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Development of a Tool for Sizing and Technical–Financial Analysis of Energy-Storage Systems Using Batteries

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In this article, an innovative approach is presented to the sizing and technical–economic analysis of battery energy-storage systems (BESS) designed for customers in the free energy market in Brazil. The tool enables the integration of photovoltaic (PV) energy sources and includes a comparison between the BESS + PV system and diesel generators. Integrating the computational capabilities of Microsoft Excel in the backend and the intuitive interface of PowerApps in the front end, the sizing process is based on analyzing historical energy invoices spanning at least 12 months or loading data with a 1 h measurement interval. The data discretization over the 8760 h of the year, considering the consumer's load profile, is facilitated by the PowerApps interface, providing a comprehensive visualization of the technical-economic sizing results for BESS. A case study is conducted for a commercial load with a specific tariff for free energy market customers, revealing viable solutions for BESS compared to diesel alternatives. In this approach, it is aimed to simplify the analysis and decision-making process, offering a valuable tool for power system engineers to evaluate sustainable and economically viable solutions in the Brazilian free energy market.

1. Introduction

The present scenario of the global energy landscape is immersed in a complex dilemma, where the need to mitigate the impacts of global warming and climate change, evidenced by the increasing effects observed in recent years, contrasts with the dependence on approximately 80% of fossil fuels for the world's primary energy and projected growth of this dependence by 2.3% annually from 2015 to 2040.[1,2] Faced with this situation, integrating renewable energy sources into the global energy matrix stands out as a potential solution to alleviate these adverse effects. Unlike fossil fuels, renewable sources do not produce emissions and can help reduce energy losses through efficiency, providing a more consistent energy source.

However, the intermittent and weather-dependent nature of renewable energy sources, such as solar and wind, makes their generation uncertain and non-dispatchable, challenging the stability, reliability, and quality of energy in the electrical system.[3–5] Battery energy-storage systems (BESS) emerge as a vital strategy in this context. BESS allows excess energy generated during periods of high production from renewable sources to be stored and discharged during periods of high demand, mitigating energy losses, and enhancing reliability.[2] Additionally, proper management of BESS can assist in reducing dependence on fossil-fuel-based generation, thereby lowering CO_2 emissions. The system exhibits versatility in terms of storage, being used in various applications, both in portable systems and permanent applications, such as backup power and renewable energy storage in isolated areas.[6]

Within this energy transition context, increasing the number of electric vehicles has become increasingly prominent, given

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that international agreements such as the Conference of the parties aim to reduce the use of fossil fuels, in addition to the advantages surrounding this issue. However, with this increase, there is a need to obtain a more significant number of electric vehicle charging stations, which can significantly impact the energy system and associated costs.[7–9] To mitigate this impact, renewable energy sources such as solar photovoltaic (PV) can be installed so that the energy supply contributes to the charging of these vehicles.[10,11] However, some challenges related to this source may arise, with its intermittent characteristic being the main one. Therefore, a better use of this source is achieved through integrating BESS in conjunction with chargers, as seen in the study.[12] It is observed that the system is optimized with energy storage during periods of lower demand or higher generation and its subsequent discharge during moments of higher demand or lower generation. It also exhibits better energy quality when compared to a system without connected energy storage. Furthermore, studies in refs. [13,14] delve into optimizing power balance and control strategies, aiming for greater financial feasibility and the effective operation of BESS in conjunction with hybrid energy systems.

The sustainability analysis of BESS in conjunction with PV energy demonstrates that this approach contributes to climate change mitigation and facilitates an effective transition to a cleaner and more efficient energy matrix. The study in ref. [15] provides a feasibility analysis for the self-consumption of these integrated systems in residences, thereby reducing reliance on the grid and offering greater financial returns for the user. Furthermore, it encompasses the combination of BESS with solar PV sources and suggests incentive policies, including a tax deduction of over 50% and a bonus for produced and self-consumed energy in PV installations; a tax deduction for BESS, albeit at a lower rate compared to the PV system; and support for the recycling industry.

Still, regarding BESS integrated with PV solar generation systems, it is crucial to highlight studies that employ advancements in this theme, especially concerning individual loads, such as buildings, houses, and energy-sharing communities. Thus, in ref. [16], a review is presented on the efficiency of specific parameters in the optimization processes of these two integrated systems in the loads. The mentioned parameters include system applicability, optimization methods, optimization objectives, and optimization constraints, in addition to presenting the advantages and disadvantages of different optimization methods for the integrated system.

The importance of BESS is even more pronounced in the context of the free energy market in Brazil, which opens doors for negotiating contracts with more favorable commercial conditions and establishes itself as a driver for implementing innovative and sustainable energy solutions. This market serves as a strategic option for consumers and generators and as a vector for adopting technologies that favor more efficient energy management aligned with sustainability principles.

A critical point to consider in BESS implementation is its optimal sizing. An oversized system may incur prohibitive costs, rendering it economically unviable. In contrast, an undersized system may fail to provide energy adequately or efficiently meet BESS applications, compromising its technical and operational viability. Therefore, from an economic and technical standpoint, optimal system planning and sizing are crucial to ensure successful deployment.

However, sizing a BESS can be challenging, requiring consideration of variables such as load profile, battery capacity, and inverter. While several commercial software tools are available to assist in the BESS sizing process, many do not exclusively focus on BESS analyses and do not specifically consider, for example, the free energy market.

Within the landscape of financial modeling and sizing of hybrid systems and microgrids, it is imperative to highlight the significant studies conducted by researchers such as ref. [17–20], who have made noteworthy contributions to the field. These studies, grounded in meticulous methodologies, base their analyses on the levelized cost of energy (LCOE) generated by various energy sources and storage systems, providing a comprehensive and detailed financial perspective.

The ref. [17] delves into the implementation and optimization of microgrids, exploring modeling techniques crucial for determining LCOE. The study navigates the complexities of energy management, proposing solutions that efficiently and economically integrate renewable and conventional sources.

Similarly, the research in ref. [18] focuses on microgrids, investigating sizing and operational methodologies to maximize efficiency while controlling operational and implementation costs. The detailed analysis of LCOE plays a fundamental role, providing a tangible assessment of the economic and technical viability of the proposed strategies.

In contrast, the ref. [19] adopts an approach exploring the interaction between different energy generation and storage technologies, examining how these interactions influence LCOE. The research provides insights into how integrating and managing various energy sources can be optimized to deliver more reliable and cost-effective energy.

Additionally, authors in ref. [20] focused on developing modeling and optimization strategies that consider LCOE and explore the feasibility of implementation in different scenarios and contexts. This study deepens our understanding of how hybrid energy systems can be adapted and optimized for various applications and environments, ensuring effective and economically viable operation.

In summary, this work addresses the need for a comprehensive tool that tackles current research gaps related to the sizing of BESS and the practical implementation of these systems, whether connected to PV solar generation sources (PV) or not, within the context of the free energy market in Brazil. By developing and analyzing this tool, we aim to address existing knowledge deficiencies and provide valuable insights, such as optimal configurations of BESS with PV and the potential reduction in pollutants in nature compared to diesel generators (DGs). These aspects are intended to optimize BESS projects in Brazil's dynamic energy scenario. This article details the methodology employed in the development of the tool, followed by a case study, results discussion, and, finally, conclusions, providing a structured exploration of its technical–economic analysis and practical applicability.

The article is structured into six sections, including the introduction: Section 2—Methodology; Section 3—Case Study; Section 4—Discussion of the results; and Section 5—Conclusions.

2. Methodology

2.1. Existing Tools

BESS sizing software tools are essential for the design and implementation of systems tailored to the specific requirements of individual users and consumer types. These software tools enable the simulation of the BESS's performance based on load profiles and BESS technical specifications.

Due to their development based on standard models, commercial software often has customization limitations that may not align precisely with the unique needs of each user. This might lead to discrepancies in the resultant values during system sizing, thereby also affecting the entire financial analysis undertaken.

To evaluate the most commercially utilized tools, they are introduced as follows. 1) Hybrid optimization of multiple energy resources (HOMER): developed by the United States National Renewable Energy Laboratory (NREL), this software facilitates the optimization of hybrid energy system designs and microgrids, including systems with battery energy storage. HOMER uses optimization algorithms to find the most efficient combination of energy sources and energy-storage systems (ESS) to meet a user's energy demands. It also supports the inclusion of both DC and AC configurations for BESSs.[21] 2) Photovoltaic design and simulation (PVSOL premium): offered by the German company Valentin Software, this software caters to the sizing of grid-connected PV systems and standalone systems combined with battery energy storage. PVSOL premium uses meteorological data to simulate system performance and provides visualization of results in charts and tables. It also enables the modeling of hybrid systems that merge multiple energy sources and storage systems.[22] 3) System advisor model (SAM): another NREL product, SAM facilitates the analysis of renewable energy systems, including PV, wind, and BESS. It employs mathematical models to simulate system performance and supports multiple project scenario analyses. Additionally, the software incorporates financial analysis tools and investment return evaluations.[23] 4) PVsyst: this software simulates PV system operations and incorporates capabilities for the size of small BESS. It uses mathematical models to simulate system performance and supports diverse project scenario analyses. PVsyst also includes tools for financial analysis and assessing investment returns.[24] 5) Renewable energy and energy-efficiency technology screening software (RETScreen): developed by the Canadian government, RETScreen serves as a platform for analyzing renewable energy project designs, encompassing PV, wind, and BESS. It employs mathematical models for the simulation of system performance and supports the analysis of various project scenarios. The software also includes tools for financial analysis and return on investment evaluations.[25]

The authors in ref. [26] emphasized in their research the criticality of performance evaluation for renewable energy technologies, particularly PV systems when creating hybrid energy configurations. For system development, HOMER Pro software was used to size a hybrid PV/grid and battery system. The cost analysis conducted considered the entire system as a unified result, with no separate observation of individual components. Meanwhile, Santos et al.[27] delineated in their paper the use of HOMER Pro to incorporate an energy management strategy with a methodology for the size and operation of microgrids. In ref. [28], the authors employed the PVSyst software to size an off-grid PV/battery system in their research. This software uniquely sizes BESS combined with PV generation.

The data presented in **Table 1** details the primary evaluation parameters of the most established software to work with BESS. An analysis of Homer Pro reveals it as an advanced tool for the technical–economic sizing of BESS. It includes load simulation models and battery energy storage, facilitating the modeling of hybrid and standalone energy systems. However, its use requires deep prior knowledge of the sizing and storage of renewable energy. Moreover, its relatively higher licensing cost compared to other software might pose a barrier for more simplistic analyses geared toward financial market viability evaluations. Conversely, PV*SOL and PVsyst are not specifically designed for sizing ESSs but do allow for the modeling of solar energy and battery hybrid systems, albeit with less detail and precision than other energy-storage-specialized tools. These software products are customized for the PV energy domain and do not facilitate the isolated analysis of BESS or any other type of ESS.

Regarding free tools, there is RETScreen, which includes features for modeling ESSs; however, with a low level of precision.

Table 1. Mapping of main software for technical–economic analysis of BESS.

Item	Parameters	HOMER	PV*SOL	SAM	PVSyst	RETScreen
Simulation system	Connected to the grid	✓	✓	✓	✓	✓
	Off-grid system	✓	✓	✓	✓	✓
	Hybrid system (BESS/PV)	✓	✓	✓	✓	✓
	Microgrid (PV, BESS, Wind, DG)	✓	✓	✓	✓	✓
	Exclusive BESS sizing	–	–	–	–	–
Financial evaluation	Payback	✓	✓	✓	✓	✓
	IRR	✓	✓	✓	✓	✓
	LCOE	✓	✓	✓	✓	✓
	Initial cost	✓	✓	✓	✓	✓
	NPV	✓	✓	✓	✓	✓
License	Acquisition costs	U$ 1500–U$ 4548/year	U$ 895–U$1295	Free	U$ 661/year	Free

This software also has its BESS size tied to other energy systems. In contrast, SAM emerges as a robust tool that allows for the modeling of ESSs for technical–economic studies; however, its interface is complex, resulting in a long learning time because it includes other energy sources and requires prior expertise around energy storage and renewable generation.

The presentation and evaluation of the tools highlight the presence of challenges associated with the use and interpretation of terms in each of them. In this sense, the main obstacles are presented as follows. 1) nonintuitive tools developed for users with prior knowledge of storage systems, renewable energies, and other energy sources; 2) technical analysis for generic systems, meaning there is no market association for better accuracy of results; 3) multiple applications exist for ESSs in the presented software; hence, the analyzed cases have no specific applicability; 4) there is no intuitive way to compare the scaled results in the analysis of cases; in other words, each file needs to be isolated for individual analysis, making the simultaneous execution of this process challenging.

2.2. Methodology for the Proposed New Tool

In this study, the aim is to propose a refined methodology for the sizing of hybrid generation systems, coupled with energy storage techniques. The core innovation of this work is the development of a computational tool capable of integrating technical and financial variables, aligning with the regulatory guidelines inherent to various energy generation mechanisms. Specifically, this tool was designed to conduct comparative analyses with diesel generation systems, serving as a baseline and allowing a detailed evaluation of indicators related to greenhouse gas emissions, as well as quantifying carbon credits.

In this sense, the tool in development surpasses the obstacles observed in commercial software and offers a customized tool with the following. 1) easy usability for beginner users and basic knowledge of BESS. 2) Technical and financial analysis of BESS only focusing on sales to customers in the free energy market, as these customers have differentiated energy costs. 3) Applicability for analyzing customer energy demands, considering the nature of the registered load, namely, residential, commercial, industrial, or flat. 4) Applicability for analyzing customer energy demands, considering the nature of the registered load, namely, residential, commercial, industrial, or flat. 5) Financial indices for the analysis and study of determining the optimal BESS scenario for the customer can be carried out by assessing various scenarios for a single customer in small steps. The scenarios include with or without PVs, the inclusion of battery technology cost or maintaining the default offered by the tool, hours of backup for the storage system, and the optional inclusion of the DG size. The tool also provides the option to dimension a DG to estimate the number of emissions that can be released into the environment and evaluate its operation with the load.

Within the context of the free energy market, this tool emerges as a distinctive asset, particularly due to its ability to simplify and democratize the BESS sizing process. The tool architecture is designed to allow data input through two methods (**Figure 1**): a manual approach that uses energy bills and an automated approach that extracts information from a preestablished database.

From a technical standpoint, the structural foundation of this tool is based on Microsoft's Power Platform, a low-code solution, which enhances maintenance and minimizes the need for intricate programming. It should be noted that in terms of security, there was an exclusive reliance on Microsoft services, thus ensuring meticulous standard security.

However, this technical choice imposes certain limitations, primarily due to the inherent dependency on Microsoft's Power Platform. **Figure 2** illustrates the architecture of the system, showing its various modules and their communication channels.

The tool is built using Power Apps, where logic is implemented in PowerFX, an Excel-inspired language used by Power Apps; data is stored in Microsoft SharePoint; flows run in Power Automate, which takes external data from the GreenAnt API, inserts it into spreadsheets, and sends the results to Power Apps; the scripts present in the calculation spreadsheet, which read data from the spreadsheet and send it to the flow, or receive data from the flow and insert it into the correct cells of the spreadsheet; the tool prototype is built in the Figma design program; and more complex calculations are performed in separate spreadsheets.

To consolidate functionalities and ensure a robust methodological approach, established techniques in the literature were used, such as Story Mapping and Card Sorting. These methodologies provided a cohesive narrative and sequential organization for the tool. Moreover, the User Journey was meticulously outlined to optimize each interaction and enhance the user experience. Based on these premises, a high-fidelity prototype was developed, which was instrumental during the testing and validation phases. Subsequently, the proof-of-concept phase was initiated, exploring technical and methodological aspects, culminating in the implementation of the entity relationship model, crucial for effective and integrated data management.

Methodologically, the combination of quantitative and qualitative techniques, paired with the integration of multiple data

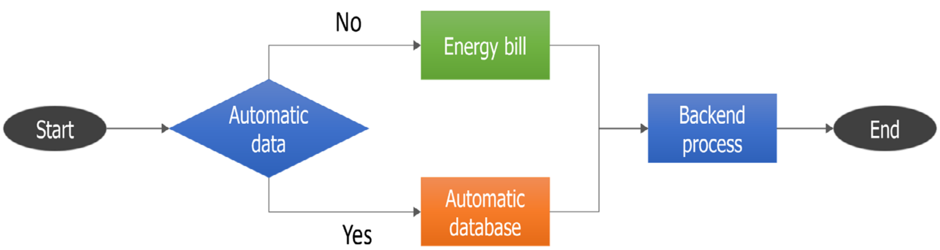

Figure 1. Data flow for sizing.

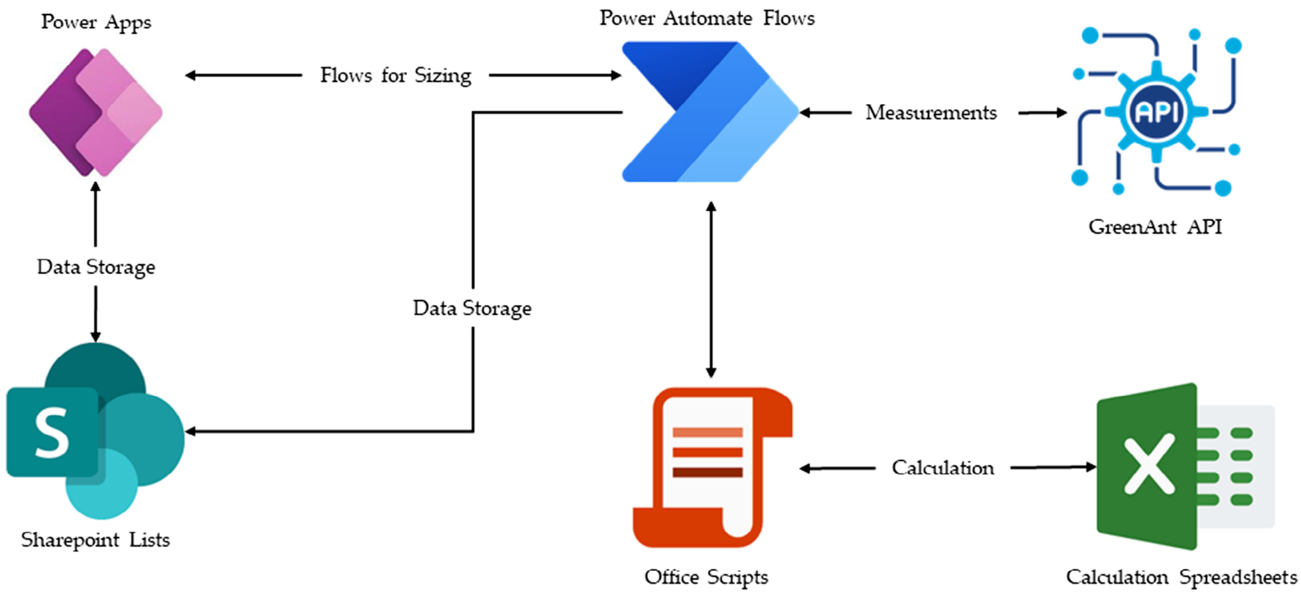

Figure 2. Architecture of the proposed sizing system.

sources, offers a comprehensive and accurate view of contemporary energy systems. The methodology employed encompasses the following. 1) Data collection and analysis: initially, the research employed a data collection approach from two main fronts: energy bills and automatic records. This multidimensional approach seeks a more holistic and accurate representation of energy consumption patterns. 2) Creation of load profiles: based on the collected data, a technique was employed to develop a load profile for each customer. This methodology included the analysis of monthly bill consumption records, as well as a detailed investigation of the data provided by Energy Research Office (Empresa de Pesquisa Energética),[29] to construct representative profiles. 3) Solar generation formulation: the research incorporated a quantitative analysis of solar generation, considering variables such as irradiance, and average efficiency obtained from the NASA Prediction of Worldwide Energy Resources platform.[30] This methodological approach aims to integrate the growing relevance of PV solar energy in the current energy landscape. 4) DG modeling and analysis: according to the guidelines established by the ERE, a modeling approach incorporates the DG into the tool analysis.[31] This step involved a technical analysis of BESS performance compared to the conventional use of DGs, as well as the flexibility to integrate data from a preexisting DG or a standard model. Emissions assessment: finally, the adopted methodology paid particular attention to environmental implications, incorporating a module dedicated to the assessment of pollutant gas emissions. This research phase aimed to establish a clear link between energy consumption and its environmental impact, highlighting the importance of sustainable energy solutions.[32]

Furthermore, it is interesting to mention some criteria adopted for developing the tool. Certain parameters have been considered so that the calculations return values increasingly close to the load consumption over the 12 billing months. These parameters will be discussed later for a more in-depth understanding of the case study.

One of the crucial parameters required for the calculations is the selection of the specific distributor, as the peak start and end times vary depending on the distributor, due to the distinct behavior of cities/regions at different times. This results in specific peak hours for each region. Another parameter to be considered is the selection of the load type, allowing for a more accurate analysis of the entered load data, which will undergo discretization, as specified in the technical note from ERE,[29] transforming the data from 12 months into 8760 data points.

The tariff modality refers to the energy rate paid by the consumer, divided into blue and green modalities. The tariff modality presents distinct rates for each distributor. Rates related to contracted demand, on-peak, and off-peak energy, and energy rate are also essential for calculating costs before and after. For financial and tax-related matters, these can be included according to the Brazilian state where the load is installed.

In summary, this tool was developed to serve clients in the Brazilian free energy market, where energy contracts can be freely negotiated with energy marketers or generators. The purpose of this tool is to provide support to the market in addressing various issues, such as exceeding demand, providing backup energy for customers sensitive to network failures, and facilitating the energy transition offered by BESS.

3. Case Study

In this chapter, a case study involving a consumer from the Brazilian free energy market is presented. To better understand this client, it is crucial to address some aspects that characterize them. At the customer registration stage, the analyzed unit must be technically specified. The client under analysis has a type of commercial load, is linked to a specific energy distributor, and adopts the green tariff modality. The choice of this client was deliberate to explore the use of BESS in comparison with DG. This is because DG is often employed as a backup and/or during peak hours. Additionally, the use of DG by clients with a commercial profile is common.[31] The importance of these specificities for the case analysis is emphasized, as they directly influence the calculations performed on the back end for the mentioned client type. The data related to the client in question are detailed in **Table 2**.

Additionally, data regarding the energy tariff is detailed in **Table 3**. As the consumer's tariff modality is green, they have only one demand tariff and a single contracted demand value. The energy tariffs are divided into peak and off-peak, and the supplier's tariff replaces the energy tariff. In this scenario, the consumer has the freedom to choose and contract energy from any generator or supplier.

The next step concerns the functionalities of the BESS, which encompass the following inputs: backup hours in the event of a power interruption to the load, the cost of the BESS system (whose inclusion is optional), sensitive load in case of power interruption, penalties for such interruption, PV generation in the load, the capital city nearest to the load, and power of the DG in the load (whose inclusion is optional). These data are described in **Table 4**. All these parameters are considered both for sizing a BESS and for sizing a DG, as these two systems must be dimensioned to enable a comparison between them, which is the principal purpose of the tool.

Table 2. Peak and off-peak energy data on the energy bill.

Month	Energy peak [kWh]	Energy off-peak [kWh]
January	11 436.60	105 572.88
February	11 105.01	100 352.49
March	11 933.25	107 812.32
April	10 098.27	101 868.06
May	11 497.29	101 791.41
June	9 850.89	88 097.31
July	9 626.82	90 984.18
August	10 582.11	89 676.93
September	10 170.51	92 032.08
October	10 374.42	99 477.21
November	10 666.74	103 952.52
December	11 630.01	105 116.34

Table 3. Tariffs values used.

Parameters	Values
Demand [kW]	270
Demand tariff [R$ kW^{-1}]	17.86
Energy off-peak tariff [R$ kWh^{-1}]	0.228
Energy peak tariff [R$ kWh^{-1}]	1.31
Energy supplier tariff [R$ kWh^{-1}]	0.18

Table 4. Functionalities of the BESS and DG.

Parameters	Values
Backup [h]	3
Cost of the BESS system [R$ kW^{-1}]	–
Sensitive load in case of power interruption (yes/no)	Yes
Penalties for interruption [R$]	10 000
PV generation in the load [yes/no]	Yes
Capital city nearest to the load	Joao Pessoa
Power of the DG in the load	–

In addition to these parameters, some financial assumptions were considered for the calculation: cost of the BESS system per utility scale (R$ kWh^{-1}), if not provided, cost of the PV system (R$ kWp^{-1}), cost of the DG (R$ kVA^{-1}), and cost of diesel (R$ L^{-1}). The percentage-based assumptions included program of social integration, a Brazilian social contribution tax percentage (PIS %), contribution for the financing of social security, a Brazilian social contribution tax percentage (COFINS - %), and tax on circulation of goods and services, a Brazilian state-level value-added tax, in percentage (ICMS - %), monetary inflation (% per annum), energy inflation (% per annum), operation and maintenance (O&M) for BESS and PV (% per annum), O&M for DG (% per annum), diesel fuel (% per annum), and battery replacement (% of capital expenditure [CAPEX]). These data are detailed in **Table 5**.

To perform the sizing, it is essential to include all load data to build the corresponding load profile. This load profile, based on the document of ref. [29], generates the customer's characteristic curve in the tool, respecting the totalized consumption data provided. In the BESS sizing process, the spreadsheet considers the maximum and minimum load consumption values, along with the contracted demand, in calculating BESS size recommendations for sensitivity analysis. These calculations use an average of 20% above and below the maximum value, following a

Table 5. Percentage and financial assumptions.

Parameters	Values
Cost of the BESS system per utility scale [R$ kWh^{-1}]	3 000
Cost of the PV system [R$ kWp^{-1}]	4 000
Cost of the DG [R$ kVA^{-1}]	800
Cost of diesel [R$ L^{-1}]	5.00
PIS [%]	1%
COFINS [%]	4.5%
ICMS [%]	18%
Monetary inflation [% per annum]	5%
Energy inflation [% per annum]	5%
O&M for BESS and FV [% per annum]	5%
O&M for DG [% per annum]	5%
Diesel fuel [% per annum]	5%
Battery replacement [% of CAPEX]	30%

conservative approach. Thus, sizing is calculated based on sensitivity, considering parameters such as the levelized cost of energy (LCOE), net present value (NPV), and internal rate of return (IRR) with the first two considered the most applied in sizing, as they are fundamental in the planning phase.[33] In the tool, it has been established that the best value for BESS sizing is the one with the lowest LCOE. As for the sizing of the DG, it is determined based on the maximum load consumption value, considering specific DG standards for sizing based on these criteria. Alternatively, if the DG power is included (optional), sizing is done according to the added value.

The calculation conducted for sizing, among other relevant parameters, is carried out to comply with the contracted demand of the load with the distributor, in addition to its performance during peak hours. In other words, for the BESS, the calculations are based on recharge and discharge conditions, BESS system limits, contracted demand, and PV energy generation. In contrast, for the DG, the calculations are focused on its performance during peak hours. Subsequently, the costs related to the load operation with the system (BESS or DG) are recalculated, followed by a comparative financial analysis that assesses the system's feasibility, cash flow, and costs before and after each system.

4. Results and Discussions

At the end of the data entry, there is a script that records all the entered information in a designated spreadsheet. Additionally, this data is saved in SharePoint lists to ensure storage whenever these data need to be modified or reviewed. Thus, are visualized all these results of interest for analysis: sizing, technical and financial feasibility, local pollutants, total costs before and after, and cash flow for each of the systems, whether it be BESS or DG.

For sizing, the results for the nominal energy and active power of the BESS were 161 kWh, while the sizing for the PV system was 270 kWp. As for the sizing of the DG, a power of 750 kW was estimated. For better visualization, the data has been consolidated in **Table 6**. It is observed that everything is sized based on all the data from the energy bill entered. The energy value is calculated based on the initially chosen backup hours, but for a conservative margin for the load, a time interval of 3 h was chosen, even if there is no backup option for the load or the value is less than 3 h. This was estimated to ensure that the system has a minimum autonomy of 3 h in off-grid mode.

The financial indicators, grouped under financial feasibility, showcase the results for both BESS and DG in **Table 7** and **8**. It is observed that there is greater feasibility for BESS compared to DG, which can be explained by the difference in peak and off-peak energy tariffs. BESS will be more feasible with increased system utilization during these hours or in-demand control scenarios (especially for the blue tariff mode). Another factor influencing the calculations is that the sizing of BESS is significantly smaller than that of DG, as DG, O&M, fuel, and initial investment values carry more weight with increasing size. This feasibility is reflected in the following indices: LCOE before and after, emphasizing that the LCOE after BESS is lower than before, whereas, for DG, it is higher both after and in comparison to BESS (after), justifying that the cost of energy for BESS is lower when compared to DG; the NPV for BESS is positive, while for DG, it is negative; the IRR for BESS is 17.56%, meaning the rate for the return on initial investment is reasonable, while for DG, it is 0%; the savings for the BESS customer are around 8.22%, while for DG, there is no savings (negative index), and the payback for BESS is 9–10 years, while there is no payback for DG.

Regarding local pollutants, the following indices are presented that can be avoided with the use of BESS: tons of CO_2-eq of direct emissions, CO, particulate matter (PM), NOx, carbon credits, and the financial value of saved CO_2-eq emissions. These data are listed in **Table 9**. These indices underscore the importance of using BESS to mitigate the negative impacts caused by polluting

Table 6. Sizing of the BESS + PV and DG system.

BESS + PV	Value	DG	Value
Nominal energy [kWh]	161	DG power [kW]	750
Active energy [kW]	161	–	–
PV power [kWp]	270	–	–

Table 7. BESS + FV financial viability.

Parameters	Value
LCOE before [R$ MWh^{-1}]	1 174.45
LCOE after [R$ MWh^{-1}]	1 077.94
NPV [R$]	982 664.34
IRR [%]	17.56
Customer savings [%]	8.22
Payback	Between 9 and 10 years

Table 8. DG financial viability.

Parameters	Value
LCOE before [R$ MWh^{-1}]	1 174.45
LCOE after [R$ MWh^{-1}]	1 327.64
NPV [R$]	−1 559 871.71
IRR [%]	–
Customer savings [%]	−13.04
Payback	–

Table 9. Environmental analysis.

Parameters	Value
Avoided tons of CO_2-eq of direct emissions (ton of CO_2/year)	144.79
CO [kg $year^{-1}$]	65.71
PM [kg $year^{-1}$]	2.98
NOx [kg $year^{-1}$]	313.86
Carbon credit	144.79
Financial value of saved emissions—carbon credit [R$]	3 764.58

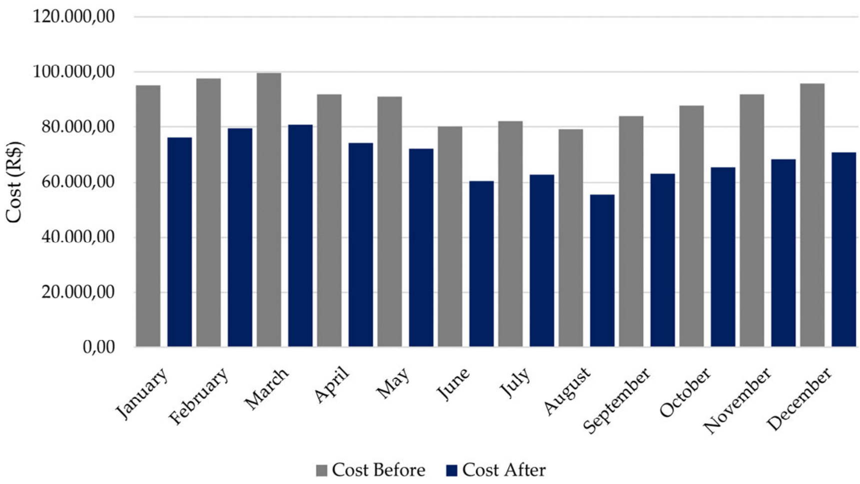

Figure 3. Costs before and after for BESS + PV.

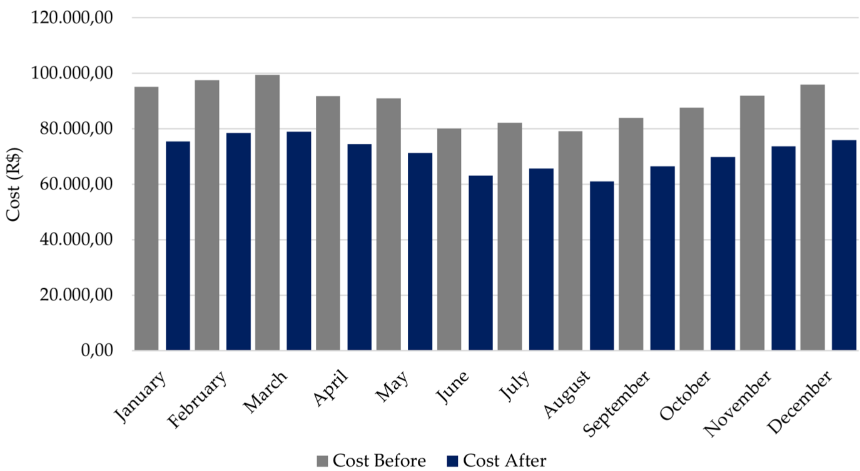

Figure 4. Costs before and after for DG.

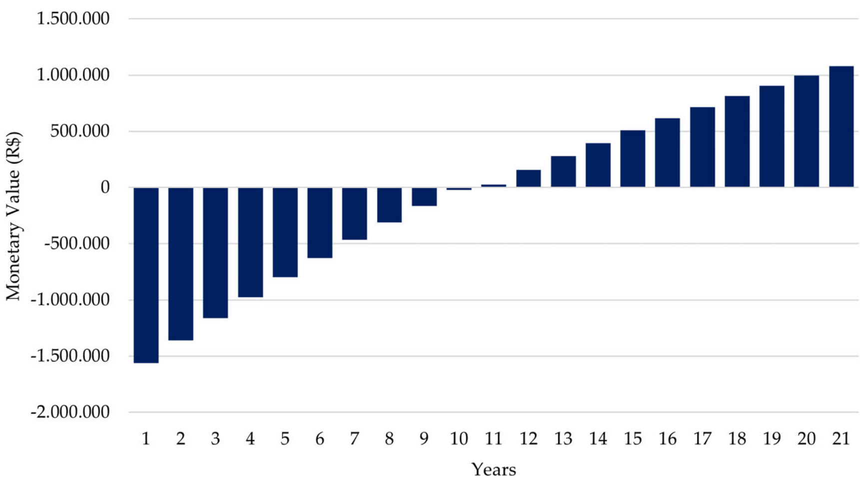

Figure 5. Cash flow for BESS + PV.

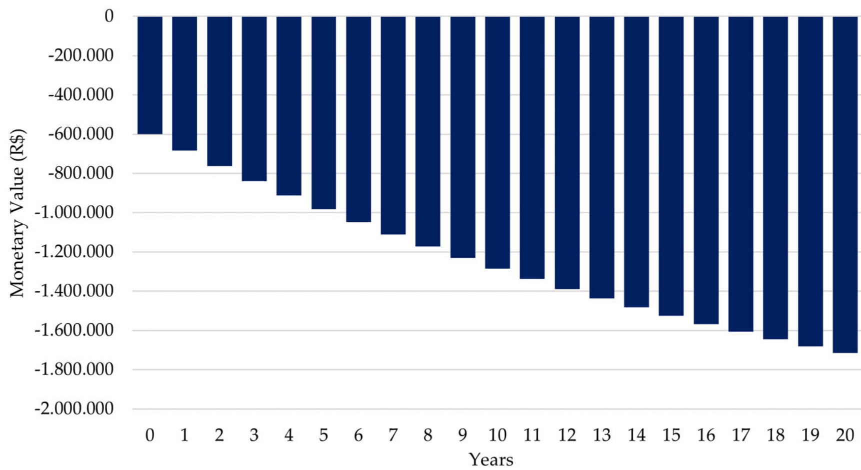

Figure 6. Cash flow for DG.

systems and emphasize the significance of these indicators when deciding which system to use.

The total costs before and after, for both BESS + PV and DG, are presented in the graphs in **Figure 3** and **4**. It is noticeable that there is a reduction in costs for both alternatives; however, BESS has a lower final cost.

Additionally, the cash flow is also displayed, in **Figure 5** and **6**, showing a decrease in costs for BESS until reaching the break-even point, indicating the system's viability. In contrast, the cash flow for DG only exhibits a continuous increase in costs, without any signs of profit.

In the case of BESS, this occurs due to a reduction in O&M costs, lower energy costs subsequently, reduced dependence on the grid, and increased utilization of the PV system for BESS recharging. Additionally, the fine that was previously paid in case of a power outage will cease to exist after the system implementation, making it profitable. In contrast, all these indicators do not make DG more viable, given that it does not utilize a PV system, incurs higher O&M costs throughout the year, and is still subject to fines in cases of power outages, as DG cannot act in milliseconds.

5. Conclusions

In conclusion, this study successfully introduced an innovative tool, carefully designed to size BESS integrated with PV systems, compared to DG. The primary focus aimed to meet customers' unique needs in the Brazilian free energy market, addressing evident gaps in current commercial sizing software. Noteworthy features include user-friendliness and technical and financial analysis, essential for energy marketers looking to offer this solution to their clients. Furthermore, the proposed tool indicates the most advantageous scenario for each analyzed customer based on recommended indicators such as LCOE, NPV, IRR, and payback.

Our approach fills the identified gap and establishes new standards by considering tariff specifics and regional characteristics unique to the Brazilian scenario. Additionally, the tool provides comparative details regarding DG, highlighting the benefits of using the sustainable system composed of BESS integrated with PV. The clear benefit includes the number of pollutants that can be saved.

Moreover, the methodology and architecture of the tool were detailed to provide a comprehensive understanding of its operation. The criteria adopted for development prioritize technical conciseness and practical relevance of each parameter in the national context. To illustrate the tool's applicability, we conducted a case study, presenting a representative customer in the Brazilian scenario. The presented data showcase the tool's ability to handle real situations and specific market variables.

A comprehensive comparison between the alternatives BESS + PV and DG reveals the viability of the sustainable option, with a payback period between 9 and 10 years and a cost savings of 8.22%. This result demonstrates that, in the analyzed case, the sustainable system has fewer incidents than the DG system, which requires constant maintenance and interventions, such as providing fuel for the generator, impacting its financial viability. However, it's emphasized that this conclusion is specific to the analyzed system size, and the financial indices indicate the best alternative in the tool.

Furthermore, the results recommend the BESS with PV system, indicating that the renewable generation source promotes greater independence from the grid and energy autonomy and enables the integrated system, as also observed in studies. Another significant, albeit qualitative, impact is using BESS as an immediate backup source, which can respond to the load more quickly than DG, which requires a startup time for its operation, especially when operating at a nominal load. This latter point becomes essential when the load is sensitive to power outages or network issues.

In summary, this tool addresses the identified gap in existing software and sets a new standard for sizing energy systems in the Brazilian context. Additionally, it catalyzes increased use and dissemination of sustainable systems (BESS + PV), which is increasingly essential given the growing installation of renewable systems in loads not necessarily present in the free energy market. There is a greater adoption of these systems in isolated regions, where the dependence on energy sources, whether sustainable or not, is more pronounced. It is due to specific issues in these areas, such as excessive tariffs, providing greater viability for storage systems in conjunction with renewable energy sources.

Moreover, there is a potential application of these systems in increasing the fleet of electric vehicles in Brazil, driving the need for larger quantities of charging stations. This, in turn, will require increased use of systems (BESS + PV) to support the power grid and recharge electric vehicles. This tool and the resulting implications represent a significant step toward sustainability, efficiency, and energy autonomy.

Regarding limitations, the tool presents some, highlighted in its final analysis, where the result is derived from a data table (spreadsheets), calculating the lowest LCOE value to provide the best system feasibility. Possible enhancements to the tool could be achieved through advanced optimization techniques, requiring a more robust option for performing calculations. Due to the nature of the platform used, there are limitations to developing more complex processes. As it is a recent service, some functionalities within the support platform may be considered limited, with the potential for future improvements. Ideally, the development of the tool could be more efficient in a more flexible environment, providing greater freedom for developers.

From a technical standpoint, considering possible improvements, the tool could be enhanced to cater to other customers in the regulated market, analyze the generation and transmission sectors, and isolate systems. Expanding the tool's scope would be highly beneficial, considering the growing importance of assets to strengthen customer sustainability and energy security.

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Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization, A.M. and T.C.; methodology, A.M. and T.C.; validation, A.M., T.C., A.V., A.C.R., R.D.F., M.A.M, A.I., and M.H.N.M.; formal analysis, A.M.; investigation, A.M., T.C., and M.A.M; resources, A.C.R., M.A.M and A.I.; data curation, A.M.; writing—original draft, A.M. and T.C.; preparation, A.M., T.C., and A.V.; writing—review and editing, A.M., T.C., A.V., A.C.R., R.D.F., M.A.M, A.I., and M.H.N.M.; supervision, R.D.F. and M.H.N.M. All authors have read and agreed to the published version of the manuscript.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Keywords

batteries, battery energy-storage systems, diesel generators, free energy markets, photovoltaics, sizings, technical-economic analyses

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