

## Techno-Economic Optimization of Hydrogen-Based Hybrid Power System for Semau Island

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**Abstract.** Island regions such as Semau Island, East Nusa Tenggara, face significant challenges in providing reliable, clean, and sustainable energy. Diesel Generator (DG)-based systems remain dominant but generate high emissions and lack energy storage components. This study analyzes the technical and economic performance of three Hybrid Renewable Energy System (HRES) scenarios: (1) DG–PV–BESS, (2) DG–PV–HESS, and (3) PV–BESS–HESS, using HOMER Pro simulation

The first scenario yields the lowest Levelized Cost of Energy (LCOE) at 0,159 USD/kWh, but with the highest CO<sub>2</sub> emissions at 584.862 kg/year and B40 fuel consumption of 225.777 L/year. The second scenario offers an Internal Rate of Return (IRR) of 29%, a payback period of 4,1 years, an LCOE of 0,217 USD/kWh, and CO<sub>2</sub> emissions of 540.715 kg/year. The third scenario, which is fully renewable, results in an LCOE of 0,213 USD/kWh, zero emissions, a renewable fraction of 100%, and the lowest Levelized Cost of Hydrogen (LCOH) at 8,34 USD/kg.

Hydrogen integration has proven to reduce battery usage (minimizing potential chemical waste), extend battery lifespan, and improve overall system sustainability. This study supports the adoption of hydrogen-based HRES as an efficient, reliable, and environmentally friendly clean energy transition solution for island communities.

**Keywords:** *Hybrid; BESS; HESS; HOMER Pro; NPC; LCOE; LCOH; CO<sub>2</sub> emissions: clean energy transition*

### 1 Introduction

The world today is indeed facing a dual challenge: to meet the continuously increasing energy demand while simultaneously reducing greenhouse gas emissions and improving efficiency. Renewable energy is an effective solution to address this challenge, as utilizing energy as efficiently as possible can significantly reduce greenhouse gas emissions. Moreover, renewable energy also plays a vital role in ensuring energy security, enhancing environmental safety, and increasing employment opportunities across various countries [1].

The conversion of Diesel Power Plants to Renewable Energy is part of the Indonesian government's efforts to explore environmentally friendly energy sources and harness local energy potential. Currently, there are 5.270 diesel power plant units with a total capacity of 3,48 GW distributed throughout Indonesia. Of these, 3.996 units are still operational. A total of 3.378 units are included in the de-dieselization program, excluding backup and mobile generator units. One sub-program of de-dieselization is the conversion of Diesel Power Plants to Renewable Energy and hybrid systems based on local energy potential. Semau Island, located in East Nusa Tenggara Province, is among the 94 initial locations targeted in the first phase of this program [2]. Most of the electricity consumption on this island is residential. The island's electricity demand is not only supplied by Diesel Power Plant with a capacity of 2.704 kW but also supported by a hybrid system that includes an existing solar PV installation with a capacity of 450 kW. The existing PV does not produce surplus energy, and its energy storage system (Battery Energy Storage System/BESS) is damaged, posing a risk of chemical waste. This condition results in the dominant use of fossil-fueled electricity generation (Diesel Generator/DG).

Energy storage is a key component in a Hybrid Renewable Energy System (HRES). Commonly used lead-acid battery technology faces challenges such as high cost, natural degradation (self-discharge), and serious environmental impact due to heavy metal waste. As an alternative, hydrogen-based storage systems (Hydrogen Energy Storage System/HESS) offer advantages including high energy density, emission-free production processes, and long-term potential to support intermittent renewable energy sources [3], [4]. Hydrogen has been globally recognized as a core technology in climate change mitigation [5]. However, the use of HESS in HRES studies in Indonesia remains very limited. This study models a hydrogen-based HRES using HOMER Pro software by combining HESS and BESS technologies. The PV system as the main source is upgraded by utilizing the local solar energy potential on Semau Island. The objective of this research is to evaluate and optimize the technical and economic aspects of a DG–PV–BESS–HESS configuration and compare various scenarios, including an emission-free setup (PV–BESS–HESS) with a minimum renewable fraction of 70%. This study also estimates the Levelized Cost of Hydrogen (LCOH) from an off-grid PV-based system as an economic reference for local hydrogen production from surplus solar energy. The combination of HESS and BESS is expected to reduce battery cycling frequency, extend battery lifespan, and lower the number of batteries required.

## 2 System Component Specifications, Climatology Data and Load Profile

The optimization of a hybrid system using HOMER Pro will select the most efficient system configuration with the lowest Levelized Cost of Energy (LCOE), which is also directly proportional to the total life cycle cost of the project (Net Present Cost/NPC). The values of LCOE and NPC can be calculated using Eq. (1) and Eq. (2).

$$LCOE = \frac{C_{TNPC}}{\sum_{H=1}^{H=8760} P_{Demand}} \times CRF \quad (1)$$

$$C_{TNPC} = \sum_{n=0}^N \frac{C_n}{(1+r)^n} \quad (2)$$

Where,

- $P_{demand}$  = Power consumed per hour (kWh)
- $C_{TNPC}$  = Net Present Cost (NPC) (USD)
- CRF = Capital Recovery Factor
- $C_n$  = Annual cost in year n (USD/year)
- r = Discount rate (%)
- N = Project lifetime (years)

### 2.1 Diesel Generator

Semau Island currently relies on a diesel power plant as its primary electricity supply. There are 5 units of diesel generator machines with a total installed capacity of 2.074 kW. The economic data of the diesel generator is shown in Table 1. For the Public Service Obligation (PSO) sector, including PLN power plants, B40 biodiesel fuel is used. HOMER Pro assumes a linear fuel consumption curve with a y-axis intercept and calculates the generator's fuel consumption rate based on Eq. (3) [6].

$$F = F_0 \cdot Y_{gen} + F_1 \cdot P_{gen} \quad (3)$$

Where:

- F = total fuel consumption (L/h)
- $F_0$  = intercept coefficient of the fuel curve (idle or no-load base fuel consumption)
- $F_1$  = slope of the fuel curve (additional fuel consumption per unit of output power)
- $P_{gen}$  = actual power output (kW)
- $Y_{gen}$  = installed generator capacity (kW)

**Table 1** Diesel Generator Economic Data.

Parameter	Value	References
Capital Cost (USD/kW)	-	-
Replacement Cost (USD/kW)	910	[7]
O&M Cost (USD/hr)	0,004	[7]
Min. Load Ratio (%)	25	Homer Default
Lifetime (hr)	10.000	Estimated

## 2.2 Photovoltaic

In 2011, Semaun Island installed and operated a Photovoltaic (PV) system with a capacity of 450 kW. The PV system uses Polycrystalline Silicon modules with an efficiency of 14,5%. Additional PV capacity needs to be planned to increase the power supply capability for meeting the electrical load demand and supporting the energy storage system. The HOMER Pro application determines the optimal PV size required by the system based on the installed hybrid components. The output power of the PV array (PPV) is calculated using Eq. (4) [6].

$$P_{PV} = Y_{PV} \times x_{PV} \times \frac{G_T}{G_{T,STC}} \times [1 + \alpha_P \times (T_c - T_{c,STC})] \quad (4)$$

Where,

- $x_{PV}$  = PV derating factor (%), used to account for losses such as dust, cables, etc.
- $Y_{PV}$  = Installed PV array capacity (kW)
- $G_T$  = Solar radiation on the PV array at a given time (kW/m<sup>2</sup>)
- $G_{T,STC}$  = Radiation under Standard Test Conditions (STC) (1 kW/m<sup>2</sup>)
- $\alpha_P$  = Temperature coefficient for power (%/°C)
- $T_c$  = PV cell temperature at a given time (°C)
- $T_{c,STC}$  = PV cell temperature under Standard Test Conditions (25°C)

The additional PV units used are of the monocrystalline silicon type. Monocrystalline PV is manufactured using a single crystal of silicon (Si) through the Czochralski process and has an efficiency of approximately 16% [8]. Table 2 presents the specifications of the additional PV used.

**Table 2** Specifications of Additional PV.

Parameter	Value	References
PV Type	<i>Monocrystalline Silicon</i>	
Nominal Operating Cell Temperature (°C)	47	[9]
Max Power Temperature Coefficient (%/°C)	-0,5	Homer Default
Module Efficiency (%)	16,6	[9]
Derating Factor (%)	85	[9]
Capital Cost (USD/kW)	877,14	[7]
Replacement Cost (USD/kW)	877,14	[7]
O&M Cost (USD/year)	7,3	[7]
Lifetime (year)	25	[9]

### 2.3 Battery

HOMER Pro models a battery as a device capable of storing a certain amount of direct current (DC) energy at a fixed round-trip efficiency (RTE), with constraints on how quickly it can be charged or discharged, how deeply it can be discharged without damage, and how many charge-discharge cycles it can undergo before needing replacement. To calculate the battery's state of charge (SOC) during charging and the corresponding calculation during the discharging phase, Eq. (5) and Eq. (6) are used [6].

$$E_b(t + 1) = E_b(t) \times (1 - \sigma) + \left( E_g(t) - \frac{E_l(t)}{\eta_{inv}} \right) \times \eta_{BC} \tag{5}$$

$$E_b(t + 1) = E_b(t) \times (1 - \sigma) + \left( \frac{E_l(t)}{\eta_{inv}} - E_g(t) \right) \times \eta_{BD} \tag{6}$$

Where,

- $E_b(t)$  = Energy stored in the battery at time t (kWh)
- $\sigma$  = Battery energy loss rate (self-discharge rate per hour); (neglected in this calculation)
- $E_g(t)$  = Energy generated by the power source (PV, generator, etc.) at time t (kWh)
- $E_l(t)$  = Load energy at time t (kWh)
- $\eta_{inv}$  = Inverter efficiency (conversion from DC to AC) (%)
- $\eta_{BC}$  = Battery charging conversion efficiency (%)
- $\eta_{BD}$  = Battery discharging conversion efficiency (%); assumed same as charging
- $E_b(t+1)$  = Battery energy at the next time step (t+1) (kWh)

The battery used in HOMER Pro is a type of lithium-ion battery known as Lithium Iron Phosphate (LiFePO<sub>4</sub>), which is a maintenance-free and rechargeable battery. Table 3 describes the specifications of the battery used.

**Table 3** Specification of Battery.

Parameter	Value	References
Battery Type	<i>LiFePO<sub>4</sub></i>	
Capital Cost (USD/kWh)	550	[7]
Replacement Cost (USD/kWh)	550	[7]
O&M Cost (USD/year)	17,55	[7]
Nominal Capacity (Ah)	100	[10]
Nominal Voltage (V)	12,8	[10]
Initial State of Charge (%)	100	[10]
Minimum State of Charge (%)	20	[10]
Round-trip Efficiency (%)	96	Homer Default
Lifetime Throughput (kWh)	<i>4.096</i>	[10]
Lifetime (year)	11	[10]

## 2.4 Electrolyzer

The excess energy generated by the PV or from its combined operation with the diesel generator will be used by the electrolyzer to split water into hydrogen and oxygen. The power transmitted by the electrolyzer to the hydrogen tank, as well as the surplus power, can be expressed in Eq. (7) and Eq. (8) [11].

$$P_{T-elz}(t) = P_{elz-surplus}(t) \times eff_{elz} \quad (7)$$

$$P_{T-elz}(t) = P_{elz-surplus}(t) \times eff_{elz} \quad (8)$$

Where,

- $P_{T-elz}(t)$  = Effective power used to produce hydrogen and store it in the tank at time  $t$  (kW)
- $P_{elz-surplus}(t)$  = Surplus power available and directed to the electrolyzer at time  $t$  (kW)
- $eff_{elz}$  = Electrolyzer efficiency (%)
- $P_{pv}(t)$  = Total power generated by the PV system at time  $t$  (kW)
- $P_{inver}(t)$  = Power required or used by the inverter to supply the load at that time (kW)
- $P_{elz-surplus}(t)$  = Power difference from PV that is not used by the inverter, considered as surplus power that can be directed to the electrolyzer (kW)

This study chooses to use a PEM electrolyzer due to its technological maturity, relatively low operating temperature (50 °C – 80 °C), and higher efficiency (approximately 50%–80%) compared to other commercially available types of electrolyzers [12]. The specifications of the PEM electrolyzer input into HOMER Pro are presented in Table 4.

**Table 4** Specification of Electrolyzer.

Parameter (Unit)	Value	References
Electrolyzer Type	PEM	
Capital Cost (USD/kW)	700	[12]
Replacement Cost (USD/kW)	700	[12]
O&M Cost (USD/year)	52,5	[13]
Efficiency (%)	83	[14]
Lifetime (year)	31	[14]

## 2.5 Hydrogen Tank

The hydrogen produced by the electrolyzer is delivered to the hydrogen tank for storage and later converted into electricity through a fuel cell when the electrical load requires additional energy supply. The stored hydrogen energy in the tank is calculated using Eq. (9) [11].

$$\epsilon_{H2}(t) = \epsilon_{H2}(t - 1) + P_{T\_elz} \cdot \Delta t \tag{9}$$

Where,

- $\epsilon_{H2}(t)$  = Stored hydrogen energy at time  $t$  (kWh)
- $\epsilon_{H2}(t-1)$  = Stored hydrogen energy at previous time step ( $t-1$ ) (kWh)
- $P_{T\_elz}$  = Power input to the electrolyzer (kW)
- $\Delta t$  = Time interval (hours)

The hydrogen storage tank considered in this study is a Compressed Gaseous Hydrogen (CGH2) tank with a lifetime of 25 years.

### 2.6 Fuel Cell

Fuel cell systems are exceptionally clean, producing no pollutants and offering high efficiency. The Proton Exchange Membrane Fuel Cell (PEMFC) is selected for this study due to its consistent performance even when there is an imbalance in hydrogen supply. PEMFCs are widely adopted in industrial applications and are known for their rapid dynamic response [6]. Table 5 provides the specifications of the fuel cell used as input data in HOMER Pro. The energy generated by the fuel cell can be calculated using Eq. (10) [11].

$$P_{fc}(t) = P_{t-fc} \times eff_{fc} \tag{10}$$

dengan:

- $P_{fc}$  = Electrical power output from the fuel cell (kW)
- $P_{T-fc}$  = Total chemical power (hydrogen energy per unit time) input to the fuel cell (kW)
- $eff_{fc}$  = Fuel cell efficiency (%)

**Table 5.** Spesification of Fuel Cell.

Parameter	Value	Reference
Capital Cost (USD/kW)	1.620	[15]
Replacement Cost (USD/kW)	1.620	[15]
O&M Cost (USD/op.hour)	0,041	[15]
Efficiency (%)	60	[16]
Minimum Load Ratio (%)	25	Homer Default
Lifetime (hour)	60.000	[15]

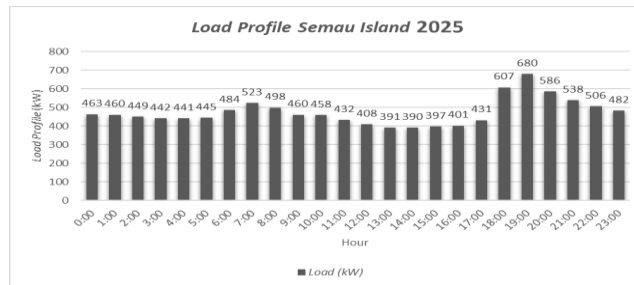
### 2.7 Converter

In a hybrid system, a bi-directional converter is used to control the flow of current in both directions (between the AC and DC buses). The main role of this converter is to supply electricity from the DC sources to the load. The

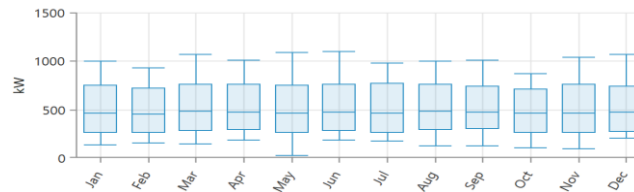
converter size is determined based on the system’s maximum energy level [6]. The converter used has a specified efficiency of 95% and a lifetime of 15 years.

**2.8 Load Profile and Enviromental Data**

The initial data used in the HOMER Pro simulation is the electrical load profile, which in Semau Island is predominantly derived from rural household consumption. The highest daily load in 2025 was recorded at 680 kW during nighttime, as shown in Figure 1. HOMER Pro calculates key metrics such as the average load of 473,83 kW, a seasonal peak load reaching 1.100,9 kW, and an average daily energy demand of 11.372 kWh/day. The seasonal load pattern is illustrated in Figure 2, which shows that peak demand occurs during the beginning of the year (January–June) and at the end of the year (November–December).



**Figure 1.** Load Profile Semau Island



**Figure 2.** Seasonal Profile Semau Island

The required environmental data include the average Global Horizontal Irradiance (GHI) and average temperature. These data can be directly downloaded through the HOMER Pro application, as shown in Figure 3 and Figure 4, by specifying the project location coordinates. Semau Island has a GHI value of 6,36 kWh/m<sup>2</sup>/day and an average temperature of 27,61 °C.

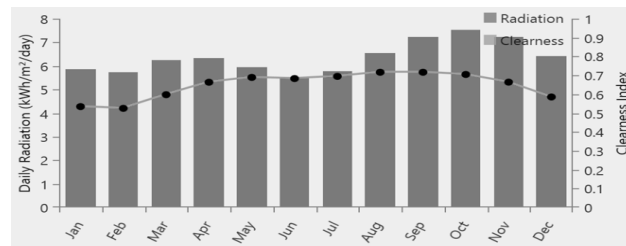


Figure 3. Global Horizontal Irradiance Average of Semau Island.

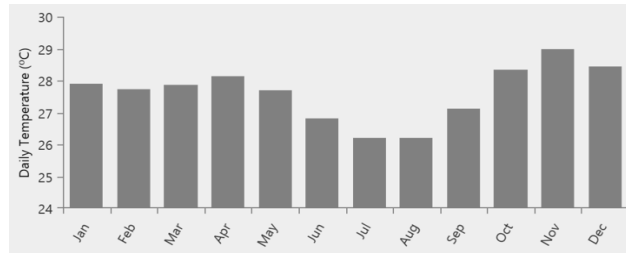


Figure 4. Average Temperature of Semau Island.

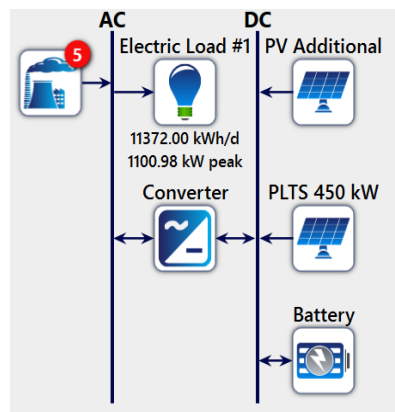
### 3 Results and Discussion

This study models three hybrid system configurations using the HOMER Pro software to manage energy efficiently under various operational conditions, with a minimum commitment of 70% renewable energy use to reduce CO<sub>2</sub> emissions. The three simulated scenarios include: (1) DG–PV–BESS, using batteries as the storage medium; (2) DG–PV–HESS, utilizing a hydrogen system (electrolyzer, fuel cell, and hydrogen tank); and (3) PV–BESS–HESS, a fossil fuel-free system entirely based on renewable energy. The simulation is conducted with a project lifetime assumption of 25 years, using Indonesian economic data as of May 2025, with a discount rate of 5,5% and an inflation rate of 1,6%. The component combinations in all three scenarios are designed to generate, store, and distribute energy optimally in the context of a clean and sustainable energy system.

#### 3.1 DG-PV-BESS

The system modeling for Scenario 1 (DG–PV–BESS) in HOMER Pro is shown in Figure 5. The simulation results are presented in Table 6, where this scenario yields the lowest LCOE value of 0,159 USD/kWh with a renewable fraction of 70,3%. The system components include 4 units of existing diesel generators with a total operating capacity of 1.546 kW, 450 kW of existing PV, an additional 1.570 kW of PV, and a total BESS capacity of 5.897 kWh. The total electricity production of the system over one year is 4.837.673 kWh/year. The

hybrid system under Scenario 1 utilizes an energy storage system to store excess energy supply in the BESS. As shown in Table 11, the optimal battery requirement is 4.607 units, with each battery cell rated at 12,8 V and 100 Ah. The total battery bank capacity for this system is 5.897 kWh, with 4.718 kWh (80%) usable capacity. The battery components in this system are expected to last for 12,8 years.



**Figure 5** Schematic Modeling of Scenario 1 (DG-PV-BESS).

**Table 6.** Optimization Results of Scenario 1 (DG-PV-BESS).

Parameter	Value
Additional PV (kW)	1.570
Existing PV (kW)	450
DG (kW)	1.546
Battery (unit)	4.607
Converter (kW)	724
LCOE (USD/kWh)	0,159
Renewable Fraction (%)	70,3

### 3.2 DG-PV-HESS

Scenario 2 (DG–PV–HESS), as shown in Table 7, results in an LCOE of 0,217 USD/kWh with a Renewable Fraction of 70,8%. This system consists of 4 diesel generator units with a total operating capacity of 1.546 kW, 450 kW of existing PV, an additional 2.974 kW of PV, a 1.810 kW electrolyzer, a 400 kW fuel cell, and a 400 kg hydrogen tank. The total electricity production reaches 9.222.227 kWh/year. The electrolyzer consumes 4.550.594 kWh/year to produce 95.755 kg of hydrogen (an average of 10,9 kg/hour; maximum 38,1 kg/hour), which is stored in a tank with an equivalent capacity of 13.333 kWh. The fuel cell generates 1.913.569 kWh of electricity per year, consuming 95.678 kg of hydrogen annually, and is capable of supplying the full load for 28,1 hours when the tank is fully charged. This system demonstrates high technical efficiency and

stable performance in supporting the energy transition, with hydrogen making a significant contribution as an energy storage medium.

**Table 7.** Optimization Results of Scenario 2 (DG-PV-HESS).

Parameter	Value
Additional PV (kW)	2.974
Existing PV (kW)	450
DG (kW)	1.546
Fuel Cell (kW)	400
Electrolyzer (kW)	1.810
Hydrogen Tank (kg)	400
Converter (kW)	396
LCOE (USD/kWh)	0,217
Renewable Fraction (%)	70,8

### 3.3 PV- BESS-HESS

Scenario 3, as presented in Table 8, results in the most optimal system with an LCOE of 0,213 USD/kWh and a Renewable Fraction of 100%, as it no longer relies on B40-fueled diesel generators. This system configuration consists of 450 kW of existing PV, an additional 5.090 kW of PV, 2.056 battery units (12,8 V 100 Ah) with a total capacity of 2.632 kWh and a lifespan of 22,6 years, as well as a hydrogen-based energy storage system (HESS). The 2.191 kW electrolyzer consumes 5.039.548 kWh/year to produce 106.043 kg of hydrogen annually, which is stored in a tank with a capacity of 1.300 kg (equivalent to 43.333 kWh). The 500 kW fuel cell then generates 2.098.127 kWh of electricity per year with a hydrogen consumption of 104.906 kg/year. This hybrid system integrates BESS and HESS synergistically to store surplus energy, making it a clean and sustainable solution with high technical efficiency.

**Table 8.** Optimization Results of Scenario 3 (PV-BESS-HESS).

Parameter	Value
Additional PV (kW)	5.090
Existing PV (kW)	450
Fuel Cell (kW)	500
Battery (unit)	2.056
Electrolyzer (kW)	2.191
Hydrogen Tank (kg)	1.300
Converter (kW)	1.487
LCOE (USD/kWh)	0,213
Renewable Fraction (%)	100

### 3.4 Comparison of Techno-Economic and Emission Analysis

Based on the simulation and optimization results using HOMER Pro software, the comparison of the three hybrid system scenarios shows significant technical and economic differences, as presented in Table 9 and Table 10.

Scenario 1 (DG–PV–BESS) produces the lowest energy cost (LCOE), which is 0,159 USD/kWh with a Renewable Fraction (RF) of 70,3%. This cost efficiency is supported by the use of fossil-fueled diesel generators, which remain relatively inexpensive, and the use of mature battery storage technology (BESS) with a capacity of 5.897 kWh. However, despite the low LCOE, this scenario is not investment-feasible as it yields no IRR value and has no payback period throughout the 25-year project lifespan.

Scenario 2 (DG–PV–HESS) replaces batteries with a hydrogen energy storage system (HESS), resulting in the highest LCOE at 0,217 USD/kWh and an NPC of 14.300.000 USD. The RF slightly increases to 70,8%, but there is a reduction in emissions due to lower B40 consumption. The main advantage of this scenario is its investment feasibility, demonstrated by a short payback period of 4,1 years and a high IRR of 29%. This system also introduces hydrogen production at a cost (LCOH) of 9,41 USD/kg, indicating its potential as a cost-effective hydrogen-based system.

Scenario 3 (PV–BESS–HESS) is the only emission-free configuration as it does not use fossil-fueled generators and relies entirely on renewable energy. This system achieves an RF of 100%, an LCOE of 0,213 USD/kWh, and a lower LCOH compared to Scenario 2, at 8,34 USD/kg. The BESS capacity used is 2.632 kWh—smaller than in Scenario 1—but with a longer lifespan of 22,6 years. This is due to the presence of HESS, which helps reduce battery cycling. This combination not only reduces costs but also contributes to minimizing battery waste that could potentially harm the environment.

**Table 9.** Comparison of Technical Parameters.

Parameter (Unit)	Scenario 1 (DG–PV– BESS)	Scenario 2 (DG–PV– HESS)	Scenario 3 (PV–BESS– HESS)
Operating Diesel Generator (kW)	1.546	1.546	–
Existing PV (kW)	450	450	450
Additional PV (kW)	1.570	2.974	5.090
Battery Nominal Capacity (kWh)	5.897	–	2.632
Electrolyzer (kW)	–	1.810	2.191
Hydrogen Tank (kg)	–	400	1.300
Fuel Cell (kW)	–	400	500
Renewable Fraction (%)	70,3	70,8	100
Total Hydrogen Production (kg/yr)	–	95.755	106.043
Battery Lifetime (year)	–	12,8	22,6
B40 Consumption (L/yr)	225.777	208.735	–

**Table 10** Comparison of Economic Parameters.

Parameter	Scenario 1 (DG-PV-BESS)	Scenario 2 (DG-PV-HESS)	Scenario 3 (PV-BESS-HESS)
LCOE (USD/kWh)	0,159	0,217	0,213
LCOH (USD/kWh)	N/A	9,41	8,34
NPC (USD)	10.500.000	14.300.000	14.100.000
CAPEX (USD)	4.000.000	4.770.000	8.760.000
O&M Cost (USD/tahun)	408.489	600.587	333.113
IRR (%)	N/A	29	N/A
Payback Period (tahun)	N/A	4,1	N/A

One of the main objectives of this study is to reduce pollution by optimizing the use of hydrogen-based renewable energy. Based on the data in Table 11, the Scenario 1 system (DG–PV–BESS) produces the highest CO<sub>2</sub> emissions at 584.862 kg/year, with B40 consumption reaching 225.777 liters/year. Scenario 2 (DG–PV–HESS) shows a reduction in emissions to 540.715 kg/year and B40 consumption of 208.735 liters/year. Meanwhile, Scenario 3 (PV–BESS–HESS) proves to be the cleanest, with zero CO<sub>2</sub> emissions (0 kg/year), as all energy demand is met by renewable sources and hydrogen fuel. This confirms that Scenario 3 is an ideal zero-emission system to support the transition to clean energy.

**Table 11** Comparison of Emissions.

Pollutants	Scenario 1 (DG-PV- BESS)	Scenario 2 (DG-PV- HESS)	Scenario 3 (PV-BESS- HESS)
Carbon Dioxide (kg/tahun)	584.862	540.715	0
Carbon Monoxide (kg/tahun)	2.757	2.549	0
Unburned Hydrocarbons (kg/tahun)	138	127	0
Particulate Matter (kg/tahun)	20,3	18,8	0
Sulfur Dioxide (kg/tahun)	313	290	0
Nitrogen Oxides (kg/tahun)	605	559	0

#### 4 Conclusion

The modeling and optimization of the hybrid renewable energy system on Semaun Island, East Nusa Tenggara, using HOMER Pro successfully compared three main configurations: DG–PV–BESS, DG–PV–HESS, and PV–BESS–HESS. Scenario 1 yields the lowest LCOE at 0,159 USD/kWh but has the highest CO<sub>2</sub> emissions (584.862 kg/year) and is not financially feasible as it has no IRR over the 25-year project period. Scenario 2 produces the highest LCOE (0,217 USD/kWh), yet it is the most economically attractive with an IRR of 29%, a

payback period of 4,1 years, and an LCOH of 9,41 USD/kg H<sub>2</sub>. Scenario 3 proves to be the most environmentally friendly, with zero emissions, a Renewable Fraction of 100%, and the lowest LCOH at 8,34 USD/kg H<sub>2</sub>, although its payback period exceeds 25 years. This system also demonstrates efficient battery usage, with a BESS capacity of only 2.632 kWh and a lifespan of 22,6 years, compared to 5.897 kWh and 12,8 years in Scenario 1. These results confirm that Scenario 3 is the most ideal for long-term investment, supporting clean energy transition while reducing emissions and potential battery waste in remote areas.

## References

- [1] Li, L., Lin, J., Wu, N., Xie, S., Meng, C., Zheng, Y., Wang, X., & Zhao, Y. (2022). Review and outlook on the international renewable energy development. *Energy and Built Environment*, 3 (2022), 139–157. <https://doi.org/10.1016/j.enbenv.2020.12.002>
- [2] PT PLN (Persero). (2025). Rencana Usaha Penyediaan Tenaga Listrik (RUPTL) PT PLN (Persero) 2025–2034. Kementerian Energi dan Sumber Daya Mineral Republik Indonesia.
- [3] Sarker, A. K., Azad, A. K., Rasul, M. G., & Doppalapudi, A. T. (2023). Prospect of Green Hydrogen Generation from Hybrid Renewable Energy Sources: A Review. *Energies* 2023, 16, 1556. <https://doi.org/10.3390/en16031556>
- [4] Le, T. S., Nguyen, T. N., Bui, D., Ngo, T. D. (2023). Optimal sizing of renewable energy storage: A techno-economic analysis of hydrogen, battery and hybrid systems considering degradation and seasonal storage. *Applied Energy*, 336 (2023) 120817. <https://doi.org/10.1016/j.apenergy.2023.120817>
- [5] Al Badi, A., & Al Wahaibi, A. (2022). Techno-Economic Analysis and Optimization of Solar Energy System for Power Generation and Hydrogen Production in Al Mazyouna Area. *International Conference on Clean and Green Energy Engineering*, 3, 26 -31. DOI: 10.1109/CGEE55282.2022.9976768
- [6] Reciou, A., & Dekhandji, F. Z. (2022). Hydrogen-based Hybrid Renewable Energy System Sizing Optimization using HOMER. *The 13th International Renewable Energy Congress (IREC 2022)*. DOI: 10.1109/IREC56325.2022.10002028
- [7] Danish Energy Agency, & Ea Energy Analyses. Technology data for the Indonesian power sector: Catalogue for generation and storage of electricity. Technical Report, Danish Energy Partnership Programme (INDODEPP), 2024.
- [8] Rahmanta, M. A., Syamsuddin, A., Tanbar, F., & Damanik, N. (2023). Analisis Perkembangan Teknologi Modul Photovoltaic (PV) Untuk Meningkatkan Penetrasi Pusat Listrik Tenaga Surya (PLTS) di Indonesia

- (Analysis of Photovoltaic (PV) Module Technology Development to Increase Penetration of Solar Power Plants in Indonesia). *Jurnal Offshore: Oil, Production Facilities and Renewable Energy*, 7(1), 22–33. (Text in Indonesian and Abstract in English)
- [9] Rahman, M. M., Ghazi, G. A., Al-Ammar, E. A., & Ko, W. (2021). Techno-Economic Analysis of Hybrid PV/Wind/Fuel-Cell System for EVCS. *International Conference on Electrical, Communication and Computer Engineering (ICECCE)*, 3. DOI: 10.1109/ICECCE52056.2021.9514084
- [10] VOZ. (2022). Battery Specification Sheet: LFP12-100 (12V100Ah) Lithium Battery Series. [Product datasheet].
- [11] Das, D., Chakraborty, I., Bohre, A. K., Kumar, P., & Agarwala, R. (2024). Sustainable Integration of Green Hydrogen in Renewable Energy Systems for Residential and EV Applications. *International Journal of Energy Research*, 2024. <https://doi.org/10.1155/2024/8258624>
- [12] International Renewable Energy Agency (IRENA). (2020). Green hydrogen cost reduction: Scaling up electrolyzers to meet the 1.5°C climate goal. IRENA. <https://www.irena.org/publications>
- [13] Ma, J. (n.d.). Renewable hydrogen energy system for household application. Master's thesis, Lund University, International Master Programme in Environmental Science.
- [14] Kumar, S. S., & Lim, H. (2022). An overview of water electrolysis technologies for green hydrogen production. *Energi Report*, 8 (2022), 13793-13813. <https://doi.org/10.1016/j.egy.2022.10.127>.
- [15] International Energy Agency (IEA). (2015). Technology roadmap: Hydrogen and fuel cells. OECD/IEA. <https://www.iea.org/reports/technology-roadmap-hydrogen-and-fuel-cells>
- [16] Luta, D. N., & Raji, A. K. (2018). Decision-making between a grid extension and a rural renewable off-grid system with hydrogen generation. *International Journal of Hydrogen Energy*, 43(20), 9535–9548. <https://doi.org/10.1016/j.ijhydene.2018.04.032>