DEVELOPMENT AND EMERGENCY APPLICATION ASSESSMENT OF A TRANSPORTABLE BATTERY ENERGY STORAGE SYSTEM WITH FIRST- AND SECOND-LIFE LITHIUM-ION BATTERIES

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Abstract

This paper presents a modular Transportable Battery Energy Storage System (TBESS) designed to support essential infrastructure during climate-induced disasters that frequently occur in southern Brazil. The system integrates first- and second-life lithium-ion batteries coordinated by an intelligent Energy Management System (EMS).Technical feasibility and environmental performance were evaluated through simulations using real demand profiles from emergency facilities in Brazil. The TBESS provided up to nine hours of energy autonomy without diesel backup, with its performance validated through real demand-based simulations. When extended operation with diesel generation is required, greenhouse gas emissions remain significantly lower than in diesel-only configurations. The battery system alone can supply 44% of the demand for 24 hours, and still provide 15% after 72 hours. This solution addresses immediate disaster-response needs while contributing to Brazil's broader energy transition. The proposed TBESS enhances both the resilience and sustainability of emergency energy supply systems.

Keywords: Transportable Battery Energy Storage System, Li-ion Battery, Second-Life Battery.

1. Introduction

Across the globe, climate change has intensified the frequency and severity of environmental disasters, which are generally driven by greenhouse gas emissions. Over the past few years, this reality has become increasingly evident in southern Brazil, as the region experiences more frequent and severe flood events (Laipelt et al. 2025). The unplanned urban expansion into vulnerable areas has aggravated these disasters, which have often severely disrupted critical infrastructure. Hospitals, emergency shelters, and water treatment facilities have struggled to remain operational under extreme conditions, while entire communities have been left isolated without electricity. The floods that took place in Rio Grande do Sul in April and May 2024 (Figure 1) are a clear illustration of this: more than 180 lives were lost, hundreds of thousands were displaced, and over 2.3 million individuals were impacted. These incidents demonstrated the conventional energy grid's vulnerability to disasters (Pillar e Overbeck 2024).

Figure 1 - Floods in Rio Grande do Sul (2024)

10.18086/swc.2025.07.05 Available at http://proceedings.ises.org

In response to escalating climate volatility, there is a growing need for modular, low-carbon energy solutions that can be rapidly deployed to support essential services. This paper introduces a semi-trailer-integrated Transportable Battery Energy Storage System (TBESS), presented in Figure 2, that was specifically engineered to address these requirements. The proposed system can be quickly transported to flood-affected areas to provide clean and stable electricity for critical facilities. The implementation of TBESS units is consistent with Brazil's increasing dedication to sustainable energy innovation and with global initiatives that result in climate-resilient energy systems (Zhang et al. 2024). According to projections, the national energy storage market could reach US$ 4 billion by 2030. Consequently, these solutions address immediate disaster-response needs and contribute to long-term energy transition goals. This project highlights how technological innovation can address the dual requirements of environmental responsibility and social resilience in the face of a changing climate.

Figure 2 – Drawing of Transportable Battery Energy Storage System (TBESS)

2. Methodology

This study was structured into four methodological pillars to evaluate the technical viability and emergency response potential of the proposed TBESS. The first pillar addresses the technical specification and design of the TBESS, including its inverter architecture, electrochemical storage configuration, and transportability capabilities. The second pillar defines operational strategies under emergency conditions, including dispatch logic, load prioritization. The simulation of energy supply in critical situations is the third pillar, which is based on real flood data and representative load profiles from emergency shelters and emergency field hospitals. The fourth pillar is dedicated to the assessment of energy resilience and environmental impact, which quantifies the system's capacity to maintain essential services and reduce CO_2 emissions in comparison to conventional diesel-based backup systems.

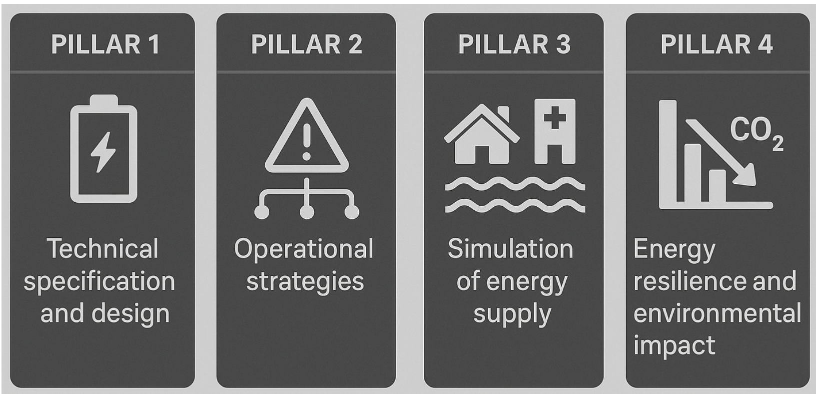

Figure 3 - Methodological pillars

2.1. Pillar 1 – Technical specification and design

The specification and design methodology of the TBESS is initially based on the operational and service requirements of the system. The first variable to be analyzed is the usable operating power, Power Conversion System (PCS) power supply, since in isolated configurations the system must be capable of supplying the total power demanded by the load. After this analysis, the second step is to evaluate the amount of required energy, or the operating hours, which must also consider the delivery constraints and availability of components from manufacturers.

The third aspect concerns the voltage level and the protection required for proper connection and safety. The following stage involves assessing the feasibility of integrating a fuel-based generator to extend the system's supply capacity. Once all components are selected, including auxiliary elements such as the AC distribution panel and DC distribution board, a spatial assessment is carried out to verify whether the complete system fits within the semitrailer structure. If it does not, design adjustments are made, primarily by resizing the expected energy capacity of the system. The Figure 4 shows the flowchart to specification and design methodology.

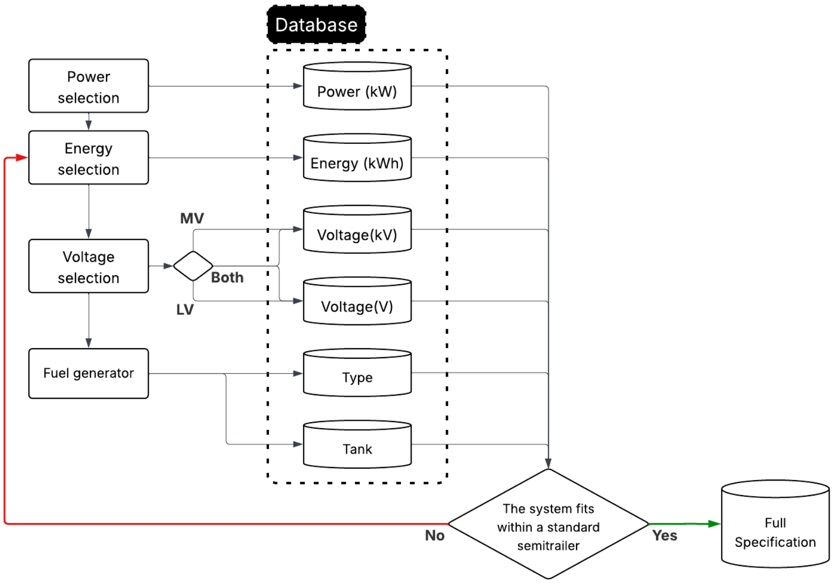

Figure 4 – Flowchart to specification and design methodology

A critical aspect of the assessment is that, if the system cannot be accommodated within a standard semitrailer, construction and layout constraints may result in a substantial reduction of the available energy capacity.

2.2. Pillar 2 – Operational strategies

In grid maintenance scenarios, the dispatch strategy requires a detailed analysis of the specified equipment in accordance with operational guidelines. The primary objective is to establish a grid-forming capable of supplying the consumer unit or the affected grid segment, ensuring full coverage of the demand and its fluctuations. The dispatch strategy is particularly evaluated based on the sequencing between different battery technologies (when multiple chemistries or ages are integrated) and the range extender system.

The TBESS operates in islanded mode, where the PCS performs the role of a grid-forming source, establishing the voltage and frequency reference for the supplied loads. In this configuration, the inverter behaves similarly to a conventional generator, enabling the supply of critical loads in the absence of the public grid. The system is not designed to perform automatic synchronization with the utility grid. Therefore, once the main grid is restored, manual intervention is required to disconnect the loads from the TBESS and safely reconnect them to the utility supply. This operational strategy prioritizes system robustness and operational safety in emergency and contingency scenarios.

2.3. Pillar 3 – Simulations

The simulations use real consumption data from the consumer unit and/or the section of the grid to be supplied. Data granularity is a key factor, the shorter the time step available, the more detailed and accurate the technical analysis of energy supply from the TBESS becomes. Simulations are carried out using the HOMER Pro®

software and a custom-developed spreadsheet, which analyzes the system's energy dispatch while identifying any point of unavailability. For a preliminary assessment, at least the electricity bills of the target consumer unit for no minimum a year are required, allowing the TBESS to be sized according to the maximum measured demand and to establish a relationship between the monthly energy required by the load and the energy available from the TBESS.

2.4. Pillar 4 – Energy Resilience and environmental impacts

The comprehensive assessment of energy resilience and environmental performance of the TBESS when deployed in degraded or faulted electrical networks. This evaluation aims to determine the system's ability to sustain essential loads, maintain service continuity, and restore critical infrastructures during partial or total grid outages. The TBESS operates as a grid-forming unit, capable of re-establishing voltage and frequency references in isolated sections, thus enabling autonomous operation of substations or distribution feeders under contingency conditions. Through quantitative analysis of supply reliability indices, recovery times, and energy autonomy, the assessment quantifies the resilience gain achieved by the TBESS when compared to conventional diesel backup systems, which typically exhibit delayed response, fuel dependency, and logistical constraints.

Beyond operational resilience, this pillar also encompasses the environmental and systemic impacts associated with TBESS deployment. By replacing or complementing fossil-based generation, the system substantially reduces CO_2 emissions contributing to a cleaner emergency response framework. The CO_2 emission reduction analysis was performed through a comparative operational assessment between the proposed configuration and a baseline scenario in which the same energy demand would be entirely supplied by a diesel generator. To provide methodological transparency, the baseline emission factor was based on the default parameters established in the UNFCCC/CDM methodological tool TOOL33 for off-grid diesel electricity generation. Considering a diesel generator in the 135–200 kW range, an emission factor of 0.8 kg CO_2/kWh was adopted, corresponding to operation under optimal load conditions (50–100% of rated power). The avoided emissions were therefore calculated as the product of the energy supplied by the TBESS and the corresponding diesel generation emission factor. It is important to note that this approach represents a simplified operational comparison and does not constitute a full life cycle assessment (LCA), as the analysis focuses exclusively on the operational emissions associated with diesel-based electricity generation.

2.5. Case of study

In this study, the load profile of an emergency facility located in southern Brazil is used as the basis for system design and analysis. Santos et al. (2021) evaluated the electrical and energy performance of an urgent care facility located in Florianópolis, Santa Catarina, southern Brazil. A measured peak demand of 45.82 kW was observed during off-peak hours and 75.03 kW during peak hours, according to the study. Furthermore, the greatest monthly energy consumption was 25.26 MWh during off-peak hours and 2.20 MWh during peak hours. By extrapolating these values to estimate the expected maximum hourly consumption, the off-peak demand corresponds to approximately 40.10 kWh per hour, while the peak demand corresponds to approximately 24.70 kWh per hour.

3. Proposed TBESS

The objective of the proposed TBESS is to design a solution that can provide a substantial amount of energy to support priority loads in an electrical distribution system. Additionally, it is imperative to guarantee that all equipment is contained within the maximum dimensions permitted for a semi-trailer in accordance with Brazilian regulations. It includes two lithium-ion battery banks: a 300 kWh first-life battery bank and a 100 kWh second-life battery bank that has been repurposed from electric vehicles. The battery system in operation at a given moment is managed and selected by a DC distribution board, which is connected to these storage systems. The AC distribution panel is connected to a single 150 kW Power Conversion System (PCS), which is complemented by a diesel generator. The operation is coordinated by an Energy Management System (EMS), which determines the energy source that supply the load at any given moment. The AC distribution board enables two load connection options: direct supply at low voltage (220 V) or medium voltage connection (13.8 kV) via a step-up transformer. The simplified TBESS diagram is shown in Figure 5.

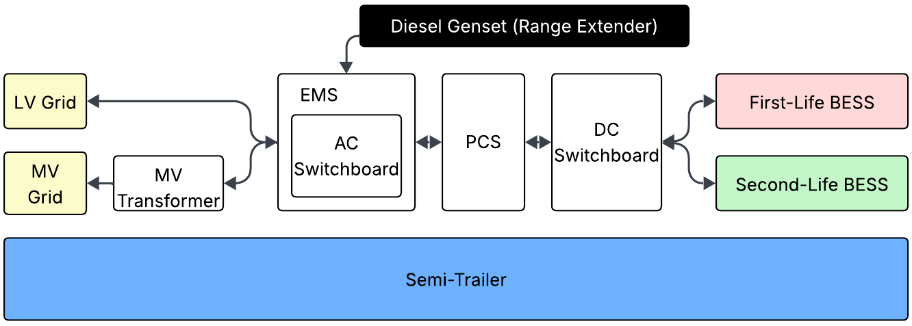

Figure 5 - Simplified assembly diagram

The simplified operation flowchart is presented in Figure 6. The operation of this system is structured into three stages. In the first stage, only the second-life battery bank is used, discharging all its stored energy. Once the State of Charge (SOC) reaches a predefined minimum level, the second-life bank is automatically disconnected, and the first-life battery bank is put into operation. In the second stage, the system operates exclusively with the first-life battery bank. The diesel generator is introduced after the first-life bank is fully discharged, thereby enabling the potential for reverse power flow to the grid. In the third stage, the diesel genset becomes the primary energy source. The system monitors the fuel level, and as long as refueling is possible, operation continues. If refueling is no longer feasible, the system disconnects from the grid.

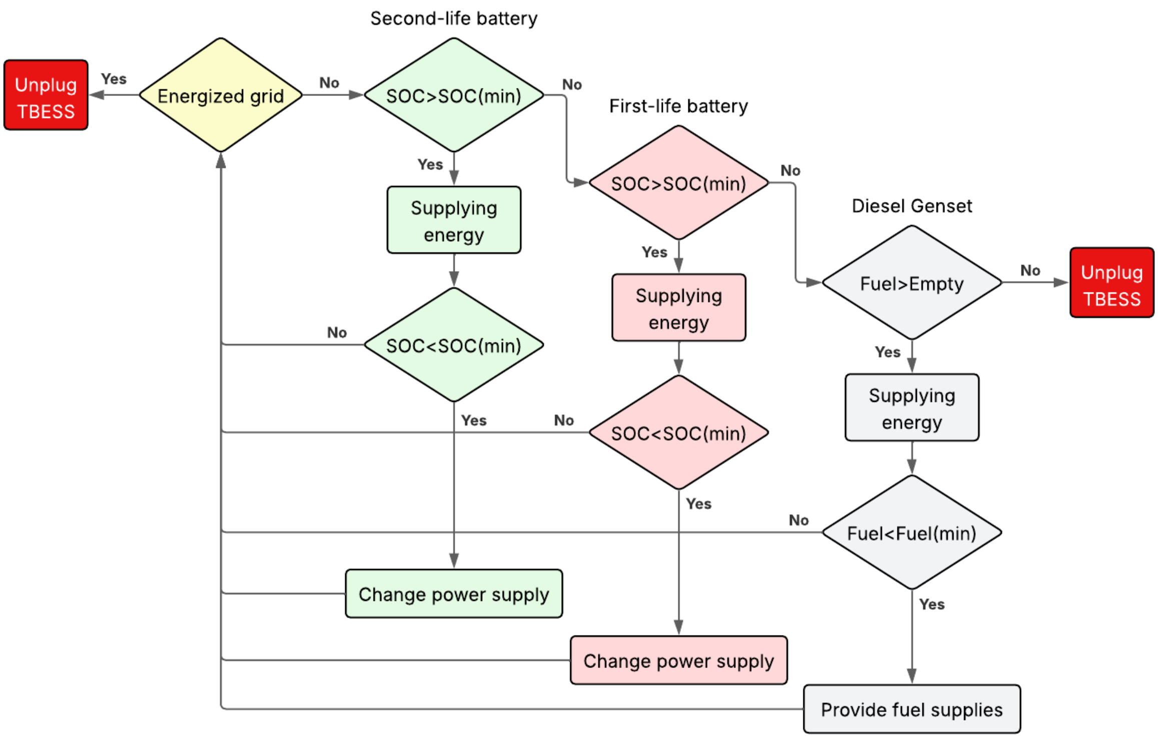

Figure 6 - Simplified operation flowchart

System modeling and simulation were performed using HOMER Pro. The hourly energy demand was estimated from the monthly electricity consumption reported in the utility bill, assuming an average hourly distribution of the total monthly energy use.

4. Results

The results show that during off-peak hours, when the overall energy consumption is higher, the TBESS's PCS configuration is capable of meeting the required power demand, with an estimated autonomy of nearly 10 hours solely from battery storage. The TBESS is capable of providing full support for the 3-hour demand period during peak hours and has an additional 326 kWh of energy to cover an additional 8 hours of off-peak demand.

Energy supply is typically prioritized over greenhouse gas emission reduction in emergencies. Nonetheless, this study evaluated the effects of employing the diesel generator as a range extender over various time frames. The battery system and the diesel genset supply energy, and the corresponding greenhouse gas emissions for various energy demand periods are represented in Table 1.

Table 1 - The battery system and the diesel genset supply energy, and the corresponding greenhouse gas emissions for various energy demand periods

Time required	Energy required	Energy supplied by batteries	Energy supplied by genset diesel	CO2 emissions
6h	229 kWh	100%	0%	0 Tons of CO2
12h	458 kWh	87%	13%	0.04 Tons of CO2
18h	687 kWh	58%	42%	0.19 Tons of CO2
24h	916 kWh	44	56%	0.35 Tons of CO2
48h	1833 kWh	22%	78%	0.96 Tons of CO2
72h	2749 kWh	15%	85%	1.57 Tons of CO2

In the context of climate-related disasters, such as those observed in southern Brazil, the TBESS system provides a technically feasible and strategic solution for energy supply in emergency situations. The combination of first- and second-life batteries, managed by an intelligent distribution and control system, has proven capable of meeting critical energy demands with significant autonomy, substantially reducing reliance on diesel generators in the early hours of operation. This highlights the potential of TBESS as an effective rapid-response tool, ensuring the operational continuity of essential services such as shelters and healthcare units.

Beyond its technical functionality, the TBESS also contributes positively to environmental goals by minimizing greenhouse gas emissions, particularly when compared to conventional fossil fuel-based solutions. In disaster scenarios, where the public grid may be unavailable or inoperative, the TBESS is designed to operate in islanded conditions as an independent grid-forming source, supplying power to critical loads without the presence of the utility grid. In this configuration, the inverter establishes the voltage and frequency reference for the local system, enabling autonomous operation. Although the diesel generator remains necessary to ensure prolonged operation, its role as an autonomy extender rather than a primary energy source represents a meaningful improvement. The TBESS strengthens the reliability of disaster response infrastructure while also promoting energy innovation toward a more resilient and environmentally sustainable future, addressing at the same time aspects of circular economy through the use of repurposed second-life Li-ion batteries originating from electric vehicles.

5. Conclusion

In the context of climate-related disasters, such as those observed in southern Brazil, the TBESS system provides a technically feasible and strategic solution for energy supply in emergency situations. The combination of first- and second-life batteries, managed by an intelligent distribution and control system, has proven capable of meeting critical energy demands with significant autonomy, substantially reducing reliance on diesel generators in the early hours of operation. This highlights the potential of TBESS as an effective rapid-response tool, ensuring the operational continuity of essential services such as shelters and healthcare units.

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6. Acknowledgments

The authors express their sincere gratitude to the Brazilian Electricity Regulatory Agency (ANEEL) and CELESC Distribuição S.A. for the financial support provided to the Research and Development Project No. 05697-0323/2023, entitled "Multifunctional Transportable Storage System Using First-Life and Second-Life Batteries for Outage Support and Seasonal Peak Demand Management in the Distribution Grid," which is being developed under the ANEEL R&D Program.

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