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Techno-Economic Comparison of Vehicle-to-Building Lithium-Ion Battery and Diesel Generator Systems for Smart Building Backup Power Using HOMER Pro

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Abstract: The transition toward a low-carbon energy system is driving the development of smart buildings that require reliable, environmentally friendly backup power systems. Diesel generators remain the dominant option despite their fossil-fuel consumption and emissions, while Vehicle-to-Building (V2B)-based Lithium-ion battery systems offer a promising but underexplored alternative, particularly in Indonesian smart buildings. This study evaluates the techno-economic feasibility of a V2B-based Lithium-ion battery system as an alternative backup power source, using HOMER Pro to model a representative five-story office building (977 m²). Two configurations were compared: Grid + Diesel Generator and Grid + V2B-based Lithium-ion Battery, assessed technically, economically (Net Present Cost, Cost of Energy, Operating Cost), and environmentally. Results show the V2B system can supply backup power for 4.10 hours and eliminate diesel fuel consumption by 100%, but produces 61.2% higher NPC, 65.7% higher COE, and 36.8% higher operating cost, with only a 0.18% reduction in CO2 emissions. Although not yet the most economical alternative, the V2B system significantly enhances building energy resilience and represents a promising pathway toward cleaner backup power as battery costs decline and electric vehicle adoption increases.

Keywords: Vehicle-to-Building (V2B), Lithium-ion Battery, Smart Building, HOMER Pro, Techno-Economic Analysis

INTRODUCTION

The transition toward clean energy sources is a global strategic agenda in efforts to mitigate climate change and achieve Net Zero Emission targets. In Indonesia, the building sector is a significant electricity consumer, and commercial buildings in particular represent a substantial opportunity for deploying energy storage technologies that improve efficiency and system resilience (IEA, 2024). The transformation toward Smart Buildings has therefore become necessary to improve energy efficiency, system reliability, and the adoption of clean energy technologies, and the Indonesian Ministry of Public Works and Housing has issued Regulation No. 10 of 2023 concerning Smart Buildings as a guideline for developing integrated and sustainable smart buildings (Ministry of Public Works and Housing, 2023).

The requirements of smart buildings extend beyond energy efficiency to include reliable and resilient electrical supply systems, in line with the broader smart-grid principle of coordinating distributed resources to enhance demand-side efficiency and response (Gellings, 2017). Diesel Generator Sets (gensets) remain the most common backup power system used during grid disturbances, despite their limitations, including high carbon emissions, dependence on fossil fuel, and relatively high operating and maintenance costs. These characteristics are less compatible with the rapid response and continuous power supply required by smart buildings, which has encouraged the development of more efficient, lower-emission backup power alternatives.

One promising alternative technology is the Lithium-ion battery, which offers high energy density, good efficiency, and a long cycle life, and whose performance has continued to improve through advances in cell chemistry and pack design (Raza et al., 2021; Luo et al., 2022). The growing adoption of electric vehicles (EVs) has opened opportunities for repurposing vehicle batteries as distributed storage assets (Bobba et al., 2022) through the Vehicle-to-Building (V2B) concept, in which an EV battery supplies electricity to a building during grid disturbances (Noel et al., 2022). The central innovation motivating this concept is that private vehicles, including EVs, are typically parked and idle for around 90-95% of their operating life, with reported estimates of vehicle-operation time spent stationary in parking areas ranging around 90% (Chen et al., 2020); for the greater part of each day, an EV's substantial onboard battery capacity therefore sits unused. V2B proposes to draw on precisely this idle capacity as a backup energy resource, rather than requiring a dedicated stationary battery purchased and left equally idle for the same purpose. Realising this concept in practice, however, requires carefully designed bidirectional charging strategies to protect battery health and ensure safe, controlled power exchange (Habib et al., 2021). Beyond technical considerations, implementing a V2B-based Lithium-ion battery system also requires economic evaluation, since the initial investment in batteries, bidirectional charging infrastructure, and power conversion equipment remains relatively high, making a comprehensive techno-economic assessment necessary (Alotaibi et al., 2023).

Most existing studies on the use of EV Lithium-ion batteries as backup power systems have examined technical or economic aspects separately, and technical studies in particular have tended to focus on battery-management-system design and degradation behaviour rather than building-level techno-economic outcomes (Hu et al., 2023). Existing studies mainly focus on battery degradation, charging strategy, or energy management. However, limited studies evaluate V2B as a dedicated emergency backup system under Indonesian commercial-building operating conditions using an integrated techno-economic framework. Studies that directly compare a Grid + Diesel Generator configuration with a Grid + V2B-based Lithium-ion Battery configuration through an integrated techno-economic analysis remain limited, particularly in the context of Indonesian smart buildings (Hossain et al., 2022). The novelty of this study lies in developing a techno-economic analysis framework that integrates the Vehicle-to-Building concept, Lithium-ion batteries, and HOMER Pro modelling to compare both configurations comprehensively from technical, economic, and environmental perspectives.

To address this research gap, this study aims to: (1) to develop a model of a Vehicle-to-Building-based Lithium-ion battery system for smart building infrastructure using HOMER Pro; (2) to obtain the technical characteristics of the system based on simulation results of energy operation under backup power scenarios; and (3) to formulate a techno-economic evaluation of the system based on technical, economic, and environmental aspects compared with a conventional diesel generator system.

The contribution of this work is threefold: (1) it provides the first techno-economic evaluation of a V2B backup power system for Indonesian office buildings; (2) it presents an integrated technical, economic, and environmental assessment within a single HOMER Pro-based framework; and (3) it establishes a framework that can inform future smart building deployments using electric vehicle batteries.

METHOD

The overall research framework, from problem identification through to the formulation of conclusions and recommendations, is summarised in Figure 1.

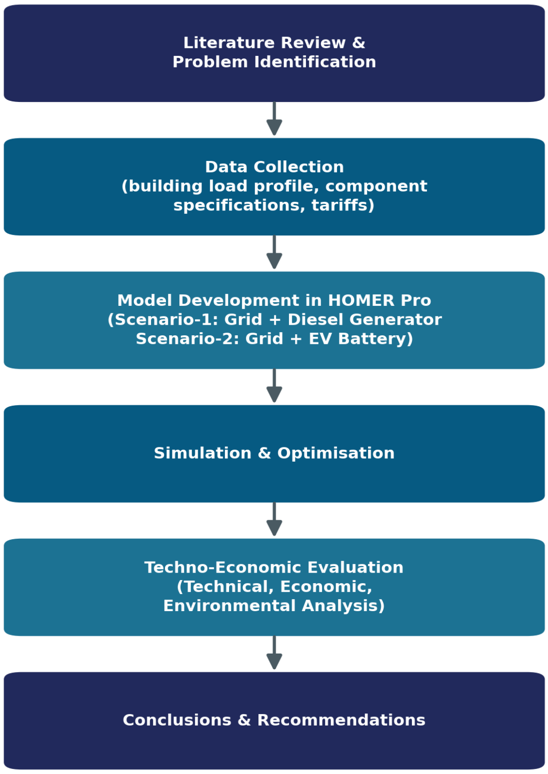

Figure 1. Research Framework Diagram

This study applies a quantitative method with a comparative approach combined with modelling and simulation, an approach well suited to producing reproducible, empirically grounded findings for engineering research (Creswell, 2018; Sugiyono, 2023). The research object is the electricity supply system of a five-story office building with a floor area of 977 m², located in Karawaci, Tangerang Regency, Banten Province, operating from 08:00 to 17:00 WIB on Mondays through Fridays. The building's total connected load is 95.33 kW, comprising lighting, air conditioning, IT and office equipment, servers and networks, security, elevators, utilities, and smart building systems; the load composition and operating schedule follow the general characterisation of commercial-building energy use described in ASHRAE Standard 90.1 (ASHRAE, 2019).

The techno-economic analysis, understood as an evaluation method that integrates technical and economic dimensions to determine the feasibility of an energy technology (IRENA, 2023), was carried out using HOMER Pro (Hybrid Optimization of Multiple Energy Resources Professional) software (HOMER Energy LLC, 2024) to model and compare two backup power scenarios: Scenario-1 (Grid + Diesel Generator) and Scenario-2 (Grid + EV Lithium-ion Battery based on Vehicle-to-Building). The input variables include the daily and annual electrical load profile, the grid electricity tariff, the capacity and cost of the diesel generator, the capacity and State of Charge (SOC) of the EV battery, the capacity and efficiency of the bidirectional converter, and economic parameters such as discount rate, project lifetime, and inflation rate.

The research stages consisted of a literature review, data collection on the building's characteristics and system components, model development in HOMER Pro, simulation of both scenarios, and comparative analysis of the results. Technical evaluation covered energy production and flow, battery autonomy, State of Charge, and system reliability, while economic evaluation used Initial Capital Cost, Operating Cost, Net Present Cost (NPC), and Cost of Energy (COE) indicators. Environmental evaluation was based on diesel fuel consumption and the CO2, SO2, and NOx emissions produced during system operation, without considering the life-cycle assessment of the battery or the manufacturing process of the electric vehicle.

RESULTS AND DISCUSSION

Justification of Key Design Choices

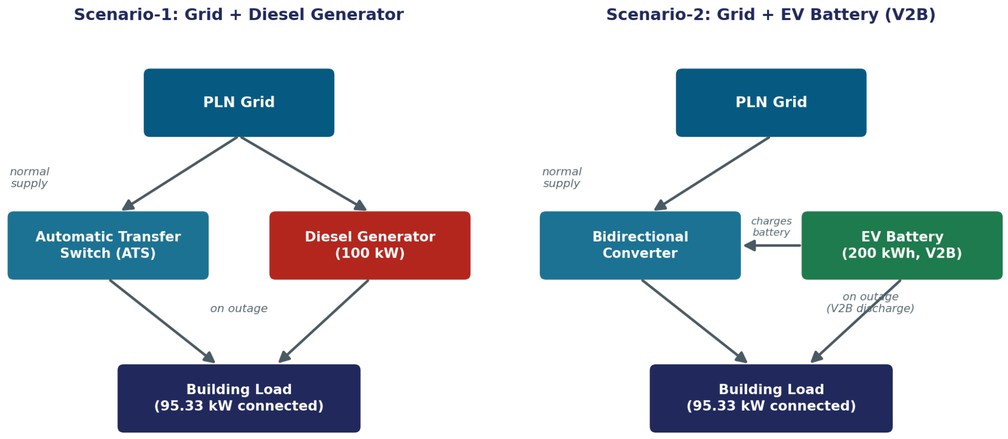

Figure 2. System Architecture of Scenario-1 (Grid + Diesel Generator) and Scenario-2 (Grid + EV Battery, V2B)

The scope of this study is deliberately limited to a direct comparison between the incumbent backup solution (diesel generator) and a V2B-based Lithium-ion battery, rather than a full hybrid renewable energy system. A PV + Battery + Grid configuration, while common in smart building design, primarily addresses continuous daytime energy supply and peak-shaving objectives; it introduces additional sizing and dispatch variables (panel area, tilt, irradiance-dependent output) that fall outside the specific research question addressed here, namely which backup power source performs better during grid outages. PV integration is therefore treated as a natural extension of this work rather than part of its present scope, and is noted accordingly in the study's recommendations for future research.

The choice of an EV battery rather than a dedicated stationary Battery Energy Storage System (BESS) is central to the V2B concept itself: V2B repurposes a battery asset that a building or its occupants would already own for transportation purposes, rather than requiring a new, dedicated capital investment in stationary storage (Noel et al., 2022; Bobba et al., 2022). Because such vehicles are typically parked and idle for the great majority of each day (Chen et al., 2020), the battery capacity that V2B draws upon during an outage is capacity that would otherwise be sitting completely unused; the innovation of this configuration lies specifically in monetising that idle time rather than in the battery technology itself, which is identical to that found in a conventional stationary BESS. This dual-use characteristic is precisely what distinguishes V2B from a conventional BESS-based backup system, and its economic implications - including the absence of a separate battery purchase cost within the building's own capital budget - are part of what this study set out to evaluate.

The 200 kWh nominal battery capacity (170 kWh usable) was selected as a realistic representative capacity for a commercially available electric vehicle or small EV fleet, sized to comfortably exceed the assumed grid-disturbance duration used in this study rather than through a formal capacity-optimisation routine. A systematic sensitivity sweep across alternative capacities (for example, 150, 300, and 500 kWh) was not performed in the present simulation and is identified as a limitation; such a sweep would show how the technical margin (autonomy) and the economic gap (NPC, COE) trade off against one another as capacity increases, and is recommended as a direct extension of this work.

The average grid-disturbance duration of 2 hours used to size the required backup autonomy was adopted as a conservative planning assumption consistent with published Indonesian grid-reliability studies, which report System Average Interruption Duration Index (SAIDI) values corresponding to individual outage events in Indonesian urban and commercial areas typically in the range of roughly one to a few hours per event (Kunaifi and Reinders, 2018). The diesel generator in Scenario-1 is dispatched only during these outage events rather than operating continuously; the reported annual fuel consumption of 473 litres therefore reflects the cumulative duration of intermittent outages across a full year of operation, not continuous generator use, which is why the figure is modest relative to the generator's rated capacity.

Load Profile and Building Characteristics

Load inventory results show a total connected load of 95.33 kW, with the largest contributions coming from the air conditioning system (36.90 kW) and IT/office equipment (19.00 kW). The daily load profile shows an increase in energy consumption starting at 08:00 as office activities begin, reaching a peak load of 75 kW at 14:00, before gradually decreasing to a base load of around 16 kW at night due to server operation, the security system, and essential utilities. This load profile served as the basis for developing the simulation model in HOMER Pro for both backup power scenarios.

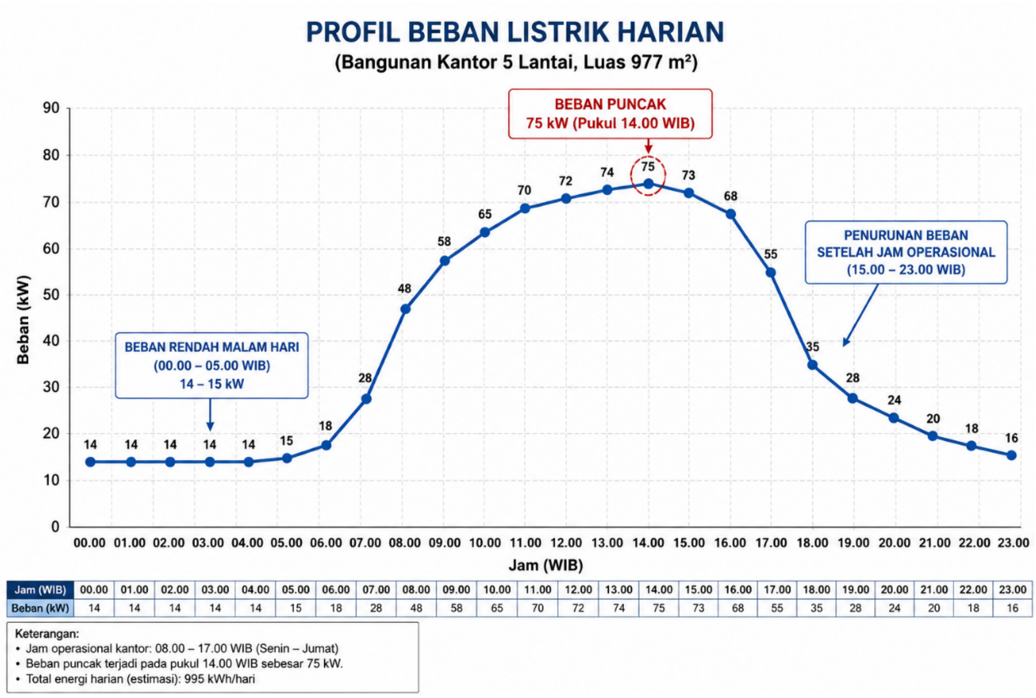

Figure 3. Daily Electrical Load Profile of the Office Building (processed by the researcher, 2026)

Technical Performance of Scenario-1 and Scenario-2

Simulation of Scenario-1 (Grid + 100 kW Diesel Generator) shows a total annual diesel fuel consumption of 473 litres, with an intermittent operating pattern since the generator only operates as a backup during grid disturbances. In Scenario-2, the EV Lithium-ion battery system, with a nominal capacity of 200 kWh and a usable capacity of 170 kWh, is able to supply backup power for 4.10 hours, exceeding the assumed average grid-disturbance duration of 2 hours, and is therefore technically capable of maintaining the building's operational continuity.

Table 1. Comparison of Technical Performance between Scenario-1 and Scenario-2

Parameter	Scenario-1 (Grid + Genset)	Scenario-2 (Grid + EV Battery)
Fuel Consumption	473 L/year	0 L/year
Autonomy	Depends on fuel	4.10 hours
Response Time	A few seconds	Instant
Reliability	High	High
Local Emissions	Present	None

Source: HOMER Pro simulation results, processed by the researcher (2026).

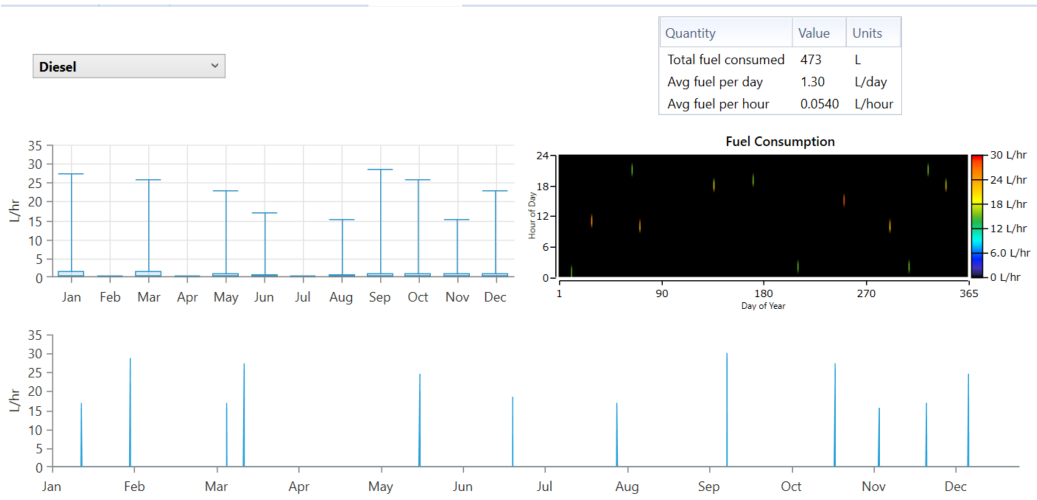

Figure 4. Diesel Generator Fuel Summary from HOMER Pro Simulation (processed by the researcher, 2026)

In addition to providing an adequate backup duration, the battery system offers the advantage of an instantaneous response without requiring the start-up process needed by a diesel generator. This characteristic is important for smart buildings with critical loads such as servers, building control systems, and sensitive electronic equipment that cannot tolerate any interruption in power supply. Achieving this level of reliability in practice, however, depends on a battery management system capable of maintaining safe State-of-Charge boundaries and coordinating charge–discharge cycles under repeated backup events, a task that becomes more complex as the number of charge–discharge cycles accumulates over the system's operating life (Hu et al., 2023).

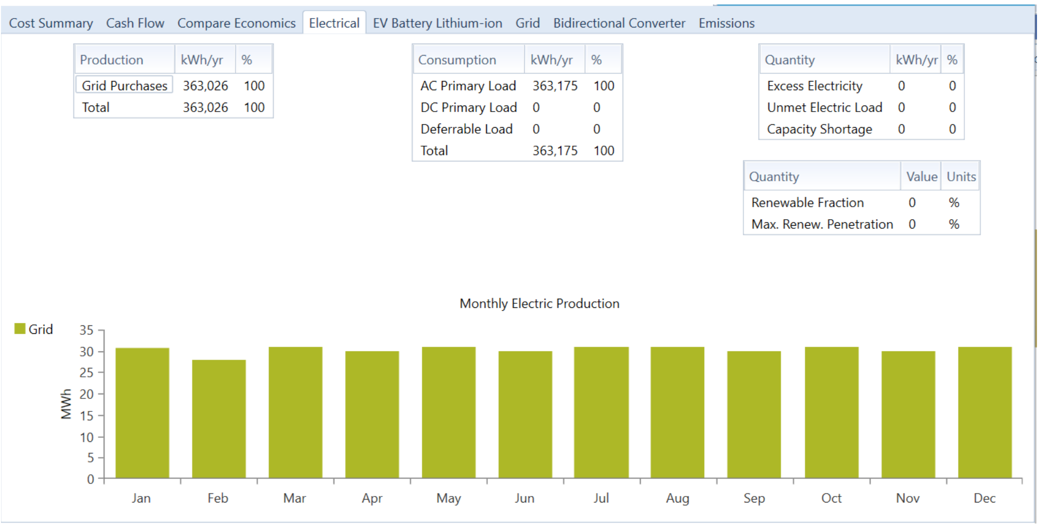

Figure 5. Annual Energy Production of the Grid + EV Battery (V2B) System from HOMER Pro Simulation (processed by the researcher, 2026)

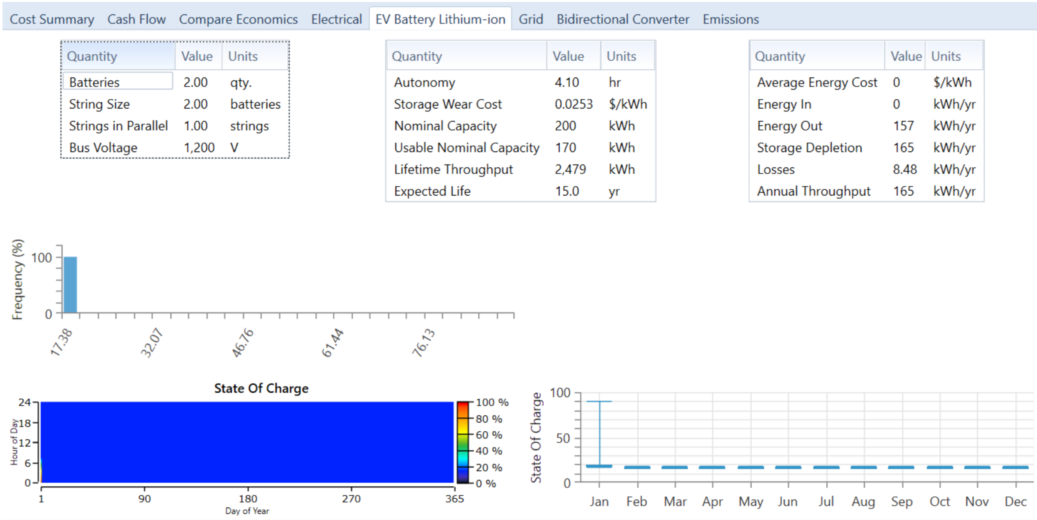

Figure 6. EV Battery State of Charge (SOC) Profile from HOMER Pro Simulation (processed by the researcher, 2026)

Economic Performance

Economic evaluation using Net Present Cost (NPC), Cost of Energy (COE), and Operating Cost indicators shows that Scenario-1 has better financial performance than Scenario-2. The NPC of Scenario-2, at USD 762,537, is 61.2% higher than that of Scenario-1, at USD 472,990. The COE increases from USD 0.091/kWh to USD 0.151/kWh (65.7% higher), while the Operating Cost increases from USD 31,642/year to USD 43,279/year (36.8% higher).

Table 2. Comparison of Economic Indicators between Scenario-1 and Scenario-2

Parameter	Scenario-1	Scenario-2	Difference
NPC	USD 472,990	USD 762,537	+61.2%
COE	USD 0.091/kWh	USD 0.151/kWh	+65.7%
Operating Cost	USD 31,642/year	USD 43,279/year	+36.8%

Source: HOMER Pro simulation results, processed by the researcher (2026).

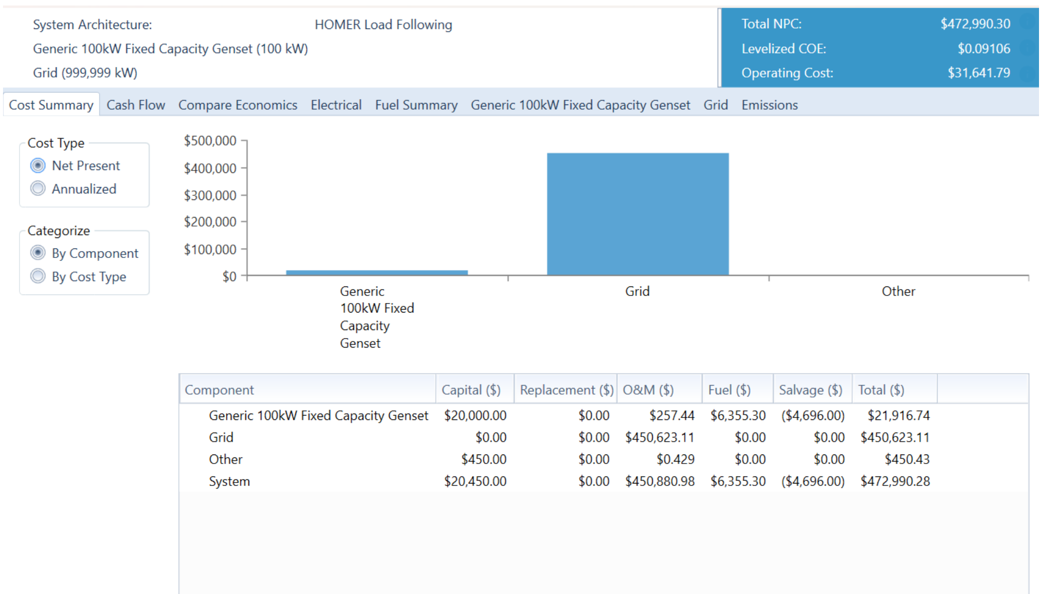

Figure 7. Cost Summary of Scenario-1 (Grid + Diesel Generator) from HOMER Pro Simulation (processed by the researcher, 2026)

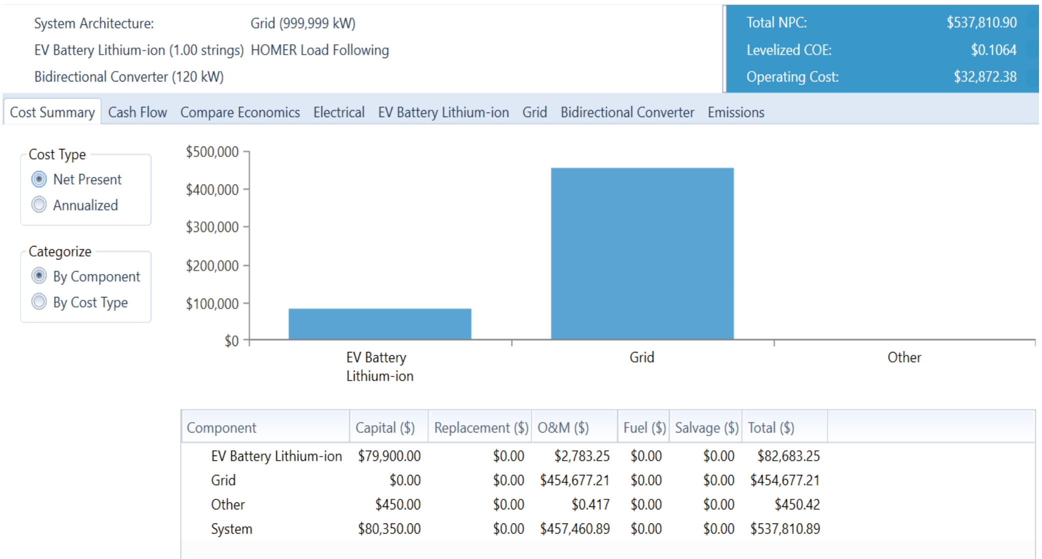

Figure 8. Cost Summary of Scenario-2 (Grid + EV Battery) from HOMER Pro Simulation (processed by the researcher, 2026)

This cost difference is mainly caused by the high initial investment cost of the Lithium-ion battery and bidirectional converter, resulting in a negative Return on Investment (ROI) for Scenario-2, with the Payback Period not achieved within the analysed project lifetime. This pattern echoes Alotaibi et al. (2023), who similarly found that V2B-based systems only become cost-competitive with conventional backup systems under specific conditions, such as higher electricity tariffs, higher diesel prices, or supporting policy incentives, rather than under general operating conditions. Rather than indicating that V2B is economically unworkable, this result is itself a useful finding: it identifies the specific cost gap (approximately USD 290,000 in NPC over the project lifetime) that battery-price reductions, incentive schemes, or additional value streams would need to close for the configuration to become competitive.

The cost gap is also likely to be conservative, since the analysis does not account for capacity fade from repeated backup cycling, which reduces a battery's usable capacity and effective lifetime and would, if included, further raise the levelised cost of the V2B configuration in this specific case (Zhao et al., 2022). Nevertheless, sensitivity analysis indicates that changes in fossil fuel prices, increases in genset operating costs, and future decreases in battery prices could improve the economic competitiveness of the V2B system (Vykhodtsev et al., 2021).

Environmental Impact

From an environmental perspective, CO2 emissions in Scenario-1 amount to 230,120 kg/year, compared with 229,700 kg/year in Scenario-2, a reduction of about 0.18%. This reduction is small because the diesel generator and the EV battery are both backup assets: across a full year, the overwhelming majority of the building's electricity is supplied by the PLN grid in both scenarios, and only the relatively brief accumulated outage hours are served by either the generator or the battery. Since grid supply, with an emission factor of 632 gCO2/kWh, dominates the annual energy balance in both configurations, replacing the small diesel contribution with a battery can only shift a correspondingly small share of total annual emissions - even though diesel generation is completely eliminated during outages themselves.

This result should also be interpreted with an important caveat regarding potential bias in the comparison. The emissions accounting in this study covers only operational, tailpipe-equivalent emissions - diesel combustion during genset operation versus grid electricity drawn to recharge the EV battery - and does not include the embodied or upstream emissions associated with manufacturing the Lithium-ion battery, which are known in the literature to be substantial (Olabi et al., 2021). Because the diesel generator's manufacturing footprint is a comparatively mature and smaller factor relative to its lifetime fuel combustion, while a large fraction of a battery's lifecycle emissions occur upstream, at the point of manufacture, an operational-only comparison of this kind is likely to be more favourable toward the battery system than a full life-cycle assessment would be. The 0.18% figure should therefore be read as a conservative, narrowly scoped operational result rather than a comprehensive environmental verdict in either system's favour; a full life-cycle assessment is identified as necessary future work before strong environmental claims can be made. SO2 and NOx emissions also decreased, although not significantly, for the same grid-dominance reasons. Beyond these numerical indicators, eliminating the diesel generator in Scenario-2 also removes local emissions and operational noise around the building, making it more consistent with the principles of smart and sustainable buildings (Olabi et al., 2021).

Sensitivity Considerations

A formal, quantified sensitivity analysis - systematically varying diesel fuel price, battery capital cost, discount rate, and battery capacity, and re-running the HOMER Pro simulation for each case - was not performed in the present study and is acknowledged as a limitation. Qualitatively, the direction of key sensitivities can nonetheless be reasoned from the underlying cost structure: because Scenario-2's cost disadvantage stems primarily from the upfront capital cost of the battery and bidirectional converter rather than from ongoing operating costs, the NPC and COE gap identified in this study would be expected to narrow under any combination of (a) rising diesel fuel prices or genset maintenance costs, (b) continued declines in Lithium-ion battery prices, which have historically fallen at a rapid rate, or (c) supporting policy incentives such as feed-in tariffs or carbon pricing that assign value to the battery's emissions reduction. Quantifying these effects precisely, and identifying the specific price thresholds at which Scenario-2 becomes cost-competitive, is recommended as a priority direction for follow-up work using the same HOMER Pro model developed here.

Comparative Synthesis

Overall, the V2B system outperforms the diesel generator system in terms of reliability, response time, elimination of fossil fuel consumption, and integration with Smart Building, IoT, and Building Energy Management System (BEMS) concepts, but still lags behind in economic performance (NPC, COE, Operating Cost, ROI, and Payback Period). Weighing these two sets of findings together, the current cost gap positions V2B less as a direct economic substitute for diesel generators today and more as an emerging option whose value proposition strengthens as battery prices fall and grid disturbances become more frequent or prolonged, consistent with the findings of Zhang et al. (2024) regarding the role of V2B in smart building energy management and with Wang et al. (2024) on the value of coupling battery storage with IoT-based building energy management platforms. Beyond its role as backup power, the same battery asset could plausibly be used for peak-shaving during normal grid operation (Tan et al., 2023), which would generate additional operational savings not captured in the present backup-only evaluation and represents a natural extension of this study.

The specific novelty of this synthesis, relative to prior V2B literature that has generally treated technical performance, economic feasibility, and environmental impact as separate lines of enquiry (Hu et al., 2023; Hossain et al., 2022), lies in showing how these three dimensions interact for a single, concrete case: the same battery asset that delivers a clear technical and environmental advantage simultaneously carries an economic penalty, and the size of that penalty (approximately USD 290,000 in NPC) can be read directly against the qualitative sensitivities discussed above to identify what would need to change for the case to reverse.

This integrated framework, rather than any single result in isolation, is what this study contributes to the Indonesian smart-building literature.

Limitations of the Study

This study has several limitations that should be considered when interpreting its findings. First, the model represents a single case-study building with a specific load profile and location, so the quantitative results are not directly generalisable to buildings with different load characteristics, grid tariffs, or diesel fuel prices. Second, the economic and technical analysis does not account for battery capacity fade over repeated cycling (Zhao et al., 2022) or for more advanced operating strategies such as peak shaving and demand response (Tan et al., 2023), both of which could alter the long-term cost and performance figures reported here. Third, the environmental evaluation is limited to operational emissions and excludes a full life-cycle assessment of battery manufacturing and end-of-life impacts, as noted above. Fourth, a formal sensitivity analysis and a systematic battery-capacity sweep were not performed; both are identified above as priority directions for follow-up work.

Suggestions (Future Research)

Building on the limitations identified above, future research is recommended to: (1) integrate renewable energy sources such as solar PV to form a more efficient PV + Battery + Grid hybrid configuration; (2) incorporate battery capacity fade, a systematic capacity sensitivity sweep (for example, 150, 300, and 500 kWh), and Time-of-Use electricity tariffs into the economic analysis; (3) conduct a full life-cycle environmental assessment covering battery manufacturing and end-of-life impacts rather than operational emissions alone; and (4) further extend V2B integration with Building Energy Management Systems, IoT, and smart meters, including peak-shaving use cases beyond backup power, to improve the efficiency and reliability of smart building energy management.

CONCLUSION

This study evaluated the techno-economic feasibility of a Vehicle-to-Building (V2B)-based Lithium-ion battery system as an alternative backup power source for smart buildings using HOMER Pro, with a conventional diesel generator serving as the benchmark. The simulation results show that the V2B system can supply backup power for 4.10 hours with a reliability level equivalent to the diesel generator, while completely eliminating diesel fuel consumption and providing an instantaneous power response. However, under current economic conditions, the V2B system does not yet perform better than the diesel generator, as indicated by a 61.2% increase in NPC, a 65.7% increase in COE, and a 36.8% increase in Operating Cost, so that investment feasibility indicators such as Payback Period, ROI, and IRR do not yet show a viable return over the project lifetime. From an environmental perspective, the V2B system eliminates fossil fuel use in the backup power system, although the reduction in total CO_2 emissions remains limited to about 0.18% due to the continued dominance of grid electricity supply. Detailed suggestions for future research are provided in the Suggestions subsection above.

Author Contributions

L.I.B.M.: conceptualisation, methodology, HOMER Pro modelling and simulation, formal analysis, data curation, writing - original draft, visualisation. L.S.W.: supervision, conceptualisation, validation, writing - review and editing. O.A.R.: supervision, validation, writing - review and editing, resources. All authors have read and agreed to the published version of the manuscript.

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