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Optimum Design of the Electricity System on Nusa Penida Island With Utilization of Renewable Energy

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ABSTRACT

Nusa Penida, an island located southeast of Bali, Indonesia, faces significant challenges in its electricity supply due to its reliance on diesel generators and isolated grid system. The increasing electricity demand, driven by growing tourism and local development, is projected to reach 22,806 kW by September 2028, potentially leading to an energy deficit. Furthermore, Indonesia's national targets to increase the renewable energy mix to 58–61% by 2050 and 70–72% by 2060 underscore the urgency to shift away from fossil fuel dependency. This study aims to design an optimal hybrid renewable energy system for Nusa Penida using HOMER Pro software, evaluating various combinations of photovoltaic (PV) panels, wind turbines (WT), batteries (BAT), converters (CON), and diesel generators (DG). The results indicate that a PV/WT/BAT/CON configuration is the most viable, achieving 100% renewable energy penetration with a net present cost (NPC) of $152 million and a levelized cost of energy (LCOE) of $0.152/kWh. This configuration not only meets projected load requirements but also aligns with national sustainability goals. The study provides practical recommendations for utility companies and policymakers to accelerate the adoption of renewable energy in remote island contexts, enhancing energy security and supporting Indonesia's clean energy transition.

Keywords: *Diesel Generator; PV; Wind Turbine; Battery; Converter; Hommer Pro*

INTRODUCTION

Indonesia is a country with abundant resources. Indonesia has a land area of 1,892,410.09 km^2 and 17,001 islands, therefore Indonesia is called an archipelago state. Indonesia consists of 6 large islands: Sumatra, Java, Kalimantan, Sulawesi, Timor, and Papua (K. P. U. D. P. Rakyat, 2023). Some of these islands are still untouched, so they have extraordinary natural beauty and special attraction for tourists to visit. With this condition, the process of transferring electrical energy from one island to another is a challeng. The process of transferring electrical energy between islands requires expensive electrical infrastructure. In addition, if there is a disruption in the electrical system between these islands, it can affect on other islands. Therefore, it is necessary to utilize the potential of new and renewable energy in each region to maintain energy independence.

One of the tourist destination is Nusa Penida Island. Nusa Penida Island is included in the Nusa Penida sub-district, Klungkung Regency with an area of 202.84 km^2. Nusa Penida Island borders the Badung Strait, the Lombok Strait and the Indonesian Ocean (Bokau et al., 2025; FI & AAB, 2023; Pratiwi et al., 2024). The population of Nusa Penida Island is 57,370 people. This area has 720 home industry businesses. Nusa Penida Island has tourist locations such as Kelingking Beach, Crystal Bay, Manta Point, Batu Meling, Batu Lumbung, Batu Abah, Toyapakeh, Malibu Point, and others. Population growth are around 2.3%. Nusa Penida Island have a range of 3000 - 6000 tourists per day, this will also increase the demand for electrical energy in that place (Badan Pusat Statistik Kabupaten Klungkung, 2021).

Nusa Penida Island have 20 kV grid system. The electricity system on Nusa Penida Island operates in isolation and still supplied using fossil fuels from diesel power plants. The capacity of Nusa Penida Island is 15,300 kW, supplied by the CDB Diesel Power Plant (6,150 kW), Genindo Diesel Power Plant (3,000 kW), BESS (1,000 kW), EDG (550 kW), and Panca Diesel Power Plant (4,600 kW) (PT PLN (Persero) UP3 Bali Timur, 2024).

The use of fossil fuels in Indonesia still dominates, around 42% for coal, 31% for oil, 14% for gas, and 12.3% from new and renewable energy. The availability of fossil fuels is very limited and will run out someday nanti (Pusat Data dan Teknologi Informasi Energi dan Sumber Daya Mineral, 2015). It produces greenhouse gases (CO_2), which are the cause of climate change. Total CO2 emissions in 2022 were 696.7 million tons, or increased by an average of 4.1% per year. These emissions were mostly contributed by electricity generation at 42.6%, industry at 29.6%, transportation activities at 22.3%, households at 0.6%, and commercial activities at 0.3%. In addition, it can have an impact in the form of a decrease in the quality of life (decreased health levels). It can slow down a country's economic growth.

Immediate action is needed to implement the energy transition towards the use of renewable energy that is more environmentally friendly. Indonesia has targets related to the use of renewable energy as stipulated in Presidential Regulation of the Republic of Indonesia Number 22 year 2017 concerning the National Energy General Plan. The target portion of renewable energy is at least 23% by 2025 and at least 31% by 2050 (Peraturan Presiden Republik Indonesia No. 22 Tahun 2017, 2017). However, the Ministry of Energy and Mineral Resources revised the target portion of renewable energy due to the missed target and the pandemic, which requires adjustments to economic growth that occurred after the COVID-19 pandemic. The achievement of the renewable energy mix in 2022 was only 12.3%.

Based on above, there needs to be an acceleration in the utilization of renewable energy, especially in areas that are difficult to reach by the electricity network. The potential for renewable energy in Indonesia totals 443,208 MW, but its utilization is still very small, at 8,215.5 MW or only 1.9% (IRENA, 2022).

This study will provide a combination that can meet the electricity needs of Nusa Penida Island by utilizing the available renewable energy potential. These combinations technically meet the economic requirements in terms of net present cost and levelized cost of energy. Therefore, this study aims to design an optimized hybrid renewable energy system for Nusa Penida by evaluating various configurations of solar PV, wind turbines, battery storage, converters, and diesel generators using HOMER Pro software, with the goal of identifying the most technically viable and economically feasible system that meets projected demand while maximizing renewable energy penetration. The findings of this research are expected to provide practical recommendations for power utilities, such as PLN, and policymakers in designing and implementing renewable energy systems for remote islands, contributing to energy security, reducing carbon emissions, supporting national renewable energy targets, and offering a replicable model for sustainable electrification in similar isolated regions.

METHOD

The design consists of the electrical load and several combinations of electricity power generation such as PV, wind turbines, converters, batteries, and diesel generators. This study consists of two buses: an AC bus and a DC bus. The DC bus is connected to the PV and battery, along with a converter to convert DC electricity to AC electricity and vice versa. The AC bus is connected to the wind turbine, diesel generator, and converter. The load is connected to the AC bus. This study use Hommer software. The design used is as follows.

The data collected then entered into the Hommer Pro application. This data will be processed and calculated using the Hommer Pro application. The results of these calculations will be calculated technically and cost-wise. Technically, the generator's ability to meet the electricity load demand will be considered, taking into account existing potential resource data. After analyzing and identifying several generator compositions that can meet the load demand, they will then be analyzed in terms of cost. The calculation results from the application will show several generator compositions along with their economic values. From these combinations, the most optimal generator composition will be determined.

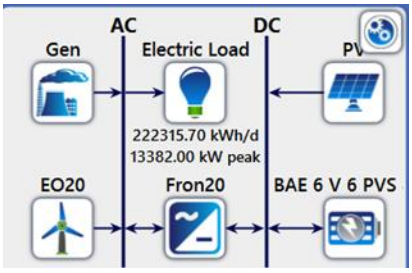

Figure 1 Research Design
Source: HOMER Pro Simulation Results, 2025

Several supporting data are required to process them and then obtain results to analize. The data in this study includes:

a. Electricity Load

The electrical load data was obtained from the recording process of substation operators spread across the Nusa Penida region. Loads are supplied by feeder lines, including the Bunga Mekar line, Tanglad line, Ceningan line, Karangsari line, Ped line, Lembongan line, and Suana line. This load is obtained from operator records on each feeder line. The actual load data in 2024 is as follows.

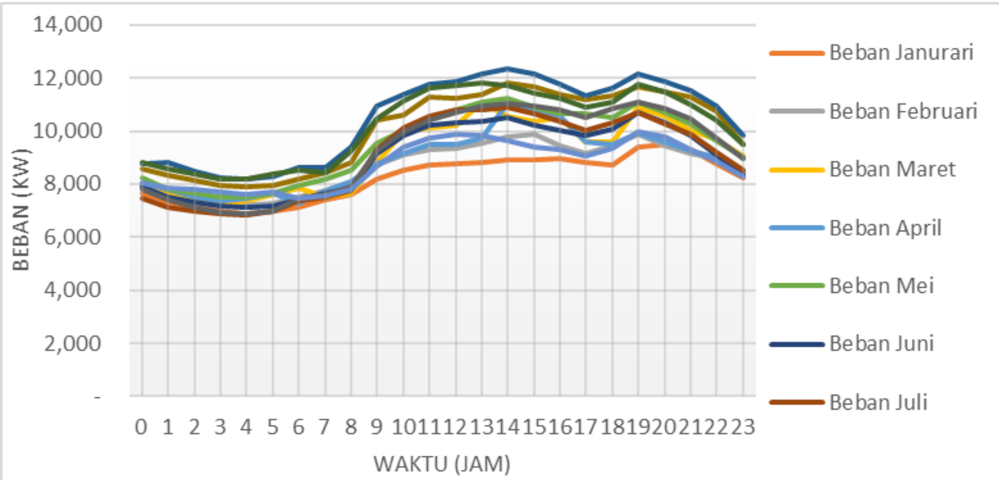

Figure 2 Actual Load Curve of Nusa Penida (2024) [3]

b. Solar Radiation

Solar energy potential on Nusa Penida is nearly evenly distributed across the island, with an estimated of 4.8 to 5.6 kWh/m²/day (A. P. Sisdwinugrha & N. Riyandi, 2024; Global Solar Atlas, 2020).

Solar energy potential on Nusa Penida is nearly evenly distributed across the island, with an estimated of 4.8 to 5.6 kWh/m²/day (A. P. Sisdwinugrha & N. Riyandi, 2024;

Global Solar Atlas, 2021). Locations with potential for solar power plants can utilize land such as shrubs or utilize rooftop solar power plants on existing buildings. Nusa Penida's solar energy potential can reach 3.2 GW. The potential for solar energy in the form of rooftop solar power plants utilizing several buildings such as government buildings, hotels, hostels, minimarkets, and village halls can provide a potential of up to 10,965 MWp (A. P. Sisdwinugrha & N. Riyandi, 2024). Solar radiation data is needed to determine the power generated by solar panels. Solar radiation data was obtained from NASA's website. The average solar radiation value is 5,336 kWh/m²/day (NASA, 2025).Temperature

Temperatures in the Nusa Penida region tend to be stable, hovering around 25.5–27.5°C. This temperature range is fairly even across the island. Ambient temperature data are obtained from the NASA website. The average temperature was 26,653 °C (NASA, 2025).

c. Wind Speed

Wind energy potential is located on the southeastern side of the island. This can be seen in the figure below. Wind speeds on Nusa Penida Island range from 3.5 to 5.3 m/s [32]. Wind speed is needed to turn a wind turbine, which is then converted by a generator to produce electricity. Wind speed data is obtained from NASA's website. The average wind speed on Nusa Penida Island is 4,427 m/s (NASA, 2025).

d. Technical Specification and Cost

The technical specifications for the power plant were obtained from relevant sources, such as journals and papers located nearby in Asia. The required power plant data includes data on PV, wind turbines, converters, batteries, and diesel generators.

Table 1 Technical Specification and Cost

Power Plant	Description	Value	Unit	Reference
PV	*Capacity*	3	kW	[17] [18] [33]
Generic Flat	*Capital cost*	2800	$	[34] [35] [36]
Plate PV	*Replacement cost*	2800	$	[37]
	O&M Cost	10	$/Tahun	
	Lifetime	25	Tahun	
	Derating Factor	10	%	
Wind Turbine	*Capacity*	20	kW	[17] [18] [33]
Eocycle EO20	*Capital Cost*	37500	$	[34] [35] [36]
	Replacement cost	28500	$	[37]
	O&M Cost	1100	$/Tahun	
	Lifetime	20	Tahun	
	Rotor Diameter	15,81	m	
	Hub height	36	m	
Converter	*Capacity*	20	kW	[17] [18] [33]
Fronius Symo	*Capital Cost*	300	$	[34] [35] [36]
20.0-3-M	*Replacement Cost*	260	$	[37]
	O&M Cost	15	$/Tahun	
	Lifetime	10	Tahun	
	Inverter Efficiency	80	%	
	Rectifier Efficiency	20	%	

Power Plant	Description	Value	Unit	Reference
Battery	*Nominal Voltage*	6	V	[17] [18] [33]
BAE Secura	*Capacity*	2,41	kWh	[34] [35] [36]
Solar 6 V 6 PVS	*Capital Cost*	180	$	[37]
420	*Replacement Cost*	150	$	
	O&M Cost	10	$/Tahun	
	Lifetime	18	Tahun	
	Roundtrip efficiency	85	%	
	Min State of Charge	20	%	
Diesel Generator	*Capital cost*	350	$	[17] [18] [33]
Autosize Genset	*Replacement cost*	300	$	[34] [35] [36]
Kapasitas $/kW	*O&M cost*	0,03	$/op.hour	[37]
	Fuel price	1.267	$/L	
	Minimum load ratio	25	Tahun	
	Lifetime	15000	Jam	

Source: Technical and Cost Data from Various

RESULTS AND DISCUSSION

Result

After all the data has been entered into the Hommer Pro, the software then performs calculations. The simulation results are as follows.

Table 2 Simulation Results of Technical Aspects

Generator Composition	PV (kW)	EO20	Gen (kW)	BAE 6 V 6 PVS 420 (#)	Fron20 (kW)
PV/WT/BAT/CON	50.858	410		221.924	13.465
PV/WT/DG/BAT/CON	54.295	546	15.000	106.162	15.073
PV/BAT/CON	74.105			229.202	14.219
PV/DG/BAT/CON	76.233		15.000	158.202	14.730
PV/WT/DG/CON	12.435	1.440	15.000		7.149
WT/DG		1.621	15.000		
PV/DG/CON	22.881		15.000		8.974
DG			15.000		

Source: HOMER Pro Simulation Results, 2025

The table above shows that there are several generator configurations available to meet electricity demand. The utilization of renewable energy, as shown in the table above, can support the target of new energy utilization by the government and companies, thereby reducing dependence on fossil fuels. The generator configurations include PV/WT/BAT/CON, PV/WT/DG/BAT/CON, PV/BAT/CON, PV/DG/BAT/CON, PV/WT/DG/CON, WT/DG, PV/DG/CON, and DG.

Table 3 Simulation Results of Cost Aspects

Generator Combination	***Cost/NPC*** **($)**	***Cost/LCOE*** **($/kWh)**	***Cost/Operating*** **cost ($/yr)**	***Cost/CAPEX*** **($)**
PV/WT/BAT/CON	152 M	0,152	3,85 M	103 M
PV/WT/DG/BAT/CON	157 M	0,152	4,82 M	95,7 M

Generator Combination	*Cost/NPC* ($)	*Cost/LCOE* ($/kWh)	*Cost/Operating* cost ($/yr)	*Cost/CAPEX* ($)
PV/BAT/CON	163 M	0,163	4,11 M	111 M
PV/DG/BAT/CON	178 M	0,171	5,68 M	105 M
PV/WT/DG/CON	325 M	0,313	19,9 M	71 M
WT/DG	331 M	0,319	20,7 M	66 M
PV/DG/CON	376 M	0,362	27,3 M	26,7 M
DG	428 M	0,413	33,1 M	5,25 M

Source: HOMER Pro Simulation Results, 2025

After the technical simulation results are presented, the table above shows the cost simulation results. Each power plant component is assessed using several values, including Net Present Cost (NPC), Levelized Cost of Energy (LCOE), Operating Cost, and Capital Expenditure (CAPEX).

Discussion

Trend Electricity Load on Nusa Penida

Based on historical data, there is an increase in electricity demand over time. This increase in electricity demand needs to be balanced with increased electricity production. Therefore, referring to the Rencana Usaha Penyediaan Tenaga Listrik 2025 - 2034 (RUPTL) in the Nusa Penida region, the Nusa Penida Solar Power Plant (PLTS) is planned to have a capacity of 4.5 MW, the Nusa Penida Wind Power Plant (PLTB) with a capacity of 10 MW, the Nusa Penida BESS (BESS) with a capacity of 7.5 MW, and the Nusa Penida Solar Power Plant (PLTS + BESS) with a capacity of 3.5 MW (Kepco) (Kementrian Energi dan Sumber Daya Mineral, 2025).

Using SPSS, we predict future load growth (time series model). The electricity load data and predicted load growth are shown in the figure below. Month 1 starts from January 2022 and ends in December 2029, which is the 96th month.

Figure 3 Electricity Load Growth Prediction Curve
Source: Load Data Analysis using Time Series Model (SPSS), 2025

The total net power capacity of the power plants on Nusa Penida Island is 22,650 kW. Considering overhauls on the power plant and the electricity distribution network, the power supply capacity of power plant will be smaller than the net power capacity. Simulation results from the SPSS application using the time series model method, a predicted load growth in September 2028 of 22,807 kW is obtained. If there is no increase in electricity production, there will potentially be an electricity deficit of 157 kW at that time. This could impact blackouts in several areas. Utilization of new energy needs to be carried out immediately to prevent this potential recurrence in the future. It is also important to consider that time is also needed to build a new power plant because it requires a process such as the project initiation process to project implementation. It is also necessary to conduct a study on the utilization of new renewable energy potential in forms other than solar energy and wind energy on the island of Nusa Penida, such as the potential for biomass energy (municipal waste pellets, gama (gliricidia sepium), biodiesel (seaweed, jatropha), ocean current/wave energy, seawater pumped hydro energy storage (PHES) (A. P. Sisdwinugrha & N. Riyandi, 2024).

Recommended Power Plant Compositions That Can be Used

From the simulation results above, it is known that there are several compositions resulting from the simulation. These compositions are PV/WT/BAT/CON, PV/WT/DG/BAT/CON, PV/BAT/CON, PV/DG/BAT/CON, PV/WT/DG/CON, WT/DG, PV/DG/CON, and DG. From these compositions, the recommended composition that can be considered for use is PV/WT/BAT/CON.

The composition of the PV/WT/BAT/CON consists of a PV with a capacity of 74,105 kW, 410 WT, 221,924 batteries, and a converter with a capacity of 13,465 kW. This composition can supply electricity loads up to 78,512,688 kWh/year. The portion of the new renewable energy mix is 100%. PV production reaches 80,063,682 kWh/year (75.6%) and WT production reaches 25,784,784 kWh/year (24.4%). Recommendations for single line diagrams are provided along with the addition of new renewable energy generating capacity.

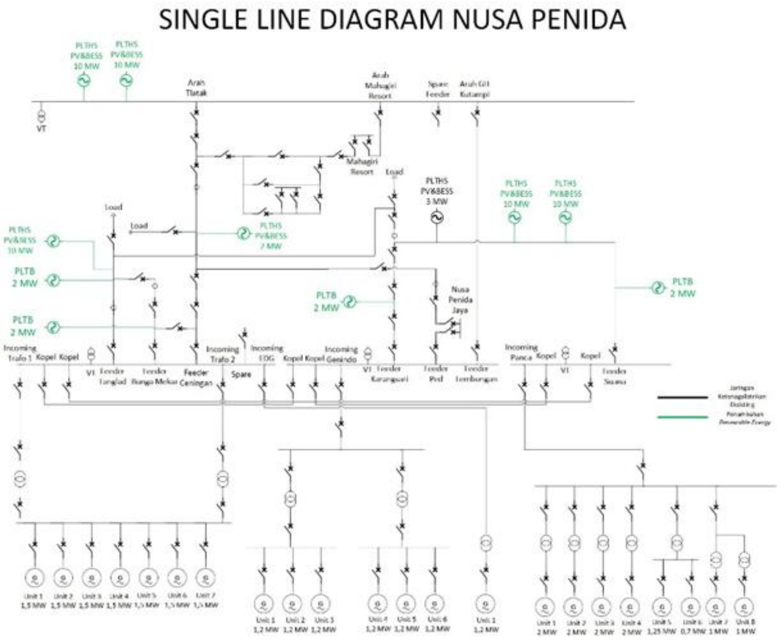

Figure 4. Single Line Diagram with Additional Renewable Energy

Source: System Simulation Design Results, 2025

Solar energy is generally distributed evenly across the island of Nusa Penida. Bushland areas can be utilized for solar energy development, particularly in locations such as Suana, Pejukutan, Tanglad, Sekartaji, and Batukandik. Furthermore, buildings can be used for rooftop solar power plants.

Wind energy is generally distributed evenly across the island of Nusa Penida. According to the global wind atlas, wind energy can be harnessed from the southern side of the island. Power grids in this area are available through Bunga Mekar, Tanglad, Karangsari, and Suana.

Figure 5 Operation of PV/WT/BAT/CON Composition
Source: HOMER Pro Operational Simulation Results, 2025

The operating of the PV/WT/BAT/CON can be seen in above. From 00:00 to 06:00, the electrical load is supplied by the WT and battery. The battery will compensate for fluctuations/intermittency from the WT to maintain the supply of electrical load. From 06:00 to 12:00, the sun begins to rise. Under these conditions, the PV produces electrical power. The WT also produces electrical power depending on wind speed. The electrical power generated by both generators is used to supply the electrical load and charge the battery. From 12:00 to 18:00, the electrical power generated by the PV will decrease. Therefore, the electrical power stored in the battery will compensate for the decrease in power from the PV to supply the electrical load. From 18:00 to 24:00, the PV does not produce electricity because the sun has set. The electrical power supply to the load will be replaced by the battery and the WT.

The PV/WT/BAT/CON composition has a low LCOE value compared to other compositions. The LCOE value of the PV/WT/BAT/CON composition is 0.152 $/kWh. The smaller the LCOE value, the cheaper the cost required to generate electricity per kWh. This value is almost the same as the PV/WT/DG/BAT/CON composition, but the NPC value of the PV/WT/BAT/CON composition is still lower at $152 M. The operating cost of the PV/WT/BAT/CON composition is still lower compared to other compositions at $3.85 M. This operating cost will tend to be stable because it does not use fossil fuels so it is not affected by fluctuations in fossil fuel costs. The weakness of the PV/WT/BAT/CON composition lies in the high capex costs compared to other compositions.

Electricity BPP Comparison

Electricity BPP is the cost of providing electricity by IUPTLU holders who have a Business Area to carry out operational activities up to the distribution of electricity to consumers. This selling price is regulated by the government through the approval of the Minister or governor in accordance with their authority. Electricity tariffs in Indonesia are differentiated based on the structure of electricity and electricity groups. Based on the structure, they are divided into high voltage, medium voltage, and low voltage. Based on the groups, they are divided into social services, households, businesses, industries, government offices, public street lighting, traction, bulk sales, services with special qualities; and/or other uses determined by the Minister. This tariff will be updated quarterly due to several factors such as currency exchange rates, primary energy prices, inflation rates, and other factors determined by the Minister (Dewan Energi Nasional, 2023).

Table 3 basic costs of providing electricity in Indonesia for the period July – September 2025

NO.	GOL. TARIF	BATAS DAYA	REGULER		PRA BAYAR (Rp/kWh)
			BIAYA BEBAN (Rp/kVA/bulan)	BIAYA PEMAKAIAN (Rp/kWh) DAN BIAYA kVArh (Rp/kVArh)	
1.	R-1/TR	900 VA-RTM	*)	1.352,00	1.352,00
2.	R-1/TR	1.300 VA	*)	1.444,70	1.444,70
3.	R-1/TR	2.200 VA	*)	1.444,70	1.444,70
4.	R-2/TR	3.500 VA s.d. 5.500 VA	*)	1.699,53	1.699,53
5.	R-3/TR, TM	6.600 VA ke atas	*)	1.699,53	1.699,53
6.	B-2/TR	6.600 VA s.d. 200 kVA	*)	1.444,70	1.444,70
7.	B-3/TM, TT	di atas 200 kVA	**)	Blok WBP = K x 1.035,78 Blok LWBP = 1.035,78 kVArh = 1.114,74 ****)	-
8.	I-3/TM	di atas 200 kVA	**)	Blok WBP = K x 1.035,78 Blok LWBP = 1.035,78 kVArh = 1.114,74 ****)	-
9.	I-4/TT	30.000 kVA ke atas	***)	Blok WBP dan Blok LWBP = 996,74 kVArh = 996,74 ****)	-
10.	P-1/TR	6.600 VA s.d. 200 kVA	*)	1.699,53	1.699,53
11.	P-2/TM	di atas 200 kVA	**)	Blok WBP = K x 1.415,01 Blok LWBP = 1.415,01 kVArh = 1.522,88 ****)	-
12.	P-3/TR		*)	1.699,53	1.699,53
13.	L/TR, TM, TT	-	-	Blok WBP dan Blok LWBP = N x 1.644,52 kVArh = N x 1.644,52 ****)	-

Catatan :
*) Diterapkan Rekening Minimum (RM):
RM1 = 40 (Jam Nyala) x Daya tersambung (kVA) x Biaya Pemakaian.
**) Diterapkan Rekening Minimum (RM):
RM2 = 40 (Jam Nyala) x Daya tersambung (kVA) x Biaya Pemakaian LWBP.
Jam nyala : kWh per bulan dibagi dengan kVA tersambung.
***) Diterapkan Rekening Minimum (RM):
RM3 = 40 (Jam Nyala) x Daya tersambung (kVA) x Biaya Pemakaian WBP dan LWBP.
Jam nyala : kWh per bulan dibagi dengan kVA tersambung.
****) Biaya kelebihan pemakaian daya reaktif (kVArh) dikenakan dalam hal faktor daya rata-rata setiap bulan kurang dari 0,85
K : Faktor perbandingan antara harga WBP dan LWBP sesuai dengan karakteristik beban sistem kelistrikan setempat
WBP : Waktu Beban Puncak.
LWBP : Luar Waktu Beban Puncak.

Source: PT PLN (Persero), 2025

Electricity BPP in Indonesia in Juli – September 2025 can be seen in the table above. The price range is between Rp 1,352/kWh to Rp 1,688.53/kWh. If the rupiah exchange rate against the US dollar is assumed to be 1 dollar equals 16,270 rupiah. Then the price range per kWh is 0.081 $/kWh to 0.104 $/kWh. Primary energy influencing factors include changes in global demand, geopolitical tensions, oil production volumes, and regional crises [41]. In general, meeting electricity needs still uses fossil fuels (primary energy). This creates uncertainty. If a company is too dependent on fossil fuels, the changes that occur can disrupt the company's cash flow because the BPP for electricity cannot be changed according to the company's wishes but is regulated by the government.

Meanwhile, the recommended composition has a value of 0.152 $/kWh. So the BPP of electricity for this composition when converted is equivalent to Rp 2,473/kWh. The BPP of electricity (recommended composition) is indeed more expensive when compared to the current BPP of electricity. This is because the cost of new renewable energy technology is still relatively expensive (high investment costs). However, this new renewable energy utilization technology is more resistant to global dynamics, because it does not depend on the use of fossil fuels and is in line with the target of the new renewable energy mix. As time goes by, the price of fossil fuels continues to increase, and has the potential to disrupt the company's cash flow due to the increasingly high BPP price. Currently, the price of primary fuel (fossil energy in Indonesia) is still supported by Government policies in the form of Domestic Market Obligations along with subsidies/capital investment to maintain the price of electricity BPP.

Validation Items to Consider for Implementing PV/WT/BAT/CON

Tabel 5 Comparison LCOE Value

Location	*Load* (kW)	*PV* (kW)	*WT*	*DG* (kW)	BAT	Kombinasi	*LCOE $/kWh*	*Ref*
Khiriya Bharka	87,6	63,3	40	130	235	*PV/WT/DG/BAT/CON*	0,127	[17]
Thayet Township	107,42	-	60	180	355	*WT/DG/BAT/CON*	0,145	[17]
Lower Manya Krobo	249,14	130	330	340	379	*PV/WT/DG/BAT/CON*	0,174	[17]
Mamfe	1.978,6	2.959	2.310	2.900	34.799	*PV/WT/DG/BAT/CON*	0,143	[17]
Bizerter, North of Tunisia	6,96	17,42	-	-	23	*PV/BAT/CON*	0,108	[22]
Hybrid Nusa Penida	10.340	3500	4000 (kW)	11.900	3500 (kW)	*PV/WT/DG/BAT/CON*	0,230	[44]
Penelitian saat ini	13.382	50.858	410		221.924	*PV/WT/BAT/CON*	0,152	-

Source: Comparative Literature Review Results [17], [22], [44]

Comparisons with other journals above show that there is not much difference between one combination and another in each region (Y. F. Nassar et al., 2024; M. Smaoui et al., 2024; Z. Arifin et al., 2021). Current research shows that the LCOE value is lower than the LCOE value of the Nusa Penida Hybrid. This difference in LCOE value is highly dependent on the costs incurred for the composition used. These costs include capital costs, replacement costs, O&M costs, fuel costs, and other costs that may arise. These are also influenced by the magnitude of the electricity load that must be met and the energy potential available in a region. The data comparison shown above indicates that the recommended PV/WT/BAT/CON composition can be implemented, provided that further validation is still needed.

The recommended PV/WT/BAT/CON results require further feasibility studies. Potential renewable energy sources, such as solar and wind energy, need to be directly measured in the field using special tools to obtain primary data to ensure the conformity of actual measurement results with simulation results. Any changes in the price of generating equipment need to be updated so that adjustments can be made if changes occur. For interconnection to the distribution network, further data such as transmission capacity data is required. This is necessary because with the addition of new power plant, it is necessary to ensure that the distribution network has sufficient capacity to deliver electricity to the customer side.

CONCLUSION

The analysis indicates several power plant compositions capable of meeting the energy demand in the Nusa Penida area, including PV/WT/BAT/CON, PV/WT/DG/BAT/CON, PV/BAT/CON, PV/DG/BAT/CON, PV/WT/DG/CON, WT/DG, PV/DG/CON, and DG, with the most optimal option being the PV/WT/BAT/CON configuration, which comprises a 74,105 kW PV system, 410 wind turbines, 221,924 batteries, and a 13,465 kW converter, able to supply up to 78,512,688 kWh/year with an LCOE of 0.152 $/kWh, an NPC of $152 million, and operating costs of $3.85 million. The utilization of solar and wind energy significantly increases the renewable energy share, where the PV/WT/BAT/CON and PV/BAT/CON compositions achieve 100% renewable penetration; PV/WT/DG/BAT/CON reaches 95.5%; PV/DG/BAT/CON reaches 54.2%; PV/WT/DG/CON and WT/DG each reach 50.7%; and PV/DG/CON reaches 24.3%, thereby supporting Indonesia's target of achieving a 23% renewable energy mix by 2025. To enhance future implementation, further validation through detailed feasibility studies is required, the capacity of the distribution network to integrate new renewable power plants must be ensured, and additional research is recommended to explore other renewable sources—such as biomass and ocean-wave energy—to strengthen the overall energy mix strategy.

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