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Techno-Economic Analysis of a Micro-Scale Off-Grid Solar Power Plant Using HOMER Software at the Operational Building

Sepannur Bandri [1*], Zuriman Anthony [1], Fauzan Ismail [1], Taufal Hidayat [1], Sitti Amalia [1], Dwi Harinitha [1], Alfith[2]

[1)] Department of Electrical Engineering, Faculty of Engineering, Institut Teknologi Padang, Padang, Indonesia
[2)]Department of Electrical Engineering, Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka
e-mail: sepannur@itp.ac.id

ABSTRACT

Rising electricity costs and fossil-fuel dependence in government facilities underscore the urgency of transitioning to renewable energy. This study determines the optimal configuration and economic feasibility of a micro-scale off-grid Solar Power Plant at the Operational Building of Balai Teknik Perkeretaapian (BTP) Kelas II Padang, supplied entirely by PLN grid tariff P1 (131,000 VA). A quantitative descriptive method combined five-day load measurement, manual calculation, and HOMER Pro simulation, using NASA POWER solar radiation data (annual average 4.62 kWh/m²/day). Manual calculation yielded 39.68 kW installed panel capacity, 339.97 kWh battery capacity (83 LiFePO4 units), and 80 kW inverter capacity; with a 10% Balance of System (BOS) allowance, Cost of Energy (COE) is IDR 1,429/kWh, 1.1% below the PLN tariff of IDR 1,444.70/kWh. HOMER Pro recommended 45.26 kW installed capacity with identical battery and inverter sizing, yielding COE of IDR 1,494/kWh with BOS, 3.4% above tariff, reversing the hardware-only comparison. Both configurations remain NPV-positive and PI above 1.0 within 25 years, but only the manual configuration is recommended as economically preferred. Sensitivity analysis identifies battery price and service life as the most critical risk factors. This study contributes measured load data with explicit BOS treatment, not previously applied to government railway facilities in Indonesia.

Keywords: Off-Grid Solar PV System; HOMER Pro; Techno-Economic Analysis; Investment Feasibility; Sensitivity Analysis

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Correspondence Author:

Sepannur Bandri
Department of Electrical Engineering,
Institut Teknologi Padang,
Jl. Gajah Mada Kandis, Kampung Olo, Nanggalo District, Padang City, West Sumatra 25143.
Email: sepannur@itp.ac.id

1. INTRODUCTION

Global electricity demand has grown at an accelerating pace, driven by industrialization, population growth, and the expanding digitalization of modern economies. Global energy demand grew by 2.2% in 2024, outpacing the average annual growth rate of 1.3% recorded from 2013 to 2023. Meanwhile, 81% of the global energy system remains fossil-fuel based, and power sector emissions reached an all-time high of 14.6 billion tonnes of CO_2 in 2024 [1]. Solar photovoltaic (PV) technology has emerged as the most strategically viable pathway for accelerated decarbonization at the building and facility level. The levelized cost of electricity (LCOE) of solar PV was 56% lower than fossil-fuel alternatives in 2023, a 90% reduction in global weighted-average utility-scale LCOE since 2010, making it the least-cost option for new generation in most markets. Wind and solar together represented more than half of all new global power generation in 2024 [2].

Indonesia's energy landscape reflects this tension between demand growth and decarbonization urgency. National on-grid electricity generation reached approximately 355 TWh in 2023, with 82% sourced from fossil fuels; coal alone contributed more than 61%, placing Indonesia among the largest coal-power generating countries in the world and raising sector emissions substantially over the preceding decade [3], [4] (Table 1). This occurs despite Indonesia possessing extraordinary solar resources. The Ministry of Energy and Mineral Resources estimates a technical potential of 3,294 GW, while the Institute for Essential Services Reform estimates up to 7,715 GW. Silalahi et al. [5] confirmed through spatial analysis that solar PV's technical, environmental, and economic potential far exceeds national energy requirements, underpinning the RUPTL 2021-2030 target of a 23% renewable share by 2025 and 4.68 GW of added PLN solar capacity by 2030.

Table 1. Indonesia Electricity Generation Mix, 2023

Energy Source	Share of Generation (%)	Generation (TWh)
Coal	61.8	~217
Natural Gas	16.0	~56
Oil and Others	4.2	~16
Hydropower	7.0	~25
Bioenergy	6.4	~22
Geothermal	4.8	~17
Solar and Wind	< 1.0	~1.2
Total	100	~355

Sources:Ember [3]; EIA [4]

Renewable deployment has fallen critically behind target. Solar and wind together accounted for under 1% of generation in 2023 despite the fastest year-on-year growth rates, leaving renewables at only 14.68% of the energy mix in 2024 against the 23% target for 2025 [3], [6], [7] (Table 2).

Table 2. Indonesia Renewable Energy Target vs. Actual Achievement

Indicator	Target	Actual	Gap
Renewable share of energy mix	23% by 2025	< 1% (2023)	Critical shortfall
Solar capacity addition	4.68 GW by 2030	~0.5 GW (2018-2023)	> 4 GW remaining
Annual RE capacity addition	2.1 GW/year	0.6 GW/year	72% below target

Sources: IEA [6]; Chambers and Partners [7]; Ember [3]

The core problem is concrete and facility-specific. The Operational Building of Balai Teknik Perkeretaapian (BTP) Kelas II Padang, a government railway-safety facility, depends entirely on PLN grid supply under tariff P1 (131,000 VA), incurring approximately IDR 102.86 million per year in electricity cost and remaining fully exposed to tariff escalation and outage disruption. A single Bali grid outage, for instance, affected over 1.8 million PLN customers, with national outage costs reaching USD 1 to 3 million per hour. The site records a favorable annual average solar irradiance of 4.62 kWh/m²/day, independently validated for the Indonesian archipelago with only 3 to 7% bias against ground stations [8], [9], confirming its technical suitability for off-grid PV. No technically rigorous, economically validated design yet exists that quantifies the true cost-benefit of converting this specific facility class to off-grid solar operation. This absence of a validated design, rather than any absence of technical potential, is the central problem this research addresses.

An off-grid PV system operates independently of the state grid, storing energy in batteries for use during low-irradiance periods [10]. HOMER Pro has become the industry-standard sizing and optimization tool, evaluating thousands of configurations and ranking them by minimum Net Present Cost. Deterministic manual-calculation methods have been shown to reproduce HOMER Pro outputs within a 5% margin under matched inputs [13], supporting a dual-method cross-validation approach.

Several prior studies have applied this approach across differing building contexts, yet a consistent gap remains. Wahyu et al. [14] and Kossi [15] sized off-grid systems for a pesantren hall and a rural area respectively, using estimated loads without HOMER cross-validation. Fauzsan et al. [16] applied HOMER to a university building but validated only NPV. Bagaskoro et al. [17] and Windarta et al. [18] confirmed feasibility for tourism and commercial facilities using estimated loads. Arifin et al. [19] compared on-grid and off-grid feasibility in Central Java using NPV and COE without manual cross-validation. More recent institutional case studies, a university library [20] and a tourism homestay [21], likewise relied on estimated rather than directly measured loads. Two 2024-2025 studies extended HOMER-based feasibility work with formal sensitivity analysis: Hasan et al. [25] for an off-grid hybrid system in Kuakata, Bangladesh, and Kumar et al. [22] for a solid-waste-based hybrid system in rural India, yet both continued to rely on estimated rather

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than directly measured load profiles. Table 3 summarizes the positioning of prior studies relative to this research.

Table 3. Comparison of Prior Studies and Research Position

Study	Load Data	HOMER Used	Economic Indicators
Wahyu et al. [14]; Kossi [15]	Estimated	No	Basic
Fauzsan et al. [16]	Estimated	Yes	NPV only
Bagaskoro et al. [17]; Windarta et al. [18]	Estimated	Yes	NPC, COE
Arifin et al. [19]	Estimated	Yes	NPV, COE
Herliyanso and Rozak [20]	Estimated	Yes (+PVSyst, ETAP)	NPV, COE, B-CR
Pradito et al. [21]	Estimated	Software-based	Basic
Kumar et al. [22]; Hasan et al. [25]	Estimated	Yes (+sensitivity)	NPC, COE
This research	5-day measured	Yes (+manual)	NPV, PI, DPP, COE, Sensitivity

Across all eleven studies, three gaps persist. None used multi-day directly measured three-phase load data as the design basis; even the most recent 2024-2025 HOMER-based sensitivity studies continued to rely on estimated load profiles. Government railway-technical facilities are absent from the literature. No study paired manual calculation with HOMER Pro simulation for a complete NPV, PI, DPP, and COE feasibility indicator set combined with formal sensitivity analysis. This research directly addresses all three gaps.

Three converging factors establish the urgency of this study. Indonesia's renewable deployment is running critically behind its own targets, and decentralized government-facility solar offers one of the most scalable near-term paths to close this gap [6]. BTP Kelas II Padang manages railway-safety infrastructure for which uninterrupted supply is an operational necessity, not an economic preference. Falling PV and LiFePO4 costs, combined with the site's favorable irradiance, create a window of opportunity that remains unquantified for this facility class. This research therefore aims to determine the optimal technical configuration of a micro-scale off-grid PLTS for the BTP Kelas II Padang Operational Building using five-day directly measured three-phase load data, to cross-validate manual engineering calculations against HOMER Pro simulation, and to conduct a comprehensive economic feasibility assessment using NPC, COE, NPV, PI, DPP, and sensitivity analysis as a complete indicator set confirming investment viability within the 25-year project lifetime.

2. RESEARCH METHOD

This research uses a quantitative descriptive method combining direct electrical load measurement, manual engineering calculation, and HOMER Pro simulation for optimization and cross-validation. The study was conducted at the Operational Building of Balai Teknik Perkeretaapian (BTP) Kelas II Padang, West Sumatra (Latitude: -0.7821° S, Longitude: 100.2904° E). Primary data were collected through direct three-phase load measurement at the Main Distribution Panel over five consecutive working days (07-11 July 2025, 08:00-20:00 WIB) at one-hour intervals using a clamp meter. Secondary data comprised NASA POWER solar radiation data (2024), component specifications and market prices, 12-month PLN billing records (January-December 2025), the Bank Indonesia reference rate of 4.75% (December 2025), and the national inflation rate of 2.72% (November 2025). Table 4 lists the instruments and software used.

Table 4. Research Instruments and Software

No.	Equipment/Software	Function
1	Clamp Meter (Hioki CM4373 or equivalent)	Measuring phase voltage and current at MDP
2	Laptop Computer	Running HOMER Pro and data processing
3	HOMER Pro Software v3.14	Techno-economic simulation and optimization
4	Microsoft Excel	Manual calculation, tabulation, DPP graph
5	NASA POWER DAV	Monthly solar irradiance and temperature data
6	PLN Mobile Application	12-month electricity consumption records

Manual calculation follows a sequential set of equations. The Temperature Correction Factor accounts for panel output degradation above the Standard Test Condition of 25°C:

$$TCF = 1 - (\Delta T \times kp) \quad (1)$$

The required PV area (Apv, m²) is determined from:

$$Apv = Ereq / (H \times TCF \times \eta panel \times \eta out) \quad (2)$$

where Ereq is daily energy requirement, H is peak sun hours, ηpanel is panel efficiency, and ηout is system output efficiency. Battery count is derived from:

$$Nbat = (Ereq \times tauto) / (Vbus \times DoD \times Cunit) \quad (3)$$

The real discount rate follows the Fisher equation:

$$ireal = [(1 + inom) / (1 + iinf)] - 1 \quad (4)$$

Net Present Cost aggregates life-cycle costs:

$$NPC = CC + RCpv + O\&Mpv - SVpv \quad (5)$$

Cost of Energy is calculated from NPC and the Capital Recovery Factor:

$$COE = (NPC \times CRF) / Eannual \quad (6)$$

$$CRF = [ireal(1 + ireal)^n] / [(1 + ireal)^n - 1] \quad (7)$$

Investment feasibility uses three indicators, where NCF is the annual PLN cost avoided minus PLTS operating cost:

$$NPV = \Sigma [NCF / (1 + ireal)^t] - CC, \text{ for } t = 1, 2, \ldots, n \quad (8)$$

$$PI = \Sigma [NCF / (1 + ireal)^t] / CC \quad (9)$$

$$DPP = \text{year at which } \Sigma [NCF / (1 + ireal)^t] = CC \quad (10)$$

A project is feasible when NPV > 0, PI > 1, and DPP is below the project lifetime. Equations (8) to (10) depend only on CC and NCF, so NPV, PI, and DPP respond most strongly to the PLN tariff and operating cost, while NPC and COE (Eqs. 5 to 6) more fully capture replacement and salvage timing; this distinction guides the sensitivity analysis in Section 3.9.

Selected components were the Trina Solar TSM-NE19R.70 620Wp monocrystalline panel (23% efficiency, -0.5%/°C temperature coefficient), the SMT Power SL5120 LiFePO4 battery (51.2V, 100Ah, 5.12 kWh/unit, 15-year service life, 80% DoD), and the Zamdon ZDTID 10348-H100 inverter (10 kW/unit, 48VDC input, integrated MPPT). HOMER Pro simulation used identical inputs: the five-day load profile scaled to a full 24-hour representative day, NASA POWER irradiance data, the same component costs, discount rate 4.75%, inflation 2.72%, project lifetime 25 years, and an annual capacity shortage tolerance of 5%. Inverter capacity was fixed at 80 kW, while PV capacity was left as a search space. HOMER evaluated 30 configurations and ranked all feasible solutions by minimum NPC, adopting the lowest-NPC configuration for comparison against the manual result. Figure 1 illustrates the overall research procedure.

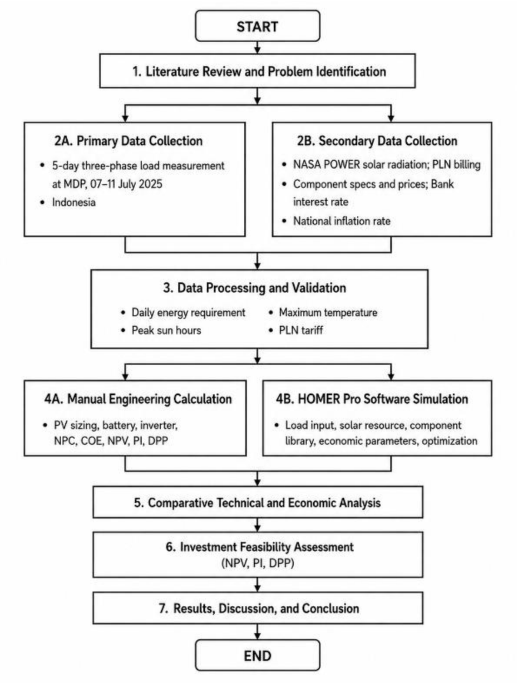

Figure 1. Research Flowchart

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3. RESULTS AND DISCUSSION

3.1. Solar Radiation Data and Research Location

Solar radiation data were retrieved from the NASA POWER Data Access Viewer for 1 January to 31 December 2024 at the research coordinates (-0.7821° S, 100.2904° E). Table 5 presents the monthly solar radiation data used as the primary resource input for both manual calculation and HOMER Pro simulation.

Table 5. Monthly Solar Radiation Data 2024

Month	Temperature (°C)	Solar Radiation (kWh/m²/day)	Clearness Index
January	27.75	4.29	0.42
February	28.44	4.42	0.42
March	28.27	4.81	0.46
April	28.57	4.86	0.48
May	28.68	4.28	0.45
June	28.31	4.58	0.50
July	28.32	5.03	0.54
August	27.96	4.36	0.44
September	27.70	4.59	0.45
October	27.63	5.26	0.51
November	27.22	4.63	0.46
December	27.31	4.34	0.44
Average	28.01	4.62	0.46

The annual average solar radiation is 4.62 kWh/m²/day, adopted as the design irradiance value, ranging narrowly from 4.28 kWh/m²/day in May to 5.26 kWh/m²/day in October. This narrow range confirms stable year-round solar resource at the site, supporting the technical viability of an off-grid PV system. The annual average temperature of 28.01°C, with a May peak of 28.68°C, is used to calculate the Temperature Correction Factor in Section 3.4. These coordinates were used as the HOMER location input (Figure 6).

3.2. Electrical Load Profile and Energy Consumption

The building's load profile was measured directly at the three-phase Main Distribution Panel over five consecutive working days (07-11 July 2025). The building is registered under PLN tariff class P1 with a connected capacity of 131,000 VA. Table 6 presents the averaged hourly profile.

Table 6. Average Three-Phase Power Load Profile, 08:00-20:00 WIB

Time	Phase R (W)	Phase S (W)	Phase T (W)	Total (W)
08:00	15,595.47	10,089.24	15,084.17	40,768.88
09:00	17,637.06	10,322.72	18,401.09	46,360.87
10:00	21,519.30	10,488.09	20,238.10	52,245.50
11:00	20,906.26	10,969.51	20,089.51	51,965.28
12:00	17,909.25	11,094.05	20,713.40	49,716.69
13:00	15,544.04	9,052.94	17,059.40	41,656.38
14:00	16,327.67	9,385.44	14,385.97	40,099.08
15:00	15,856.19	11,716.04	14,110.01	41,682.24
16:00	12,690.81	10,035.15	9,305.77	32,031.73
17:00	13,055.34	6,004.85	10,617.83	29,678.01
18:00	9,451.90	4,936.18	10,855.11	25,243.19
19:00	9,442.90	7,962.28	10,029.51	27,434.69
20:00	10,496.72	10,511.74	10,752.73	31,761.19
Average	-	-	-	39,280.29

Peak load occurs at 10:00 WIB (52,245.50 W), coinciding with full office operation, and declines progressively as staff shift to field activities; Phase S consistently carries the lowest load, a factor considered in inverter and array distribution. Because this profile was measured only during working hours across a five-day business week, it excludes the much lower standby load on nights, weekends, and holidays: summing the thirteen hourly readings already yields about 510.6 kWh for the working window alone, far above actual metered daily consumption. Table 4 is therefore used only to set the design PEAK LOAD for inverter sizing (Section 3.4) and to characterize the relative hourly SHAPE of demand for HOMER's 24-hour load profile (Section 3.5). Daily and annual ENERGY requirements for PV and battery sizing instead come from the 12-

month PLN billing history, which averages consumption across all 365 days and is the authoritative basis for capacity design; this separation of peak-power measurement from energy accounting resolves the apparent magnitude gap between Table 4 and the billing-derived figures below.

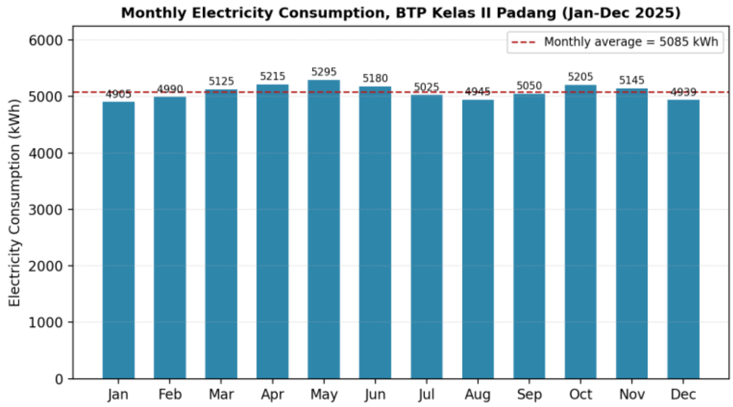

Figure 2. Monthly Electricity Consumption, BTP Kelas II Padang (Jan-Dec 2025), compiled from 12-month PLN billing records

Figure 2 shows a 12-month cumulative consumption of 61,019 kWh, averaging 5,085 kWh/month. This single measured value, 61,019 kWh/year, is used consistently for both the design daily energy requirement and the COE denominator. Dividing by 365 days gives a historical average of 167.18 kWh/day; a design value (Ereq) of 169.5 kWh/day is adopted, a deliberate 1.4% margin for load growth and rounding. The corresponding annualized design value, 61,867.5 kWh/year, is used only where explicitly required, while COE (Section 3.7) uses the measured 61,019 kWh/year figure.

3.3. Component Selection

Three primary system components were selected based on technical compatibility with the 48V DC bus architecture, Indonesian market availability, and optimal balance between performance specifications and unit price. Figures 3 and 4 show the selected solar panel and inverter.

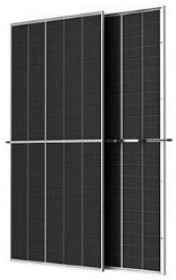

Figure 3. Trina Solar TSM-NE19R.70 620Wp Panel

Figure 4. Zamdon ZDTID 10348-H100 Inverter

The Trina Solar TSM-NE19R.70 620Wp monocrystalline panel offers 23% efficiency, a -0.5%/°C temperature coefficient, and 0.4% annual degradation. The SMT Power SL5120 LiFePO4 battery (51.2V, 100Ah, 5.12 kWh/unit) was chosen for its 15-year service life, 80% usable depth of discharge, and thermal stability at the site's 28.01°C average temperature, reducing required replacement cycles over 25 years from five (lead-acid) to one. The Zamdon ZDTID 10348-H100 string inverter (10 kW/unit, 48VDC, integrated MPPT) allows modular one-to-one pairing with each panel array.

3.4. Technical Analysis, Manual Calculation

The maximum ambient temperature (28.68°C, May) gives a 3.68°C rise above STC, yielding TCF = 0.98. Using this TCF with Ereq = 169.5 kWh/day, irradiance 4.62 kWh/m²/day, panel efficiency 23%, and output efficiency 95%, the required PV area is 171.337 m², equal to a required continuous capacity of 39.407 kWp, or 63.56 panels, rounded up to 64 units installed (39.68 kWp, 0.7% above the continuous requirement). This required-versus-installed distinction is maintained throughout the study.

The 64 panels form 8 arrays of 2 series x 4 parallel strings (Figure 5), each producing 4,960 Wp, for a total estimated output of 183.32 kWh/day, 8.2% above the design requirement. Battery sizing requires 83 units (339.97 kWh usable at 80% DoD), sufficient for 48 hours of autonomy. Inverter sizing from the measured

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peak load (52,245.50 W) with a 1.25 safety factor requires 65,306.88 W, rounded up to 80 kW (8 x 10 kW units, one per array).

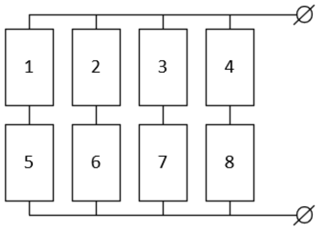

Figure 5. Solar Panel Array Circuit Configuration (2 Series x 4 Parallel per Array)

3.5. Technical Analysis, HOMER Software Simulation

HOMER Pro was configured with inputs identical to the manual calculation. Figure 6 shows the research location entered in HOMER at the exact building coordinates.

Figure 6. Research Location Setting in HOMER Software

Economic parameters matched the manual calculation: discount rate 4.75%, inflation 2.72%, capacity shortage tolerance 5%, project lifetime 25 years. As explained in Section 3.2, the working-hours measurement (Table 4) defined only the normalized hourly SHAPE of demand, which HOMER scaled to the design daily energy target across a full 24-hour day, with off-hours (21:00-07:00) set at the measured minimum load. This yielded a display average load of 7.06 kW, a peak of 11.23 kW, and a load factor of 0.63, a much lower peak than the raw working-hours peak (52.25 kW) because it represents demand spread across 24 hours rather than a 12-hour business window; the two are not directly comparable. Solar radiation data (Figure 7) were imported directly from NASA POWER for hour-by-hour simulation across the 25-year lifetime.

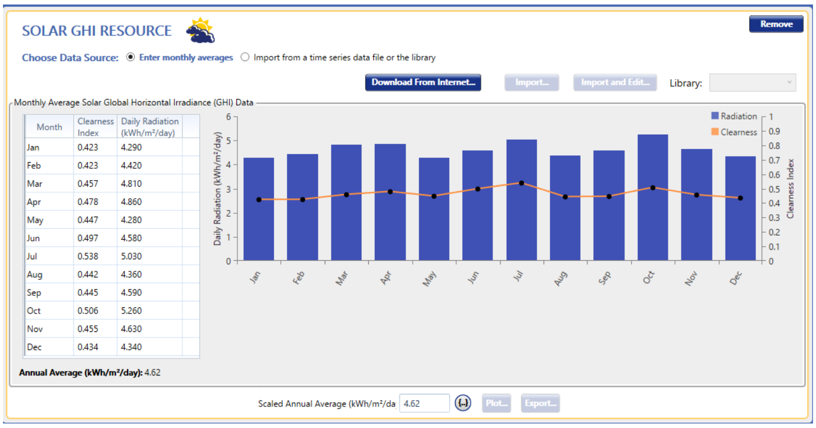

Figure 7. Solar Radiation Data Input in HOMER (NASA POWER Monthly Time Series)

HOMER evaluated 30 configurations, of which 22 were technically feasible within the 5% capacity shortage constraint. Table 7 lists the top five, ranked by NPC.

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Table 7. Top Five Optimal System Configurations from HOMER Simulation

Config.	PV (kW)	Battery (units)	Inverter (kW)	NPC (IDR)	COE (IDR/kWh)
1 (Optimal)	45.2	83	80	1,624,727,000	1,405
2	46.0	83	80	1,627,715,000	1,402
3	47.8	83	80	1,633,692,000	1,396
4	49.6	83	80	1,639,669,000	1,391
5	53.1	83	80	1,651,623,000	1,386

All five feasible configurations share identical battery (83 units) and inverter (80 kW) capacity, varying only in panel size. Configuration 1 (45.2 kW, NPC IDR 1,624,727,000) is the minimum-cost solution and is adopted as optimal.

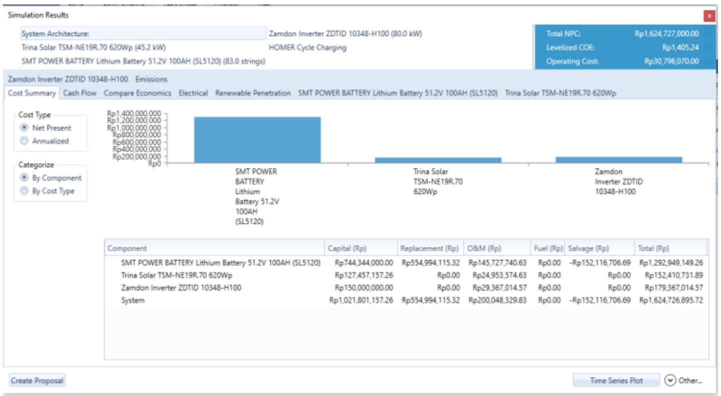

Figure 8. HOMER Optimal Configuration Cost Summary (System Architecture and NPC Breakdown)

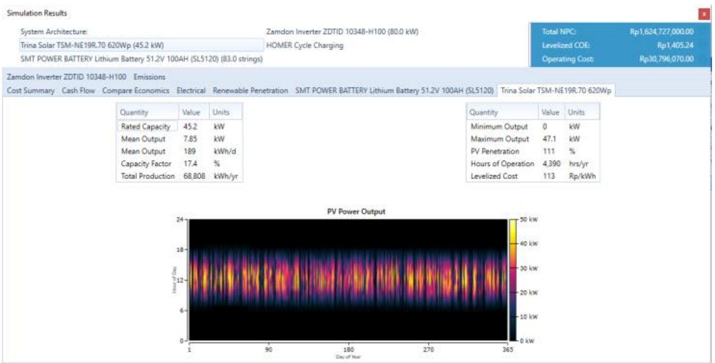

Figure 9. PV Array Production Profile from HOMER Simulation (Optimal Configuration)

The optimal HOMER configuration comprises 45.2 kW required PV capacity, 83 LiFePO4 battery units (340 kWh, 48.1-hour autonomy), and 80 kW inverter capacity. HOMER treats PV capacity as continuous; converted to discrete 620 Wp panels, 45.2/0.62 = 72.9, rounded up to 73 units (45.26 kWp installed). This is 14.7% above the manual calculation (39.407 kW required, 39.68 kW installed), because HOMER's dynamic simulation accounts for below-average months such as May (4.28 kWh/m²/day) to preserve supply reliability.

3.6. Comparative Technical Analysis

Table 8 compares both methods, distinguishing required (continuous) from installed (whole-unit) capacity.

Table 8. Comparison of Technical Analysis Results: Manual Calculation vs. HOMER Simulation

Parameter	Manual Calculation	HOMER Simulation
Solar panel capacity, required (continuous)	39.407 kWp	45.2 kWp
Solar panel capacity, installed (whole units)	39.68 kWp (64 units)	45.26 kWp (73 units)
Estimated daily PV output	183.32 kWh/day	189 kWh/day
Battery capacity	339.97 kWh (83 units)	340 kWh (83 units)
Autonomy time	48 hours	48.1 hours
Inverter capacity	65.31 kW → 80 kW	80 kW (8 x 10 kW)

Battery and inverter sizing converge almost exactly across methods (339.97 vs. 340 kWh; identical 80 kW), confirming that manual calculation reliably replicates HOMER's logic given identical inputs. The two methods diverge mainly in panel capacity (14.7%), because manual calculation uses a single annual average irradiance while HOMER simulates the full monthly time series, adding margin for low-irradiance months.

3.7. Economic Analysis

Table 9 presents the initial capital cost for the manual-calculation configuration.

Table 9. Initial Capital Cost, Manual Calculation Configuration

No.	Component	Qty	Unit Price (IDR)	Total (IDR)
1	Trina Solar TSM-NE19R.70 620Wp	64 unit	1,750,000	112,000,000
2	SMT Power SL5120 LiFePO4 Battery	83 unit	8,968,000	744,344,000
3	Zamdon ZDTID 10348-H100 Inverter 10kW	8 unit	18,750,000	150,000,000
4	Balance of System (BOS): mounting, cabling, protection, installation labor	10% of items 1-3	-	100,634,400
	Total Capital Cost (CC)			IDR 1,106,978,400

A Balance of System (BOS) allowance, covering mounting, cabling, protection devices, and installation labor, is included at 10% of hardware cost, the moderate end of ratios reported for medium-scale off-grid systems (well below the 30-50% typical of small residential rooftops, which lack installation economies of scale). With BOS, total capital cost rises from IDR 1,006,344,000 to IDR 1,106,978,400, and the LiFePO4 battery remains the dominant cost share at 67.2%.

Using a real discount rate of 1.98%/year, one battery replacement at year 15 (present value IDR 554,994,115), O&M present value IDR 196,935,220, and battery salvage value IDR 152,116,707 (BOS items carry no replacement or salvage value), the manual calculation yields NPC of IDR 1,706,791,028 and COE of IDR 1,429/kWh, using the measured 61,019 kWh/year as the energy denominator. The same 10% BOS allowance applied to HOMER's own itemized cost (Figure 8) raises its NPC from IDR 1,624,727,000 to IDR 1,726,907,000. Table 10 compares both methods.

Table 10. Comparison of Economic Analysis Results

Parameter	Manual Calculation	HOMER Simulation
Capital cost incl. BOS (IDR)	1,106,978,400	1,123,981,273
Net Present Cost / NPC (IDR)	1,706,791,028	1,726,907,000
Cost of Energy / COE (IDR/kWh)	1,429	1,494
Margin vs. PLN tariff (1,444.70)	+1.1% below	3.4% above

With BOS included, the two designs no longer both beat the PLN P1 tariff of IDR 1,444.70/kWh. The manual configuration remains cost-competitive (IDR 1,429/kWh, a narrow 1.1% margin), while the larger HOMER configuration, carrying proportionally more BOS cost, exceeds the tariff by 3.4% (IDR 1,494/kWh). This reversal is examined further in Sections 3.9-3.10.

3.8. Investment Feasibility Analysis

Annual net cash flow (NCF), the PLN cost avoided minus PLTS operating cost, is unaffected by BOS since BOS carries no operating cost. Annual electricity expenditure is IDR 102,862,427; manual-method NCF is IDR 92,798,987/year and HOMER-method NCF is IDR 72,066,357/year. With BOS-inclusive capital cost, these give the indicators in Table 11.

Table 11. Comparison of Investment Feasibility Results

Parameter	Manual Calculation	HOMER Software
Net Present Value / NPV (IDR)	709,039,675	286,312,213
Profitability Index (PI)	1.641	1.255
Discounted Payback Period (DPP)	13.742 years	18.838 years
Feasibility status	Feasible (NPV>0, PI>1)	Feasible (NPV>0, PI>1)

.

Figures 10 and 11 show the BOS-inclusive discounted cash flow curves used to determine DPP.

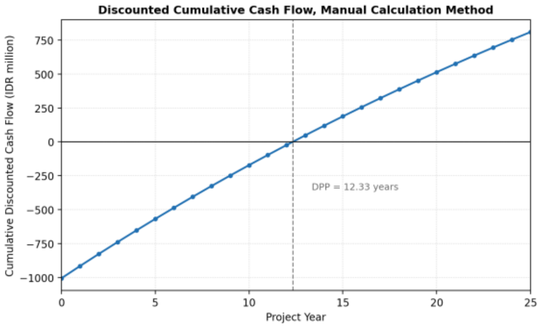

Figure 10. Discounted Cumulative Cash Flow, Manual Calculation Method

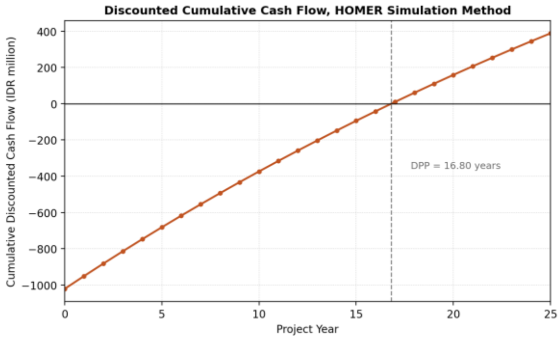

Figure 11. Discounted Cumulative Cash Flow, HOMER Simulation Method

Both methods remain feasible on NPV and PI, with capital fully recovered before year 25. BOS narrows the margin versus pre-BOS figures: manual NPV falls 12.4% (PI 1.805→1.641), while HOMER NPV falls 26.3% (PI 1.380→1.255, DPP extending to 18.838 years), a larger deterioration since BOS cost scales with panel capacity and HOMER carries 14.7% more capacity. This establishes the manual configuration as the more economically robust design once installation cost is included, discussed in Section 3.10.

3.9. Sensitivity Analysis

Four parameters were identified as the dominant sources of economic risk, consistent with the battery's large capital share: battery price, PLN tariff, solar irradiation, and battery service life. Each was varied individually from the BOS-inclusive manual-calculation base case, following the single-factor approach used in comparable HOMER Pro studies [22], [25]. Scenario 1 raises battery price 20%. Scenario 2 lowers the PLN tariff 10%. Scenario 3 lowers irradiation 10%, requiring 7 additional panels. Scenario 4 shortens battery life from 15 to 10 years, requiring two replacements instead of one; per Eqs. (8)-(10), this affects NPC and COE only, not NPV, PI, or DPP. Table 12 summarizes the results.

Table 12. Sensitivity Analysis Results (BOS-Inclusive Manual Calculation Base Case)

Scenario	NPC (IDR)	COE (IDR/kWh)	NPV (IDR)	PI	DPP (yr)
Base case (+BOS)	1,706,791,028	1,429	709,039,675	1.641	13.74
S1: Battery +20%	1,936,235,310	1,622	560,170,875	1.446	15.91
S2: Tariff −10%	1,706,791,028	1,429	507,744,345	1.459	15.75
S3: Irradiation −10%	1,719,041,028	1,440	696,789,675	1.623	13.92
S4: Battery life 10yr	2,190,658,995	1,835	709,039,675*	1.641*	13.74*

**NPV, PI, and DPP are unaffected by replacement timing in this model; only NPC and COE reflect Scenario 4.*

Battery price and service life are the most critical risk parameters: under Scenario 1, COE reaches IDR 1,622/kWh, and under Scenario 4, IDR 1,835/kWh, both far above the PLN tariff. Scenario 3 leaves only a 0.3% margin below tariff, showing the design is now sensitive to moderate irradiation error once BOS is included. Scenario 2 leaves COE unchanged but cuts NPV by 28.4% and extends DPP to 15.75 years, remaining feasible with thinner headroom. Overall, the BOS-inclusive base case has converted this project from comfortably feasible to conditionally feasible, contingent on battery procurement price, verified service life, and reasonably accurate irradiation estimation, consistent with sensitivity studies on comparable systems [22], [25], [26].

3.10. Discussion

Both analytical methods converge closely on battery and inverter sizing (339.97 vs. 340 kWh; 80 kW vs. 80 kW), diverging mainly in panel capacity (39.68 kW manual vs. 45.26 kW HOMER, installed), a gap justified by HOMER's simulation of the worst-month irradiance in May. Once a realistic 10% BOS allowance is added (Table 7), this technical divergence has a direct financial consequence: the smaller manual design yields COE of IDR 1,429/kWh, 1.1% below the PLN tariff, while the larger HOMER design yields IDR 1,494/kWh, 3.4% above it. Both remain NPV-positive and PI above 1.0, so neither is unambiguously infeasible, but only the manual configuration remains cheaper than grid electricity. This is the central refinement of this study: HOMER's larger, more reliable design is economically dominated by the smaller manual design once installation cost scales with capacity. This study therefore recommends the manual configuration, 39.68 kW panel capacity, 83 battery units, and 80 kW inverter capacity, as the economically preferred choice, while noting that a facility manager prioritizing reliability over the marginal COE gap may reasonably choose the

HOMER configuration as a deliberate trade-off. These findings extend prior work. Pre-BOS COE values were comparable to Bagaskoro et al. [17] and Arifin et al. [19], but neither study itemized BOS cost separately, so the sensitivity of their conclusions to this omission is unknown, a gap this study addresses directly. This study's main contribution over prior work remains the use of five-day directly measured load data, in contrast to Wahyu et al. [14], Fauzsan et al. [16], and Kossi [15], and in contrast to the more recent HOMER-plus-sensitivity studies of Kumar et al. [22] and Hasan et al. [25], which also relied on estimated demand. Combined with explicit BOS treatment and formal sensitivity analysis, this study offers a more conservative, decision-ready feasibility assessment, and demonstrates that omitting BOS cost, a common simplification in the literature, can be enough to reverse the cost-competitiveness conclusion for the larger of two otherwise-feasible designs.

4. CONCLUSION

This research concludes that a micro-scale off-grid Solar Power Plant at the Operational Building of BTP Kelas II Padang is technically feasible and, under the manual-calculation configuration, economically viable once realistic BOS and installation costs are included. Both methods produced consistent designs, with battery (83 units, 340 kWh) and inverter (80 kW) sizing converging closely and panel capacity diverging by 14.7% (39.68 kW manual vs. 45.26 kW HOMER, installed). With BOS included, the manual configuration yields COE of IDR 1,429/kWh, below the PLN tariff of IDR 1,444.70/kWh, while the larger HOMER configuration yields IDR 1,494/kWh, above it, reversing the hardware-only comparison. Both remain NPV-positive and PI above 1.0 within 25 years, so this study recommends the manual configuration as the economically preferred choice, with the HOMER configuration retained as a reliability-focused alternative at a modest premium. Sensitivity analysis shows this conclusion is conditional on battery price and service life remaining within design assumptions, and, to a lesser extent, on accurate irradiation estimation; a 20% battery price increase, a 10-year service life, or a 10% irradiation shortfall would each erode or eliminate the cost advantage over PLN. Battery procurement terms and installation cost estimation should therefore be treated as primary due-diligence items before project commitment, with a full bill-of-quantities BOS estimate recommended at the detailed-design stage.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

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BIOGRAPHIES OF AUTHORS

Sepannur Bandri received his degree in Electrical Engineering and is currently a lecturer and researcher at the Department of Electrical Engineering, Faculty of Engineering, Institut Teknologi Padang (ITP), Indonesia. His research interests include renewable energy systems, techno-economic analysis of power generation, and off-grid photovoltaic system design. He serves as the corresponding author of this study and can be contacted at email: sepannur@itp.ac.id.

Zuriman Anthony is a lecturer at the Department of Electrical Engineering, Faculty of Engineering, Institut Teknologi Padang (ITP), Indonesia. His research interests include electrical power systems, renewable energy integration, and energy conversion technology. He can be contacted at email: zuriman@itp.ac.id.

Fauzan Ismail is affiliated with the Department of Electrical Engineering, Faculty of Engineering, Institut Teknologi Padang (ITP), Indonesia. His research interests include power system analysis, instrumentation, and renewable energy applications. He can be contacted at email: fauzan.ismail@itp.ac.id.

Taufal Hidayat is a member of the Department of Electrical Engineering, Faculty of Engineering, Institut Teknologi Padang (ITP), Indonesia. His research interests include electrical measurement, power distribution systems, and renewable energy technology. He can be contacted at email: taufal.hidayat@itp.ac.id.

Sitti Amalia is affiliated with the Department of Electrical Engineering, Faculty of Engineering, Institut Teknologi Padang (ITP), Indonesia. Her research interests include renewable energy systems, energy efficiency, and electrical power system planning. She can be contacted at email: sitti.amalia@itp.ac.id.

Dwi Harinitha is a lecturer at the Department of Electrical Engineering, Faculty of Engineering, Institut Teknologi Padang (ITP), Indonesia. Her research interests include power system engineering, renewable energy technology, and techno-economic evaluation of energy projects. She can be contacted at email: dwi.harinitha@itp.ac.id.

Alfith is a lecturer at the Department of Electrical Engineering, Faculty of Engineering, Institut Teknologi Padang (ITP), Indonesia. and he is currently pursuing his doctoral program at Universiti Teknikal Malaysia Melaka. His research interests include power system analysis, instrumentation, and renewable energy applications. He has contributed to applied research on electrical load measurement and system data acquisition for institutional facilities. He can be contacted at email: alfit.st.tumangguang@gmail.com

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