. The battery supports a maximum charging current of 50 A and a maximum discharging current of 100 A, with a high coulombic efficiency of 95.3%. The dimensions are 883 mm in height, 600 mm in width, and 510 mm in depth, with a weight of 79 kg. This battery system ensures reliable energy storage for use during periods of energy deficits.

2.3. Data processing

From the obtained data, the next stage is to design and simulate the desired solar power plant model in PVSyst. The simulation will result in detailed reports consisting of parameters used in the PV array (module and inverter), 3D perspective for shading, sun height to azimuth diagram, system production data (annually), loss diagram, and other necessary data. Financial parameters can also be included in which greenhouse gas emission reduction can be obtained. This information will be processed technically to analyze and provide conclusions on how effective the installation of the solar power plants is in the designated locations.

3. RESULTS AND DISCUSSION

The collected data and parameters have been processed to design the solar power plant in the selected region, Oefafi Village in Kupang, specifically at -10.18 °S, 123.71 °E. In summary, the systems, being grid connected, consist of PV field orientation of fixed plane with 30 tilt and 0 azimuth which has been set based on comparative variation to get the maximum output. The number of modules amounts to 6,552 units (564 strings multiplied by 12 series) with a total Pnom of 3,997 kWp, along with 274 inverters having 3,288 kWac of Pnom total and 1.216 Pnom ratio as well as 2,000 units of battery (20 series multiplied by 100 parallel) by 1,024 V and 5,200 Ah. The energy produced by this plant accounts for 7,212,130 kWh/year, with used energy of 8,760,000 kWh/year. The specific production is 1,805/kWh/kWp/year with a PR of 80.34% and a solar fraction of 56.56%. Since this power plant is designed to be located in an open area, the visualization can be shown in Figure 5, in which 650 sheds with a spacing of 5 m are placed, with each shed consisting of 10 modules.

Under the allocation of the sheds, the movement of the sun becomes one of the considered aspects. The trajectories of solar radiation by height to PV modules based on tilt and azimuth are shown in Figure 6. Thus, the irradiation potential and energy output from the simulation of the solar power plant based on this data can be shown in Figures 7 and 8. Figure 8(a) illustrates the normalized production while Figure 8(b) shows the performance ration, both in bar graph. Figure 9 would typically depict the electrical connections within the solar power plant, showing the flow of energy from PV modules through inverters and into the grid or battery storage.

Figure 6 illustrates the solar radiation trajectories as they impact the photovoltaic (PV) modules, taking into account the tilt and azimuth angles. It visually represents how the sun's position changes throughout the day and year, helping to optimize the placement of solar panels. The shading losses, which vary depending on the time of day, are also shown to help predict potential energy generation losses due to shadows.

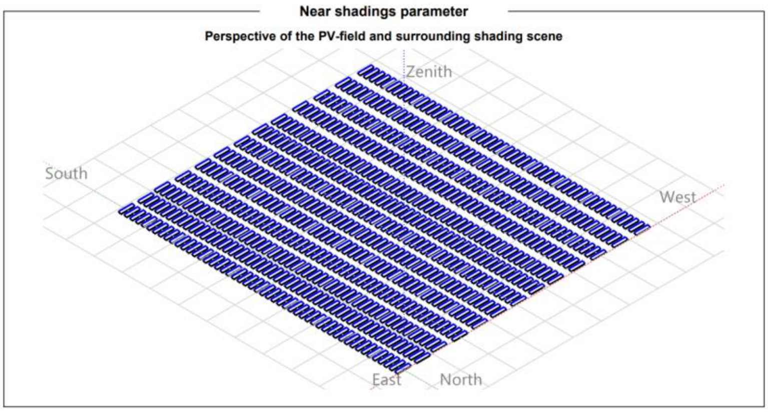


Figure 5. Sheds configuration

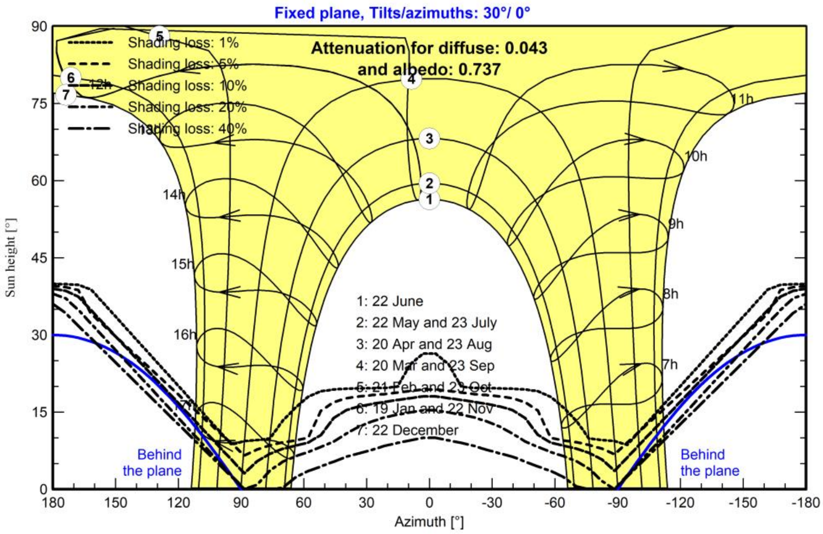


Figure 6. Trajectories of solar radiation in Kupang

Balances and main results

	GlobHor	DiffHor	T_Amb	GlobInc	GlobEff	EArray	E_User	E_Solar	E_Grid	EFrGrid
	kWh/m²	kWh/m²	°C	kWh/m²	kWh/m²	kWh	kWh	kWh	kWh	kWh
January	179.4	88.77	27.19	142.4	133.5	475773	744000	391247	66083	352753
February	164.6	68.85	27.05	141.4	133.9	473347	672000	343536	108688	328464
March	188.2	76.00	27.09	180.3	172.5	604983	744000	412481	165795	331519
April	184.7	59.18	27.43	201.6	194.9	675510	720000	423721	223147	296279
May	169.5	53.17	27.52	203.3	197.2	684402	744000	429026	226942	314974
June	156.7	47.13	26.03	196.1	191.1	667989	720000	412341	227597	307659
July	177.9	39.93	26.19	220.0	215.0	743819	744000	433484	280001	310516
August	203.1	34.77	26.41	232.1	226.3	778683	744000	440043	307531	303957
September	204.2	52.90	26.96	206.1	199.0	690497	720000	421483	240350	298517
October	220.3	70.97	28.48	196.9	188.3	656298	744000	430503	197214	313497
November	211.0	69.94	28.44	169.4	160.1	561913	720000	403917	131534	316083
December	205.3	84.29	27.68	156.7	146.5	520817	744000	413232	82233	330768
Year	2265.1	745.90	27.21	2246.2	2158.4	7534033	8760000	4955015	2257115	3804985

Legends

GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_User	Energy supplied to the user
T_Amb	Ambient Temperature	E_Solar	Energy from the sun
GlobInc	Global incident in coll. plane	E_Grid	Energy injected into grid
GlobEff	Effective Global, corr. for IAM and shadings	EFrGrid	Energy from the grid

Figure 7. Radiation and energy production

The table in Figure 7 presents data on global irradiation, including both horizontal and diffuse irradiation, as well as the corresponding energy output from the solar power plant. It also includes ambient temperature data, which can affect the performance of PV modules. The table displays monthly data that encompasses energy supplied to users and energy fed into the grid. A key value highlighted is the effective global irradiation (GlobEff), which indicates the usable solar energy after accounting for losses such as shading and the angle of incidence.

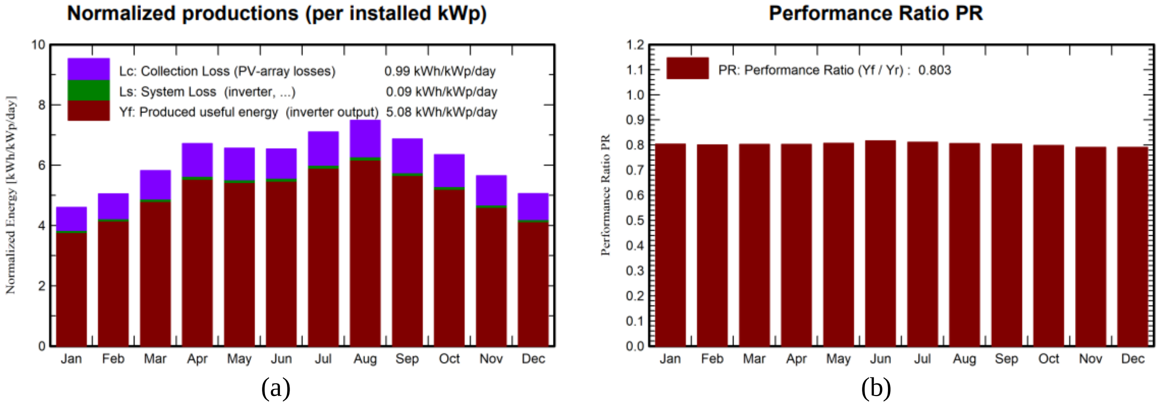


Figure 8. Output bar graph on (a) normalized production and (b) PR of the solar power plant

The first graph in Figure 8 shows the normalized energy production per installed kilowatt-peak (kWp), along with the system losses and collection losses (Lc and Ls). This helps visualize the energy output trends over the year. The second graph highlights the PR of the solar power plant, which is an indicator of how efficiently the system converts sunlight into usable electricity. A stable PR of 0.803 indicates consistent system performance across all months, with slight variations due to seasonal changes. Then, the single line diagram is shown in Figure 9.

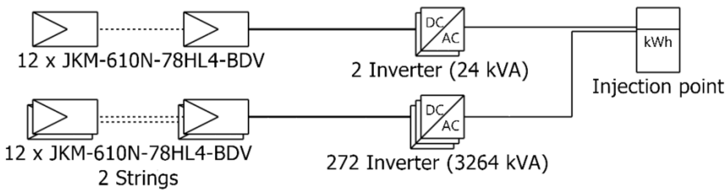


Figure 9. Single line diagram of solar power plant

Aside from the given data and visualization, the losses of solar power plants are also calculated. These losses include irradiance loss, shading loss, thermal impact loss, and system loss [20]. According to the report results, the losses are dominated by temperature loss in PV, about 9.13%. This is followed by IAM or incidence angle modifier loss which means that the irradiance that reaches the PV modules decreases under normal incidence by 2.14%. Other losses are also caused by a mismatch loss of 2.10%, a near-shading loss of 1.81%, and an inverter loss of 1.66%. Thus, from the input of 2,265 kWh/m^2, after a decrease due to irradiation loss, the global horizontal irradiation that reaches the PV amounts to 2158 kWh/m2 multiplied by about 18,000 m^2, producing 8,632,583 kWh regarding the efficiency at standard test condition (STC) by 21.84%. End users will receive about 5,000 MW, while the grid receives more than 2,200 MW. Detailed losses are depicted in Figure 10.

The economic aspect is also important to be analyzed alongside the technical data, which can be broken down in Figure 11. Installation cost, including PV modules, inverters, batteries, other components, studies and analysis, and installation, is given in Figure 11(a). On the other hand, Figure 11(b) shows the financial analysis, including the return on investment (ROI).

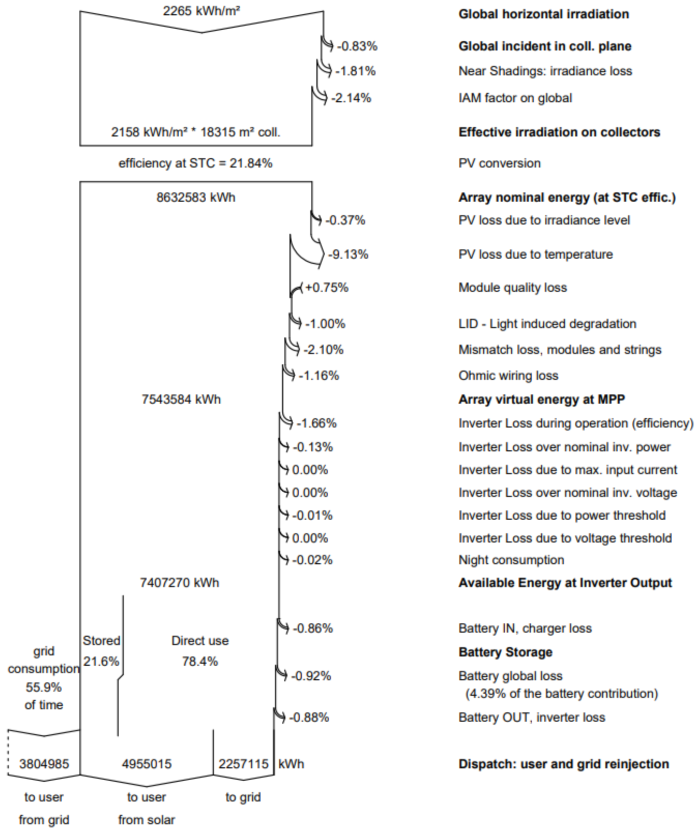


Figure 10. Losses of designed solar power plant

Installation costs

Item	Quantity units	Cost IDR	Total IDR
PV modules			
JKM-610N-78HL4-BDV	6552	4773000.00	31272696000.00
Inverters			
MOD 12KTL3-X	274	13500000.00	3699000000.00
Batteries	2000	7850000.00	15700000000.00
Other components			
Accessories, fasteners	1	10000000.00	10000000.00
Wiring	14000	1000.00	14000000.00
Monitoring system, display screen	10	10000000.00	100000000.00
Measurement system, pyranometer	30	5000000.00	150000000.00
Studies and analysis			
Engineering	1	25000000.00	25000000.00
Permitting and other admin. Fees	1	10000000.00	10000000.00
Environmental studies	1	15000000.00	15000000.00
Economic analysis	1	15000000.00	15000000.00
Installation			
Global installation cost per module	6552	10000.00	65520000.00
Global installation cost per inverter	274	20000.00	5480000.00
Global installation cost per battery	2000	20000.00	40000000.00
Transport	1	400000000.00	400000000.00
		Total	51521696000.00
		Depreciable asset	50681696000.00

Operating costs

Item	Total IDR/year
Maintenance	
Provision for inverter replacement	739800000.00
Total (OPEX)	739800000.00
Including inflation (3.00%)	993935152.35

System summary

Total installation cost	51521696000.00 IDR
Operating costs (incl. inflation 3.00%/year)	993935152.35 IDR/year
Unused energy	4955 MWh/year
Energy sold to the grid	2257 MWh/year
Cost of produced energy (LCOE)	513.380 IDR/kWh

(a)

Financial analysis

Simulation period

Project lifetime	20 years	Start year	2025

Income variation over time

Inflation	3.00 %/year
Production variation (aging)	0.00 %/year
Discount rate	0.50 %/year

Income dependent expenses

Income tax rate	0.00 %/year
Other income tax	0.00 %/year
Dividends	0.00 %/year

Depreciable assets

Asset	Depreciation method	Depreciation period (years)	Salvage value (IDR)	Depreciable (IDR)
PV modules				
JKM-610N-78HL4-BDV	Straight-line	20	0.00	31272696000.00
Inverters				
MOD 12KTL3-X	Straight-line	20	0.00	3699000000.00
Batteries	Straight-line	20	0.00	15700000000.00
Accessories, fasteners	Straight-line	20	0.00	10000000.00
		Total	0.00	50681696000.00

Financing

Own funds	51521696000.00 IDR

Electricity sale

Feed-in tariff	1000.0000 IDR/kWh
Duration of tariff warranty	20 years
Annual connection tax	0.00 IDR/kWh
Annual tariff variation	0.0 %/year
Feed-in tariff decrease after warranty	0.00 %

Self-consumption

Consumption tariff	1000.0000 IDR/kWh
Tariff evolution	0.0 %/year

Return on investment

Payback period	8.3 years
Net present value (NPV)	66654768234.86 IDR
Internal rate of return (IRR)	10.62 %
Return on investment (ROI)	129.4 %

(b)

Figure 11. Economic analysis of designed solar power plant (a) installation and operating cost and (b) financial

In the case of financial analysis, the parameters that are sought include solar power plant components such as PV modules, inverters, batteries, and other complying components as well as other expenses including feasibility studies, installation, and operation costs. The price for components is based on the market price while others are based on assumption which relies on studies for solar power plant installation as well as local comparison [30]. The total installation cost reaches above 51 million IDR while the operating cost to almost 1 million IDR. With the electricity sale, rounding to 1,000 IDR/kWh [31] along with the self-consumption tariff given with the same amount, the payback period is 8.3 years starting from 2025. Assuming that the inflation rate is 3% and the discount rate by 0.5% as an assumption, this project is profitable since the net present value reaches 66.6 million IDR, the Internal Rate of Return by 10.62% and the ROI by 129.4%.

Finally, based on the report, the saved CO_2 emission amounts to 134110.3 tCO_2 shown in Figure 12, which is the difference between the saved emissions (based on IEA standard) with the system production/manufacturing (or generated emission) carbon emissions or footprints. This carbon footprint can be defined as a measurement of the amount of carbon dioxide and other greenhouse gases released during the whole life cycle due to human activities. This may come directly and indirectly since renewable energy has reduced the carbon footprint but not entirely. This is due to the processes other than operation, such as extraction, manufacturing, construction, maintenance, and decommissioning [32]. Although it was found in negative correlation was found between renewable energy consumption growth and carbon dioxide emissions per capita growth for countries that consume significant amounts of this energy [6]. The carbon footprint visualization can be shown in Figure 13.

Total: 134110.3 tCO_2

Generated emissions

Total: 7412.97 tCO_2

Source: Detailed calculation from table below:

Replaced Emissions

Total: 163108.1 tCO_2

System production: 7407.27 MWh/yr

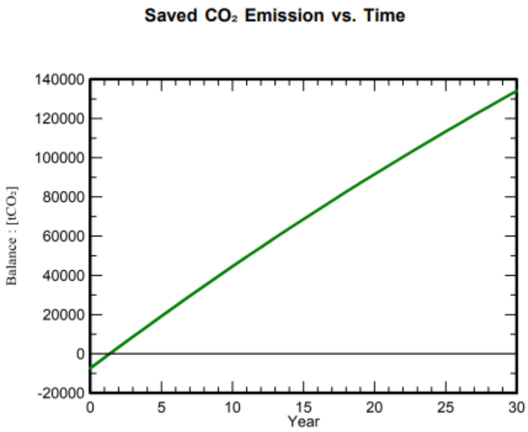
Grid Lifecycle Emissions: 734 gCO_2/kWh

Source: IEA List

Country: Indonesia

Lifetime: 30 years

Annual degradation: 1.0 %



System Lifecycle Emissions Details

Item	LCE	Quantity	Subtotal
			[$kgCO_2$]
Modules	1292 kgCO2/kWp	5303 kWp	6849578
Supports	4.90 kgCO2/kg	86940 kg	425639
Inverters	485 kgCO2/units	284 units	137748

Figure 12. Greenhouse gas emissions saving data

Figure 13 shows that fossil fuels dominate the emissions amount, followed by geothermal, tidal and biomass, solar, wind, hydropower, and nuclear. About solar energy, it can be seen that this type is inevitable from zero emissions since the figure shows indirect activities cause greenhouse gas. Moreover, to support this finding, a report intergovernmental panel on climate change (IPCC) shows that solar energy emits carbon dioxide by 62.5% of natural gas utilization, specifically around 170 to 250 gCO_2/kWh due to the use of lithium, glass manufacturing and high-purity silicon manufacturing as the raw material of PV system which is based on coal [33], [34]. This shows the reality of carbon footprint effectiveness in correlation with solar energy usage. However, it undoubtedly shows a better scheme rather than the dependency on fossil fuels.

Compared to a similar study on PVSyst utilization, which is only from [30], the use of PVSyst and its tools are not extensively discussed. First, using additional software such as ArcGIS is not explored to consider the potential area based on irradiation. This study highlights the use of ArcGIS along with Google Earth to locate suitable locations based on irradiation and space potential. In addition, the study does not consider aiming up than the target of 4 MW since, based on the narration from [28], the fulfillment of the deficit will only be used to solve the scheduled blackout during the night, but not providing additional electricity for emergency use as well as electrification to other unsupplied villages. This study finalizes the production by 20 MWh per day for the mentioned purposes. Finally, this study presents the contribution towards cleaner energy transition which is elaborated through saved CO_2 emissions data presented by PVSyst along with an explanation that supports the findings, which is lacking in the previous study.

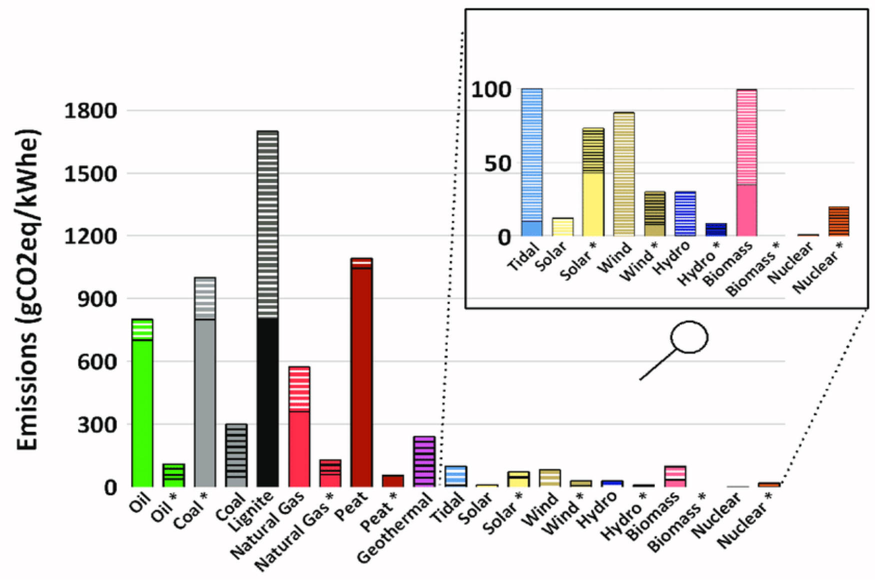


Figure 13. Direct and indirect (*) greenhouse gases emission in gCO_2eq/kWh

However, this study is limited to only simulation. Therefore, the use of real-time data of irradiation, as well as other factors such as available space for system installation, along with the availability of solar system components product, cannot be accurately known and marked, constraining the feasibility study process. Moreover, the investment costs of 51 million IDR are categorized as expensive, although based on the narration, the national power plant supplier (*Perusahaan Listrik Negara* or PLN) stated that despite the high initial investment cost, the use of the current Oelpuah Solar Power Plant has significantly contributed to the saving of 1.5 million diesel usage. Consequently, future research should use substantial parameters with additional software such as the use of other software to give a comparison for analysis purpose of the solar system behavior. It is also suggested to incorporate artificial intelligence to manage external systems such as battery and power electronic systems for better efficiency. To sum up, the design of the solar power plant in Oefafi based on PVSyst with the help of several tools such as ArcGIS and Google Earth has shown the generation of more than 7,200 MWh/year based on over 6500 modules that occupy 18,000 m^2 with cost reaches above 51 million IDR. Responding to the deficit of 4MW in this region, it is estimated to provide 20 MW per day to cover and even supply electricity more than estimated. Hence, this process may help in solving Kupang's electricity issues which may even be distributed to the neighboring cities for usage.

4. CONCLUSION

Corresponding to the need for renewable energy transition, detailed validation for the power plant system is needed, which can be used by software simulation. PVSyst presents an authentic analysis of a planned solar power plant based on the location and parameters. Thus, this study presents an investigation of a planned solar power plant that is intended to serve as an additional energy source to comply with electricity deficit, blackout, and inaccessibility in the Kupang region. Using geospatial analysis with the help of ArcGIS, the specific area that has a low potential for natural disasters and a high potential for irradiation is Oefafi, Kupang, East Nusa Tenggara, in which open spaces are available. With the estimation of the whole system occupying 18,000 m^2, the production reaches 7,212,139 kWh/year (nearly 20 MWh/day) based on 6,552 modules of Jinkosolar 610 Wp JKM-610N-78HL4-BDV, 274 units of Growatt 12KTL3-X inverters, and 2000 BYD B-Box PRO 2.5 1,024 V 5,200 Ah battery. System losses include temperature loss in PV by 9.13%, mismatch loss by 2.10%, IAM factor by 2.14%, and inverter operation loss by 1.66%. In the financial aspects, the total installation cost reaches above 51 million IDR and the operating cost of almost 1 million IDR, which gives a payback period of 8.3 years, NPV of 66.6 million IDR, IRR of 10.62% and ROI of 129.4% for an inflation rate of 30%, a discount rate of 0.5% and electricity tariff of 1,000 IDR/kWh. Finally, the amount of greenhouses saved accounts for 134,110.3 tCO_2 in which is based on manufacturing and production that are based on fossil fuel usage. Based on the results, it is more than enough to fill the 4 MW deficit on Kupang to prevent scheduled blackouts as well as show the potential to distribute to other unsupplied regions by providing almost 20 MWh/day. It should be noted that when designing solar power plants using PVSyst software, it's crucial to take into account the location, area, irradiation rate, PV tilt and azimuth angles, desired power adjusted to area limits, type and number of PV modules, inverters and batteries, loss calculations, and financial analysis to achieve the best simulation results. Future research should rely on more accurate parameters upon designing, use artificial intelligence for external systems management, and with additional software utilization to get a comparison of the planned solar power plant behavior investigation.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data that support this study's findings are available in https://globalsolaratlas.info/map?c=43.074746,106.244816,10&r=IDN&s=43.024535,106.513202&m=site for Global Solar Atlas information and https://geoservices.big.go.id/portal/apps/webappviewer/index.html?id=9917592df1f24501ae804b7d346c08fb for Kupang map.

REFERENCES

[1] N. Pranata and F. R. Saputri, "Renewable energy in Indonesia: a critical review of sources, technologies, and strategies for clean energy transition," *Journal of System and Management Sciences*, vol. 14, no. 7, pp. 122–144, Jun. 2024, doi: 10.33168/jsms.2024.0707.

[2] T. Wambui, M. Hawi, F. Njoka, and J. Kamau, "Performance enhancement and emissions reduction in a diesel engine using oleander and croton biodiesel doped with graphene nanoparticles," *International Journal of Renewable Energy Development*, vol. 12, no. 3, pp. 635–647, May 2023, doi: 10.14710/ijred.2023.51785.

[3] S. A. Moosavi, M. Aghaalikhani, B. Ghobadian, and E. Fayyazi, "Okra: A potential future bioenergy crop in Iran," *Renewable and Sustainable Energy Reviews*, vol. 93, pp. 517–524, Oct. 2018, doi: 10.1016/J.RSER.2018.04.057.

[4] N. Pranata and F. R. Saputri, "Simulation and analysis of wind energy potential for turbine systems in Pekanbaru-Indonesia based on MATLAB Simulink," *International Journal of Power Electronics and Drive Systems*, vol. 16, no. 2, pp. 1341–1347, Jun. 2025, doi: 10.11591/ijpeds.v16.i2.pp1341-1347.
[5] D. Maradin, "Advantages and disadvantages of renewable energy sources utilization," *International Journal of Energy Economics and Policy*, vol. 11, no. 3, pp. 176–183, 2021, doi: 10.32479/ijeep.11027.
[6] C. Chen, M. Pinar, and T. Stengos, "Renewable energy and CO2 emissions: New evidence with the panel threshold model," *Renew Energy*, vol. 194, May 2022, doi: 10.1016/j.renene.2022.05.095.
[7] F. R. Saputri, A. R. Stanlee, I. H. Prasetya, and S. D. Wijaya, "Analysis of solar power plant utilization for public street lighting In Probolinggo, Jawa Timur, Indonesia," *International Journal of Science*, 2023, doi: 10.46729/ijstm.v4i4.862.
[8] Neha and J. Rambeer, "Renewable energy sources: a review," in *Journal of Physics: Conference Series*, IOP Publishing Ltd, Aug. 2021, doi: 10.1088/1742-6596/1979/1/012023.
[9] N. S. Mammadov, N. A. Ganiyeva, and G. A. Aliyeva, "Role of renewable energy sources in the world," *Journal of Renewable Energy, Electrical, and Computer Engineering*, vol. 2, no. 2, p. 63, Nov. 2022, doi: 10.29103/jreece.v2i2.8779.
[10] P. Cabrera, H. Lund, J. Z. Thellufsen, and P. Sorknæs, "The MATLAB Toolbox for EnergyPLAN: A tool to extend energy planning studies," *Sci Comput Program*, vol. 191, p. 102405, Jun. 2020, doi: 10.1016/J.SCICO.2020.102405.
[11] A. A. Adeleke *et al.*, "Simulation technology in renewable energy generation: a review," in *2023 2nd International Conference on Multidisciplinary Engineering and Applied Science, ICMEAS 2023*, Institute of Electrical and Electronics Engineers Inc., 2023, doi: 10.1109/ICMEAS58693.2023.10429880.
[12] P. Jenkins, M. Elmnifi, A. Younis, and A. Emhamed, "Hybrid power generation by using solar and wind energy: case study," *World Journal of Mechanics*, vol. 09, no. 04, pp. 81–93, 2019, doi: 10.4236/wjm.2019.94006.
[13] T. A. Hamed and A. Alshare, "Environmental impact of solar and wind energy-a review," *Journal of Sustainable Development of Energy, Water and Environment Systems*, vol. 10, no. 2, Jan. 2022, doi: 10.13044/j.sdewes.d9.0387.
[14] K. R. Kumar, N. V. V. K. Chaitanya, and N. S. Kumar, "Solar thermal energy technologies and its applications for process heating and power generation – A review," *Journal of Cleaner Production*, vol. 282, p. 125296, Feb. 2021, doi: 10.1016/J.JCLEPRO.2020.125296.
[15] A. O. M. Maka and J. M. Alabid, "Solar energy technology and its roles in sustainable development," *Clean Energy*, vol. 6, no. 3, pp. 476–483, Jun. 2022, doi: 10.1093/ce/zkac023.
[16] N. O. Adelakun and B. A. Olanipekun, "A review of solar energy," 2019, [Online]. Available: www.jmest.org
[17] A. I. Osman *et al.*, "Cost, environmental impact, and resilience of renewable energy under a changing climate: a review," *Environmental Chemistry Letters*, vol. 21, no. 2, pp. 741–764, Apr. 2023, doi: 10.1007/s10311-022-01532-8.
[18] B. Jarčuška *et al.*, "Solar parks can enhance bird diversity in agricultural landscape," *Journal of Environmental Management*, vol. 351, p. 119902, Feb. 2024, doi: 10.1016/J.JENVMAN.2023.119902.
[19] R. Y. Chock *et al.*, "Evaluating potential effects of solar power facilities on wildlife from an animal behavior perspective," *Conservation Science and Practice*, vol. 3, no. 2, Feb. 2021, doi: 10.1111/csp2.319.
[20] F. R. Saputri, N. Pranata, and F. Dwiputra, "Analysis of solar power plant design using RETScreen and PVSyst in Pekanbaru-Indonesia," in *2023 13th International Conference on Power, Energy and Electrical Engineering (CPEEE)*, 2023, pp. 496–500, doi: 10.1109/CPEEE56777.2023.10217460.
[21] P. R. Mishra, S. Rathore, and V. Jain, "PVSyst enabled real time evaluation of grid connected solar photovoltaic system," *International Journal of Information Technology*, vol. 16, Jan. 2024, doi: 10.1007/s41870-023-01677-x.
[22] N. Pranata and F. R. Saputri, "Comparative modelling and simulation of small wind turbine system using MATLAB/Simulink based on various power coefficient models in Kupang-Indonesia," in *2025 9th International Conference on Green Energy and Applications (ICGEA)*, 2025, pp. 1–6. doi: 10.1109/ICGEA64602.2025.11009962.
[23] D. Tamara, "How far has renewable energy been utilized in East Nusa Tenggara province?," Coaction Indonesia. Accessed: Mar. 11, 2025. [Online]. Available: https://coaction.id/sejauh-mana-pemanfaatan-energi-terbarukan-di-provinsi-nusa-tenggara-timur/
[24] Danur Lambang Pristiandaru, "4 largest solar power plants in Indonesia," *Kompas.com*, 2023. Accessed: Mar. 11, 2025. [Online]. Available: https://lestari.kompas.com/read/2023/12/26/100000486/4-plts-terbesar-di-indonesia?page=all
[25] Indonesia Energy Outlook 2022, "DEN," 2022. Accessed: Oct. 28, 2023. [Online]. Available: https://den.go.id/index.php/publikasi/download/136.
[26] A. M. Akbar, F. R. Saputri, and D. Tee, "Techno-economic analysis of a 4 MW solar photovoltaic capacity expansion in a remote Indonesian village," International Journal of Electrical and Computer Engineering (IJECE), vol. 15, no. 4, p. 4133, Aug. 2025, doi: 10.11591/ijece.v15i4.pp4133-4147.
[27] W. A. Nugroho and B. Sudiarto, "Performance evaluation of 5 MW solar PV power plant in Kupang," *IOP Conference Series: Materials Science and Engineering*, vol. 1098, no. 4, p. 042069, Mar. 2021, doi: 10.1088/1757-899x/1098/4/042069.
[28] F. R. Saputri, I. H. Prasetya, and A. M. Akbar, "Optimization of electricity supply in East Nusa Tenggara through communal solar power plants: a case study of Kupang City using PVSyst," *G-Tech: Jurnal Teknologi Terapan*, vol. 8, no. 4, pp. 2597–2602, Oct. 2024, doi: 10.70609/gtech.v8i4.5294.
[29] BPBD Provinsi NTT, "Disaster Risk Map 2019-2023 KRB Kupang Regency," 2023. Accessed: Jun. 16, 2024. [Online]. Available: https://bpbd.nttprov.go.id/bpbdkabkota/peta
[30] S. Sowe, N. Ketjoy, P. Thanarak, and T. Suriwong, "Technical and economic viability assessment of pv power plants for rural electrification in the gambia," in *Energy Procedia*, Elsevier Ltd, 2014, pp. 389–398, doi: 10.1016/j.egypro.2014.07.091.
[31] Adi Ahdiat, "Solar power generation costs to drop 19% by 2022," 2023. Accessed: Mar. 11, 2025. [Online]. Available: https://databoks.katadata.co.id/utilitas/statistik/1ac76da3b8bdc28/biaya-pembangkitan-listrik-tenaga-surya-turun-19-pada-2022
[32] A. Kerem, "Investigation of carbon footprint effect of renewable power plants regarding energy production: A case study of a city in Turkey," *Journal of the Air and Waste Management Association*, vol. 72, no. 3, pp. 294–307, 2022, doi: 10.1080/10962247.2022.2028690.
[33] C. ÓhAiseadha, G. Quinn, R. Connolly, M. Connolly, and W. Soon, "Energy and climate policy—an evaluation of global climate change expenditure 2011–2018," *Energies (Basel)*, vol. 13, p. 4839, Sep. 2020, doi: 10.3390/en13184839.
[34] Stacy Liberatore, "The big eco lie: Solar panels produce five TIMES more carbon dioxide than previously thought, report claims," *Dailymail.com*, 2023. Accessed: May 19, 2024. [Online]. Available: https://www.dailymail.co.uk/sciencetech/article-12356901/The-big-eco-lie-Solar-panels-produce-five-TIMES-carbon-dioxide-previously-thought-report-claims.html

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