Techno-Economic Feasibility Study of Renewable Energy Power Generation: A Case Study in Sumba Jaya Area, East Nusa Tenggara Province, Indonesia

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Abstract

The Sumba Island electricity is divided into two central systems, the Waingapu and Waikabubak. The load growth of the Waikabubak system, which is in the Sumba Jaya area, is predicted to be higher than that of the Waingapu system. The existing power generation systems in this area consist of solar PV system (PLTS) Bilacenge along with vanadium redox battery (VRB), micro hydro power plant (PLTMH) Lokomboro and Umbuwango, the diesel power generation (PLTD) Waikabubak and Waitabula (Baru Laratama). The existing configuration of these systems produces renewable energy penetration below 45%. Hence, this condition shows that renewable energy exploration has yet to be carried out optimally, even though this area has an average potential for solar irradiation and wind speed reaching 5.84 kWh/day and 5.29 m/s, respectively. This research proposes an optimization design for developing the electricity system in the Sumba Jaya area, including Sumba Barat and Sumba Barat Daya Regency, East Nusa Tenggara Province. The proposed design searches for the optimal capacity of the existing system by adding renewable energy power generation in the form of wind turbine generation (PLTB) in Wanokaka with a capacity of 3,000 kW. The modelling was conducted using Hybrid Optimization of Multiple Energy Resources (HOMER) software to assess the feasibility of the proposed system. As a result, the payback period of the proposed system is achieved around four years, with the net present cost (NPC) and cost of energy (COE) lower than the existing system. In addition, the level of CO_2 emissions was reduced, with the increased renewable energy penetration rate at around 96.6%.

Keywords: techno-economic analysis, renewable energy, solar PV, Sumba Island, HOMER.

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1. Introduction

The escalating population growth rate precipitates an increasing demand for energy resources. Renewable energy is an alternative solution to anticipate an energy crisis, alongside potentially reducing environmental pollution due to fossil fuels [1]. Also, it can offer promising solutions for rural areas with decentralized electricity systems [2]. Hence, distributed generation and microgrids based on renewable energy sources are developed to meet load needs in remote areas [3].

East Tenggara Timur (NTT) Province in Indonesia has 88 isolated electricity systems, with 18 having high peak loads. The Waingapu - Waikabubak electricity system on Sumba Island is part of 18 NTT systems with high peak loads. The total peak load in this system is estimated to reach 5,500 kW with a base load of 2,500 kW. Due to the need for electrical energy increases along with economic development and population growth, the electricity demand in both areas has grown 6% and 8% yearly based on the electricity supply business plan (RUPTL) Indonesia State Electricity Corporation (PT PLN).

Several studies have proposed optimization designs for the electricity system on Sumba Island. A study proposes the integration of bio-diesel power plants (PLTD) and solar PV (PLTS) [4]. The used fuel is from the transesterification process result called Jatropha Methyl Ester (JME). It has a very low sulfur content, rendering it highly advantageous for diesel engines by effectively mitigating corrosive effects. However, the fact shows that PLTD still dominates most of the electricity in the Waingapu area [5]. Consequently, integrating renewable energy, such as a wind power plant (PLTB), emerges as a viable solution, offering a renewable energy source that can complement existing diesel infrastructure. The proposed design in the Mondu District produces the system more efficiently and reduces emissions [6].

Furthermore, the Waikabubak electricity system exhibits higher load growth rates than the Waingapu system. This system in the western part of Sumba Island has several renewable energy power plants, such as the PLTS Bilacenge 500 kWp and the Lokomboro and Umbuwango 2,900 kW micro hydropower plants (PLTMH). Both support the diesel power plants Waikabubak and Waitabula (Baru Laratama), which have 2,300 kW and 3,230 kW. However, renewable energy penetration contributed by Waikabubak electricity is still below 45%, which does not fully comply with the Decree of the Minister of Energy and Mineral Resources (ESDM) No. 3051K/30/MEM/2015 concerning the Sumba Iconic Island (SII) program. The electrification ratio target is 95% in 2020, with 65% renewable energy penetration and is expected to reach 100% in 2025 [7], [8]. Hence, developing renewable energy electricity systems must still be carried out to realize the determined targets.

This research proposes an optimization design for developing the electricity system in Sumba Jaya Area, East Nusa Tenggara Province. The proposed design searches for the optimal capacity of the existing system by adding PLTB in Wanokaka with a capacity of 3,000 kW. Solar energy potency is also explored, especially in the Sumba Barat Daya region, which has great potential, with an average solar irradiation of 5.84 kWh/m^2/day. It was realized by investigating the scale-up of the capacity of the PLTS Bilacenge. The optimization was conducted using Hybrid Optimization of Multiple Energy Resources (HOMER) software to assess the feasibility of the proposed system. As a result, the payback period of the proposed system is achieved around four years, with the net present cost (NPC) and cost of energy (COE) lower than the existing system. In addition, the level of CO_2 emissions was reduced, with the increased renewable energy fraction rate at around 96.6%.

2. Method

2.1. Sumba Jaya Electricity System Profile

The electricity system in the Sumba Jaya area covers Sumba Barat and Sumba Barat Daya Regency. It has three renewable energy power generations: the PLTS Bilacenge 500 kWp with Vanadium Redox Flow Battery (VRB) storage system, the PLTMH Lokomboro and Umbuwango 2,900 kW, as shown in Figure 1. In addition, it has PLTD Waitabula (Baru Laratama) and Waikabubak 3,230 kW and 2,300 kW, respectively. This research utilized data from PLN ULP Sumba Jaya, including Sumba Barat and Sumba Barat Daya load profiles from November 7th, 2019, to November 13th, 2019, the average hourly electricity load on weekdays (Monday-Friday) and weekends (Saturday-Sunday) shown in Table 1. Then, it scaled up to 4% each year to model the representative condition for 25 years of project lifetime.

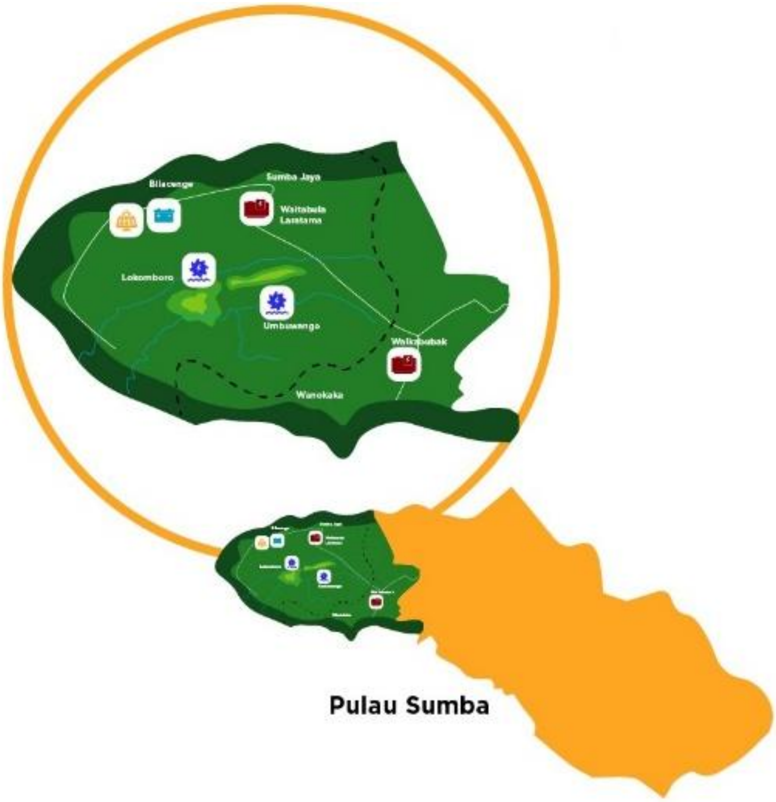

Figure 1. The Sumba Jaya electricity system map

2.2. Hybrid Optimization Model for Multiple Energy Resources (HOMER)

The HOMER software is a powerful tool designed to optimize renewable energy projects. It is widely employed for conducting feasibility studies and analyzing hybrid energy systems. Developed by the National Renewable Energy Laboratory (NREL) in the United States, HOMER facilitates the simulation of both grid-connected and off-grid energy systems [9]. The simulation outputs provided by HOMER offer insights into the most efficient system architecture by considering critical economic parameters such as

Net Present Cost (NPC), Cost of Energy (COE), and the payback period compared to a base case scenario. Additionally, the software calculates the Renewable Fraction (RF), which quantifies the proportion of renewable energy contributing to the hybrid system. The HOMER software performs three primary functions: simulation, optimization, and sensitivity analysis [10]. These functions enable users to assess the performance of hybrid systems under various scenarios, identify the optimal configuration, and evaluate how input changes affect system performance.

Table 1. Sumba Jaya electricity loads

Time	Weekdays (kW)	Weekends (kW)
00.00	3280.8	3129.0
01.00	2603.2	2740.0
02.00	2567.6	2653.0
03.00	2455.2	2632.0
04.00	2616.4	2668.5
05.00	2600.2	2632.0
06.00	2637.8	2537.5
07.00	2447.4	2435.0
08.00	2570.8	2684.5
09.00	2526.6	2773.5
10.00	2620.4	2769.5
11.00	2509.2	2836.5
12.00	2496.2	2567.0
13.00	2485.4	2332.5
14.00	2557.6	2516.0
15.00	2579.4	2583.5
16.00	2730.8	2580.0
17.00	3151.4	2812.5
18.00	3806.6	3669.0
19.00	4284.2	4190.5
20.00	4170.6	4092.0
21.00	4196.4	4178.5
22.00	3992.2	3864.0
23.00	3586.4	3550.5

2.3. Techno-Economic Parameters

This study employed the HOMER software, which is used to optimize renewable energy projects and conduct feasibility studies and analysis of hybrid systems. Many researchers have utilized this software to develop renewable energy power generation [11]–[14]. To comprehensively evaluate the operational performance across various potential scenarios, assessing renewable energy projects typically necessitates the application of specific criteria tailored to the site's unique conditions. This ensures an accurate and context-sensitive analysis of the system's viability and effectiveness. This work employed the methodology framework to guide the assessment, illustrated in Figure 2 [15].

Several parameters are needed by HOMER simulation, including economic and technical aspects. This study uses the discount and inflation rates of 6.25% and 2.5%, respectively. Both are determined by Indonesia Bank policy in April 2024. Also, the price assumption for power plant components used is determined. Table 2 shows the prices estimation of power plant components in this research.

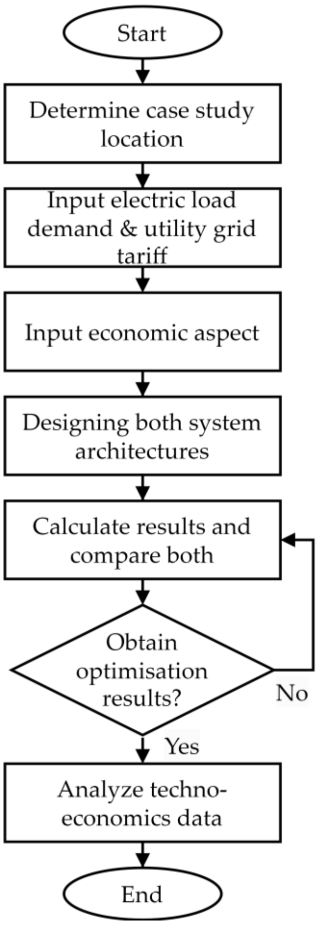

Figure 2. The methodology framework

Table 2. Prices estimation and types of power plant components

Parameter	Specification
Photovoltaic Module	
Model name	Yangtze YS250P-60
Power rating	0.25 kW/module
Lifetime	25 years
Efficiency	15.40%
Derating factor	80%
Capital cost	IDR 2,716,000/kW
Replacement cost	IDR 2,716,000/kW
O&M cost/year	IDR 10,864/kW
Converter	
Model name	Growatt WIT 50-100K-H/HU 50KW
Power rating	50 kW/unit
Lifetime	10 years
Inverter efficiency	98.2%
MPPT efficiency	98.2%
Capital cost	IDR 70,000,000/unit
Replacement cost	IDR 70,000,000/unit
O&M cost/year	IDR 700.000/year
Vanadium Redox Flow Battery (VRB)	
Model name	Generic Vanadium Flow
Initial state of charge	100%
Minimum state of charge	20%
Capital cost of cell stacks	IDR 71,577,500/kW

Replacement cost of cell stacks	IDR 71,577,500/kW
O&M/year of cell stacks/year	IDR 1,431,550/kW
Lifetime of cell stacks	15 years
The capital cost of electrolyte	IDR 2,863,100/kWh
Replacement cost of electrolyte	IDR 2,863,100/kWh
Variable O&M cost of electrolyte	IDR 71.58/kWh
Lifetime of electrolyte	15 years
Microhydro Power Plant	
Model name	Generic
Capacity	2,900 kW
Lifetime	30 years
Available head	60.64 meter
Design flow ratio	5,000 L/s
Minimum flow ratio	50%
Maximum flow ratio	150%
Pipe head loss	15%
Efficiency	97.5%
Capital cost	IDR 85,606,690,000/unit
Replacement cost	IDR 85,606,690,000/unit
O&M cost/year	IDR 1,745,059,450/year
Diesel Generator	
Model name	Generic
Lifetime	219,000 hours
Minimum load ratio	25%
Diesel fuel price	IDR 6,800/liter
Capital cost	IDR 7,167,000,000/kW
Replacement cost	IDR 7,167,000,000/kW
O&M cost	IDR 430.02/op.hr
Wind Turbine	
Model name	Generic 1,500 kW
Lifetime	20 years
Hub height	120 meter
Capital cost	IDR 28,103,921,250/unit
Replacement cost	IDR 28,103,921,250/unit
O&M cost/year	IDR 2,810,392/year
Lithium-Ion Battery	
Model name	Generic Lithium-Ion
Capacity	1,000 kWh
Lifetime	15 years
Roundtrip efficiency	90%
Minimum state of charge	20%
Capital cost	IDR 997,202,500,000/unit
Replacement cost	IDR 997,202,500,000/unit
O&M cost/year	IDR 99,720,250/year

2.4. The Existing System Architecture Modelling

The existing power generation system in Sumba Jaya consists of the PLTS Bilacenge, which is equipped with a converter and VRB, PLTMH Lokomboro and Umbuwango, PLTD Waikabubak and Waitabula (Baru Laratama). The modelling of the existing power generation system by HOMER is shown in Figure 3. The solar energy data in the Bilacenge area are obtained from the Solar Global Horizontal Irradiance (GHI) by Prediction of Worldwide Energy Resources (POWER), National Aeronautics and Space Administration (NASA), as listed in Table 3. Meanwhile, the average water debit of Lokomboro Waterfall is 2,500 L/s [16].

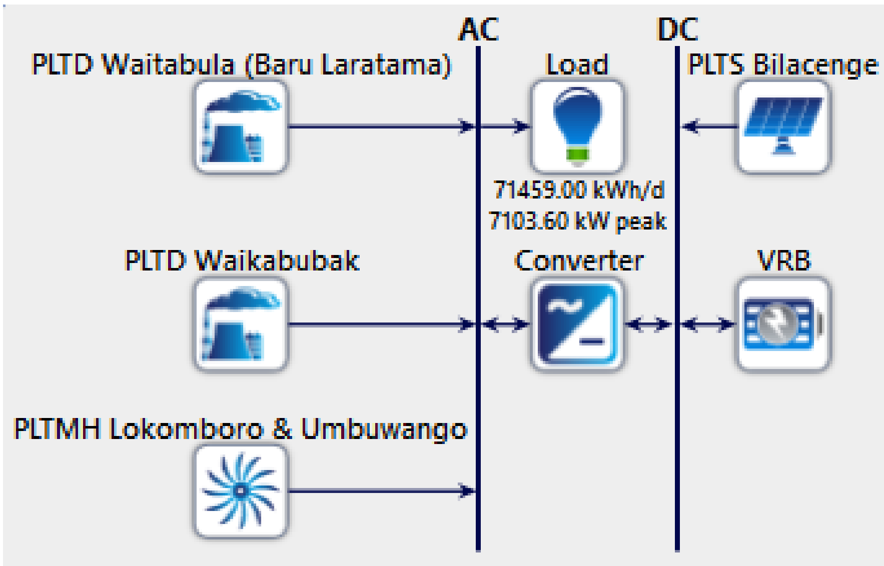

Figure 3. The existing system modelling

Table 3. The solar GHI profile at PLTS Bilacenge

Month	Clearness Index	Daily Radiation (kWh/m²/day)
January	0.489	5.35
February	0.486	5.29
March	0.555	5.82
April	0.605	5.83
May	0.649	5.64
June	0.636	5.20
July	0.637	5.34
August	0.647	5.94
September	0.660	6.66
October	0.628	6.71
November	0.591	6.43
December	0.535	5.83

2.5. The Proposed System Architecture Modelling

The proposed power system model uses the existing design by adjusting the capacity and adding a new design based on renewable energy sources, as shown in Figure 4. Lithium-ion (Li-ion) batteries with 1,000 kWh capacity replace the VRB for the storage system. The total capacity of the PLTMH Lokomboro and Umbuwango is 2,900 kW. The proposed system reduces the PLTD Waitabula (Baru Laratama) and Waikabubak capacity. Meanwhile, the PLTB Wanokaka is added to the proposed system. The optimized capacity is calculated using the HOMER optimizer method.

PLTB Wanokaka is located at coordinates 09º46’52.62’’ Latitude 119º20’12.27’’ Longitude. This site’s annual average wind speed is 5.29 m/s, which has the potential to realize a wind power plant [17]. The highest speed was in July at 6.93 m/s, while the lowest was 3.84 m/s in November. Table 4 shows the wind speed profile by the POWER NASA database.

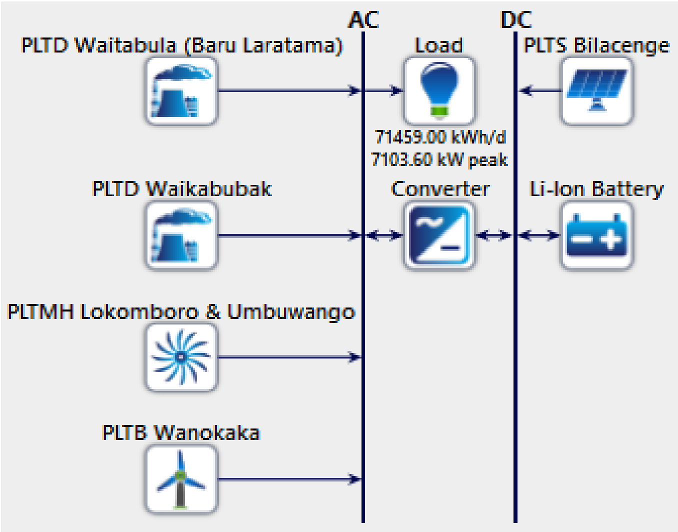

Figure 4. The proposed system modelling

Table 4. The wind speed profile at PLTB Wanokaka

Month	Average Wind Speed (m/s)
January	4.81
February	5.07
March	4.25
April	5.00
May	6.07
June	6.69
July	6.93
August	6.52
September	5.54
October	4.67
November	3.84
December	4.05
Annual Average	5.29

3. Results and Discussion

Table 5 shows the architecture and the power plant's capacity for the existing and proposed system, which HOMER has simulated. The existing system represents the actual condition in Sumba Jaya, and the proposed system optimizes the existing systems. The existing system capacity from the simulation is appropriate for the actual condition. Hence, optimizing the existing system for a novel configuration is feasible. Furthermore, the energy output results from both are listed in Table 6.

A significant reduction in fuel consumption and fuel cost can be conducted by adopting the proposed system. The proposed system can suppress both by around 16.7 times more than the existing system. Note that it is aligned to the reduced capacity of both PLTD. Hence, the economic aspect is evaluated by comparing NPC to identify the lowest cost between the existing and proposed system. Table 7 shows the economic aspects of comparing both systems, including operating, total fuel, and energy costs. In addition, the following comparison in the form of both system performances is listed in Table 8, covering the total fuel consumption, renewable energy fraction, and producing CO_2 due to the generating electricity activity.

Table 5. The architecture and capacity power plant

Architecture	Capacity	
	Existing System	Proposed System
PLTS Bilacenge	500 kWp	6,986 kWp
VRB	500 kWh	-
Li-Ion Battery	-	33,000 kWh
Converter	500 kW	3,880 kW
PLTMH Lokomboro & Umbuwango	2,900 kW	2,900 kW
PLTD Waitabula (Baru Laratama)	2,300 kW	1,500 kW
PLTD Waikabubak	3,230 kW	1,500 kW
PLTB Wanokaka	-	3,000 kW

Table 6. The output energy

Parameters	Output	
	Existing System	Proposed System
PLTS Bilacenge		
Energy Production (kWh/year)	864,947	12,102,684
VRB		
Annual Throughput (kWh/year)	6,727	-
Li-Ion Battery		
Annual Throughput (kWh/year)	-	6,264,894
Converter		
Mean Output (kW)	85	897
PLTMH Lokomboro & Umbuwango		
Energy Production (kW)	1,233	1,233
PLTD Waitabula (Baru Laratama)		
Energy Production (kWh)	5,586,108	649,446
Operational Hour (hours)	2,010	979
Fuel Consumption (liters)	1,595,070	205,428
Fuel Cost (IDR/year)	10,846,474,240	1,396,908,928
PLTD Waikabukak		
Energy Production (kWh)	9,035,799	168,850
Operational Hour (hours)	7,338	288
Fuel Consumption (liters)	2,758,624	54,815
Fuel Cost (IDR/year)	18,758,645,760	372,742,752
PLTB Wanokaka		
Energy Production (kWh/year)	-	9,167,206

Table 7. Economic aspects

Parameters	Capacity	
	Existing System	Proposed System
NPC (IDR)	828,330,900,000	431,225,300,000
Capital Cost (IDR)	157,360,750,000	277,556,470,595
Operating Cost (IDR/year)	41,414,010,000	9,484,840,000
Fuel Cost (IDR/year)	29,605,120,000	1,769,651,680
COE (IDR/kWh)	1,960	1,021

Table 8. System performances

Parameters	Capacity	
	Existing System	Proposed System
Total Fuel (liter/year)	4,353,694	260,243
Renewable Fraction (%)	43,9	96,9
CO_2 (kg/year)	11,387,442	680,686

The NPC from the proposed system is less than that of the existing system. Because of this, it has been proven that the proposed system is more effective based on cost parameters. It is because NPC is obtained by comparing the present value of all the system costs over the project lifetime minus the present value of all the revenues it earns over the project lifetime [18]. The proposed system can decrease the NPC nearly two times. Also, the operating cost was successfully suppressed to 4.4 times by the proposed system thanks to decreasing both PLTD capacities. The next significant difference is the cost of energy. The proposed system results in COE IDR 1,021/kWh while IDR 1,960/kWh for the existing system. This means the proposed system can sell electricity cheaper than the existing one, even under the national electricity prices of about IDR 1,445/kWh for the middle household rating [19].

The renewable faction increased since the total fuel for the proposed system decreased, and PLTB Wanokaka was added. It becomes 96,9%, more than two times that of the existing model. In addition, the proposed system can reduce CO_2 by up to 10,706,756 kg/year. This fact proves that the existing system in Sumba Jaya can be optimized by making several adjustments, such as the proposed system. The simple payback period of this investment is around four years from the 25-year project lifetime. It is obtained from the intersection of cumulative cash flow between the existing and proposed system, as shown in Figure 5.

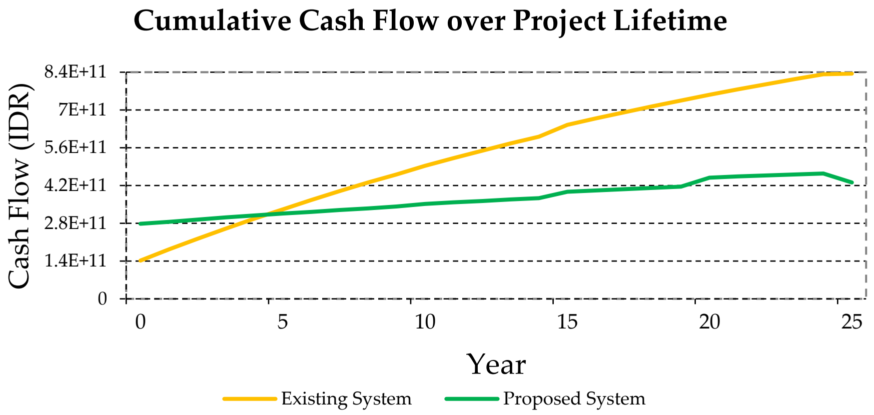

Figure 5. The cumulative cash flow of existing and proposed system

By optimizing the existing system, this study validates that the Sumba Jaya area has excellent renewable energy potency, especially solar and wind energy. Hence, this potency can support the SII program, which aims to achieve 100% renewable energy, as introduced by the Directorate General of New Renewable Energy and Energy Conservation - MEMR, supported by HIVOS in 2010 [20]. The proposed system, which adds PLTB Wanokaka, is the correct way to increase renewable penetration because wind energy is the cheapest production method [21].

4. Conclusion

The optimization design for developing the electricity system in the Sumba Jaya area, covering Sumba Barat and Sumba Barat Daya Regency, East Nusa Tenggara Province, has been carried out using HOME software. The proposed design is conducted by scaling up PLTS Bilacenge capacity, replacing VRB with a Li-Ion battery, and adding renewable energy power generation in the form of PLTB Wanokaka with a capacity of 3,000 kW. The capacity of PLTD Waikabubak and Waitabula (Baru Laratama) is successfully downgraded to optimize the role of renewable energy power generation. NPC and COE have become lower than the existing system, with the payback period of the proposed system being around four years. In addition, the level of CO2 emissions was reduced, with the increased renewable energy penetration rate at around 96.6%.

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