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23rd International Conference on Renewable Energies and Power Quality
(ICREPQ'25) Tenerife (Spain), 25th to 27th June 2025
ISBN-13: 978-84-09-66511-2

Development of a Computational Platform for the Analysis of Financial Indicators in Institutions of the Brazilian Federal Education Network in the Context of Distributed Generation: A Case Study of the University of Brasília

Brenno S. do Vale[1], Alex Reis[1], Loana. N. Velasco[1], Tânia M. Francisco[2], Ênio C. Resende[3] and Luiz C.G. Freitas[3]

[1] Faculty of Science, Technology in Engineering, and Energy Engineering, University of Brasilia
University of Brasilia, Brasilia, Brazil
[2] Administration, Federal University of São Paulo, São Paulo, Brazil
[3] Faculty of Electrical Engineering,
Federal University of Uberlandia, Uberlandia, Brazil

Abstract. The motivation for this study stems from the need for universities to improve energy efficiency and financial management amid increasing sustainability commitments. The main objective of this work is to create a computational platform to provide a comprehensive financial report model, aimed at administrative and financial managers at the University of Brasília (UnB), with specific indicators for monitoring expenses and savings related to electricity consumption. The methodology involves a thorough analysis of several indicators, including expense composition, energy tariffs, savings generated by Distributed Generation (DG) systems, fines, and demand contracts. The results demonstrate that it is possible to obtain a detailed view of the dynamics of energy consumption in government institutions, highlighting critical areas of spending and savings opportunities. The report model developed is a powerful tool for managers, allowing for more informed and strategic decision-making by focusing on efficiency and sustainability. It concludes with policy recommendations to promote reduced electricity costs, including suggestions for generating locally viable sustainable energy, changes to demand-side contracts, and reduced expenditure on fines related to power factor.

Key words. Consumption Analysis, Demand Side Management, Energy Management System, Peak Demand, Solar Energy.

1. Introduction

The theme Environmental, Social, and Governance (ESG) has attracted global attention in recent years. ESG foundations are based on the 17 Sustainable Development Goals (SDGs), established by the United Nations and various international entities. They represent a set of criteria that assess an organization's performance in areas related to sustainability, social responsibility, and the effectiveness of corporate governance [1]. The impact of this new trend can be seen not only in the private corporate world but also in projects in public and governmental institutions [2]-[6].

In Brazil, as Higher Education Institutions (HEIs) intensify their efforts to incorporate ESG principles into their operations and strategies, it becomes clear that efficient resource management, especially electrical energy, plays a fundamental role in this commitment. Responsible use of energy not only contributes to reducing environmental impact but also saves valuable financial resources, thereby promoting responsible governance [4], [7]. However, actions aimed at improving Energy Efficiency (EE) and promoting local generation through renewable sources face management challenges and typically require specialized professionals to monitor the system. For example, when a Photovoltaic (PV) system connected to the grid is installed, a reduction in electricity costs is expected, but for this to occur, careful performance monitoring is necessary. As noted in [8], [9], despite a reduction in active energy consumption, reactive energy will remain, resulting in a decrease in the consumer unit's power factor, which may lead to fines for excess reactive power, thus reducing the attractiveness of the investment if poorly managed.

Moreover, numerous factors demand the decision-maker's attention to promote truly sustainable energy management. Among these are: the composition of expenses, highlighting waste and potential savings; proper tariff classification and appropriate sizing of the contracted demand; constant monitoring of energy generated by PV systems to ensure the expected return; and, finally, the mitigation of fines, whether due to excess reactive power or contract demand violations.

In this context, in October 2016, the University of Brasília (UnB) launched an ambitious energy efficiency and DG program in partnership with the National Electrical Energy Agency (ANEEL). This initiative encompassed a broad range of actions, from installing PV plants to modernizing existing facilities. As part of these efforts, a comprehensive Integrated Energy Management System (SIGE) was created, aimed at reducing electricity costs and increasing the institution's productivity through the establishment of well-planned policies, objectives, responsibilities, procedures, training, and internal audits, as noted in [10]-[12].

The SIGE calculates key performance indicators that allow managers to differentiate expenses, identify improvement opportunities, and monitor the results of EE actions implemented in a fully data-driven manner [13]-[15]. Consequently, financial control, previously done only through the energy bills of Consumer Units (CUs), can be expanded to a detailed analysis of each measurement point.

Given the above, the main purpose of this work is to present a proposal for a computational platform designed to provide a comprehensive financial report model for administrative and financial managers. The platform includes specific indicators to monitor expenses and savings related to electricity consumption. The methodology involves an in-depth analysis of various factors including expense composition, energy tariffs, savings generated by DG units based on PV systems, fines, and energy demand contracts established with power companies.

To present the findings, the paper is organized as follows: Section 2 describes the project's methodology; Section 3 presents the results obtained through data analysis from the four campuses of the University of Brasília; and finally, Section 4 offers final considerations and recommendations to reduce electricity costs, encourage locally viable sustainable energy generation, optimize demand contracts, and minimize fines related to power quality indicators.

2. Materials and Methods

The University of Brasília (UnB) has four main campuses, which are the focus of this study: Darcy Ribeiro Campus, located in Asa Norte; the UnB Gama Faculty Campus (FGA), located in Gama; the UnB Ceilândia Faculty Campus (FCE), located in Ceilândia; and the UnB Planaltina Faculty Campus (FUP), located in Planaltina.

The first step in analyzing energy consumption is assessing the tariff category for each unit. The National Agency of Electric Energy (Agência Nacional de Energia Elétrica - ANEEL) defines the regulatory obligations of each consumer based on installed power capacity. As high-voltage consumers, all four campuses fall under Group A, classified in the Public Power subgroup. Regarding the tariff type, the FGA, FCE, and FUP campuses are all under the Green Hourly Tariff (GHT), while the Darcy Ribeiro campus falls under the Blue Hourly Tariff (BHT), with the key distinction being the variation in demand tariff periods.

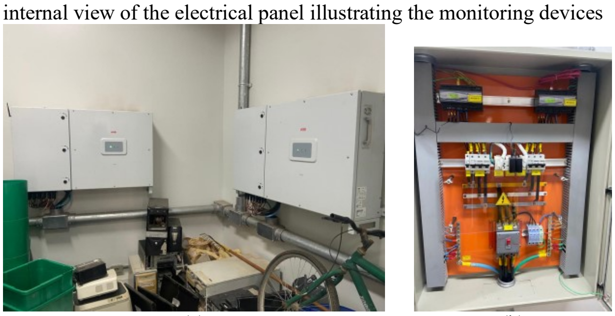
In addition to electrical information about each campus, it is necessary to describe the current stage of the installed data acquisition system. In this paper, the authors analyze six measuring points located in the Gama Faculty Campus (FGA) - Laboratory for Transport Development and Alternative Energies (LDTEA), and Academic Unit (UAC) -, installed next to the inverters of the PV plants, as portrayed in Figure 1. Figures 2 and 3 illustrate the inverters along with the electrical panel. The electrical panel serves as the Point of Common Coupling (PCC) between the inverters, the load, and the grid. Figures 2(b) and 2(c) offer an internal view of the panel connections, highlighting the switches that connect the photovoltaic solar plant and electrical loads to the PCC, as well as the monitoring devices.

(a) (b)

Fig. 1. Gama Campus of the University of Brasília: (a) (1) Teaching Unit (UED); (2) Academic Unit (UAC); (3) Sports and Equipment Services Module (MESP); (4) Laboratory for Transport Development and Alternative Energies (LDTEA); (b) Solarimetric stations installed nearby (1) Teaching Unit (UED).

(a) (b)

Fig. 2. PV **LDTEA**: Electrical devices that connect the PV power plant to grid and loads: (a) 30kVA CANADIAN SOLAR inverters (b) internal view of the electrical panel illustrating the monitoring devices



(a) (b)

Fig. 3. PV **UAC**: Electrical devices that connected the PV power plant to grid and loads: (a) 50 kVA ABB solar inverters (b) internal view of the electrical panel illustrating the monitoring devices

The 128 kWp PV array installed on the roof of the LDTEA consists of 320 photovoltaic modules manufactured by Canadian Solar, model HiKu CS3W-400P. Each module has a peak power of 400 Wp, is tilted at a 15º inclination, and is oriented to geographic north. The PV modules are connected to four CSI-30K-T400GL02-E three-phase string inverters from the manufacturer Canadian Solar, each one with 30 kVA of rated power.

The PV array installed on the roof of the Academic Unit (UAC) consists of 297 PV modules manufactured by Canadian Solar, model KuMax CS3U-355. Each module has a peak power of 355 Wp, is tilted at a 15º inclination, and is oriented to geographic north. The photovoltaic modules are connected to two ABB PVS-50-TL three-phase string inverters, each with a rated power of 50 kVA.

Given this setup, this work primarily focuses on developing indicators and reports for the university's financial management sector, due to the greater data availability and potential impact. Efficient Energy Management has been identified as a high-potential area capable of generating significant financial savings. Financial indicators, such as the reduction of energy expenses and Return On Investment (ROI), are more tangible and easier to communicate.

The construction of the indicators was carried out in collaboration with the Administration Office team to ensure coherence and accuracy. The report was designed to present the data clearly and accessibly, with interactive screens that give the manager more control and understanding over the analysis.

3. Financial impact of the PV power plants at the University of Brasília (UnB)

Three main goals of the report were identified. The first one is to classify the university spending on energy. Two main indicators were identified to clearly and simply assess this objective: (i) the breakdown of total electricity expenses, identifying costs and savings reflected in the electricity bill (e.g., consumption costs, demand charges, contributions to public lighting – CIP, etc.), and (ii) the monitoring of average monthly tariffs. The composition of the total electricity expeses was calculated based on the collection of the following costs/discounts from the accessible bills: Off-peak consumption, Peak consumption, Power demand (peak and off-peak), Reactive power surplus fines, Public lighting tariff, Tariff flag surcharges (null for the analyzed period), Credits for continuity violation (null for the analyzed period), Credits for energy generation (injection into the grid).

The accuracy and reliability of the data used in this analysis were ensured by collecting information directly from official and verifiable sources. Electricity cost and consumption data were extracted from utility bills issued by the provider for the University of Brasília (UnB), ensuring authenticity.

Photovoltaic generation values were obtained directly from meters installed on the inverters of solar plants, ensuring precise measurements aligned with available monitoring equipment.

Some limitations should be considered. The analysis of savings from solar plants was restricted to the FGA campus due to the availability of specific meters. Additionally, data variations may result from external factors such as fluctuations in solar irradiation and possible measurement inaccuracies. These limitations do not compromise the overall validity of the results but highlight the need for continuous monitoring and improvement of measurement systems.

3.1. General analysis of energy expenses at the University of Brasília (UnB)

A detailed analysis revealed that UnB's total electricity costs amounted to approximately R$ 4.38 million between May and August 2023 (around US$ 730,000.00). There was a decrease of 8.92% in total expenses from May to June and from July to August. The main factor behind this reduction is the vacation period, as the lower number of students results in less energy consumption. This conclusion is supported by the fact that energy consumption is the main cost in all months. While all other costs decreased by less than 5% between June and August, the expenses for peak and off-peak consumption showed a 13% reduction. Figure 4 illustrates the total energy spending over the analyzed period.

The percentage of each listed category was also clearly identified. The largest energy costs, in descending order, occur during the off-peak period, followed by peak consumption, peak demand, and off-peak demand. These four categories account for an average of 99.26% of the total energy expenses across the four campuses. No penalties for late payments, additional charges from tariff flags, or demand exceedance fees were recorded. This demonstrates that electricity expenses are consistently paid on time and that the demand contract for the units aligns with the university's needs.

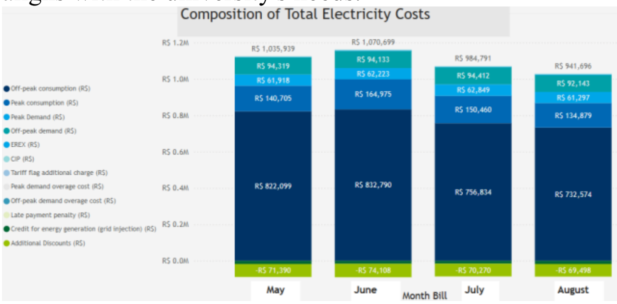


Fig. 4. Total electricity expenses per month – General. Note: US$ 1.00 (United States Dollar) = R$ 5.86 (Brazilian Real).

Another key aspect of interest involves the savings derived from solar credits and tax exemptions, which totaled R$ 352,000 (approximately US$ 55,000). The tax immunity for ICMS, CIP, among others, accounted for nearly 80% of this amount. In relation to the economy provided by energy injection by the photovoltaic systems, it was verified savings of R$67k (around US$ 11k), totaling 20% of the abovementioned amount.

By filtering data by campus, it is also possible to observe the distribution of expenses and savings for each particular case. As expected, the Darcy Ribeiro campus represents the largest share of costs, accounting for 92.8% of total expenses, as well as discounts, at 76.3%.

No discounts were recorded from energy injection. This does not mean there are no savings from on-site power plants, but rather that generation does not produce a surplus at any time of the day. The FUP campus ranks as the second campus with the highest expense, accounting for 2.7% of the total. However, it is the unit with the smallest recorded discounts, both in percentage and absolute terms (only US$ 1.26k). Additionally, no energy injection was recorded, a situation similar to the Darcy campus.

The FGA campus would have expenses similar to FUP; however, due to the significant amount of energy generated by the PV power plant, it stands out as the most self-sufficient campus of the university. Of the R$ 55.8k in savings, energy injection accounts for 93.3%. Meanwhile, the FCE campus has the lowest total electricity expenses among the four campuses and recorded minimal energy injection.

3.2. Monitoring of the economy provided by the solar power plants at the University of Brasília (UnB)

The second objective of this study is to establish a routine for monitoring the financial savings generated by the university's solar power plants. This analysis was based on two indicators: real and apparent energy savings and power generation. It is worth noting that only data related to the FGA campus and to the period from June to August will be considered. This limitation is due the need of using data from the energy meters, which are installed directly on the inverters of the power plants at this campus only.

Monthly savings and actual generation at FGA were calculated based on data from the meters installed at FGA. Firstly, the generation data from each device were extracted and grouped by reading month. From there, the calculation was performed to obtain the monthly savings for each month.

Figure 5 presents the savings and total solar generation at FGA. The data was obtained by six measuring devices installed in FGA. It is possible noticing that between June and August the real power generation was 76.1MWh which corresponds to a R$46.6k economy. This value is 24.6% bigger than all campus injected energy, even considering that the power plants of the Assis Chateaubriand Art São Paulo Museum (MASP) and from the Unidade de Ensino e Docência (UED) were not included in the monitoring.

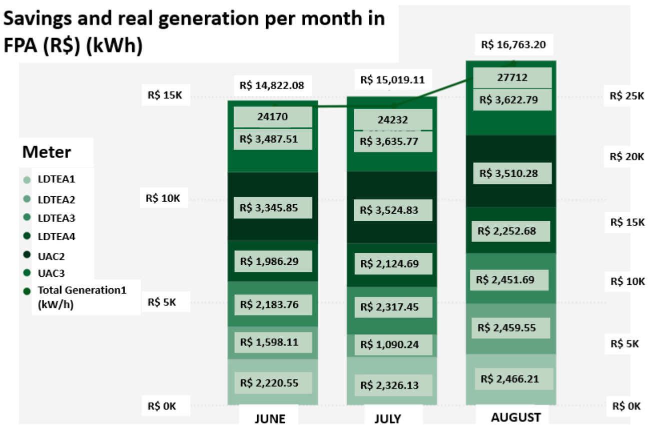


Fig. 5. Economy and real power generation at FGA.

The power generation fluctuation observed in this period can be a direct consequence of the solar irradiation variation. This variability was confirmed using irradiation data provided by the Centro de Referência para as Energia Solar e Eólica Sérgio de S. Brito (CRESESB). In relation to each inverter contribution, it was concluded that the inverters installed at Desenvolvimento de Transportes e Energias Alternativas (LDTEA) generated the largest amount of power in the period, totaling 41.6 MWh (54.7% of the total monitored).

Meanwhile, the photovoltaic power plant of the Academic Unit (UAC) was responsible for generating the remaining 45.3% of the total monitored generation. The average monthly generation was approximately 11.5 MWh, 20% below the estimated value. A similar difference was also noted between the measured and estimated average generation for the LDTEA plant. This reduction can be explained by various factors, such as the previously mentioned variation in solar irradiation, as well as the natural loss of system efficiency over time.

The analysis of economy and monthly apparent power generation was performed on the basis of the data provided by electric bills from the FGA. The results are shown by Figure 6. Notably, a reduction in savings was observed between June and July, which is not reflected in Figure 5.

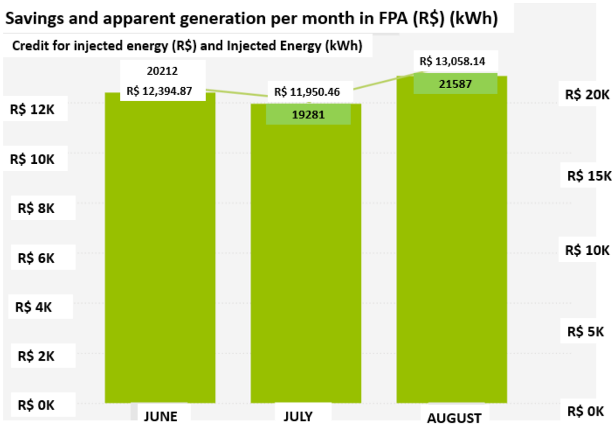


Fig. 6. Savings and apparent generation per month at FGA.

3.3. Opportunities for cost cuts and value gains provided by the solar power plants at the University of Brasília (UnB)

The final objective of the proposed report was to identify opportunities for cost reductions and value improvements. In this sense, three indicators related to this goal were identified: the reactive power surplus penalty (EREX) per campus, monthly energy consumption, and monthly energy demand.

The EREX is a penalty related to consumers of Group A that presented power factor below 0.92, as established by ANEEL. Figure 7 presents the values of EREX for each one of the UnB campuses. It is possible to notice that the campus Darcy Ribeiro suffered the biggest EREX penalty, totaling 95.6% of the total EREX value considering the four campuses. However, there is a potential for reduction by controlling the power factor by capacitor banks installation or by the new motors acquisition.

Based on the collected data on peak and off-peak consumption and their respective costs, the graph shown in Fig. 5 was constructed. The total consumption during the period was approximately 5.76 million kWh. Additionally, 90% of this energy was consumed during off-peak hours and 10% during on-peak hours.

As shown in the analysis of total expenses in Figure 4, energy consumption follows the same variation pattern throughout the analyzed months. Moreover, by applying filtering by campus, it is also evident that the units with the highest expenses are those with the highest consumption: Darcy Ribeiro with the highest consumption (93.9% of the total), followed by FUP (2.3%), FGA (2.1%), and FCE (1.2%).

This type of analysis is particularly useful for helping managers identify where the greatest potential for consumption reduction lies and adjust priorities for implementing energy efficiency (EE) projects. This approach can yield results that significantly impact both the university's finances and UnB's role in promoting sustainable development within society.

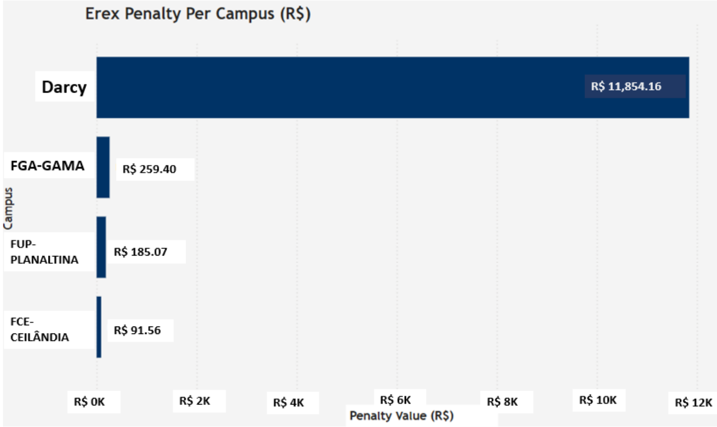


Fig. 7. EREX penalty per campus.

Effective energy management requires monitoring routine and analysis of demand contracts for a facility. This analysis is based on three essential pieces of information: the measured demand, the contracted demand value, and the billed demand amount. To facilitate this process, the graph illustrated in Figure 8 was proposed.

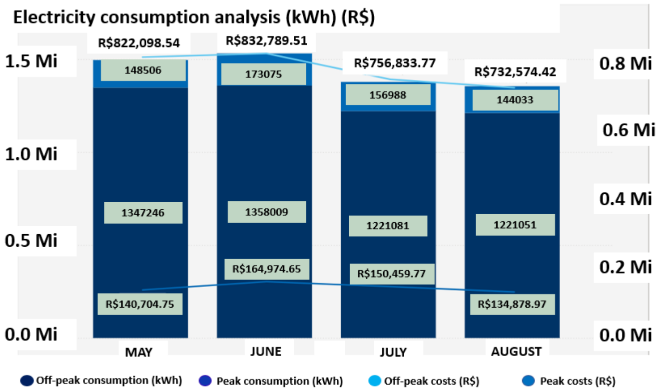


Fig. 8. Monthly energy consumption analysis.

Analyzing energy demand in a general context—encompassing all four campuses—shows that the contracts are almost perfectly meeting the university's total demand. The total billed demand exceeded the total contracted demand by only 79 kW, representing an excess of less than 0.01%.

Applying campus-specific filters reveals the unique characteristics of each unit's energy demand. For instance, Darcy Ribeiro, as expected, shows the highest billed demand among the units, accounting for approximately 93.9% of the total. Due to its tariff model, its contract includes two demand billings: off-peak and peak hours.

This phenomenon can be linked to the academic break period, as most energy consumption and demand occur during off-peak hours, while peak-hour demand is naturally lower during this period. Therefore, the most significant difference is observed during off-peak hours.

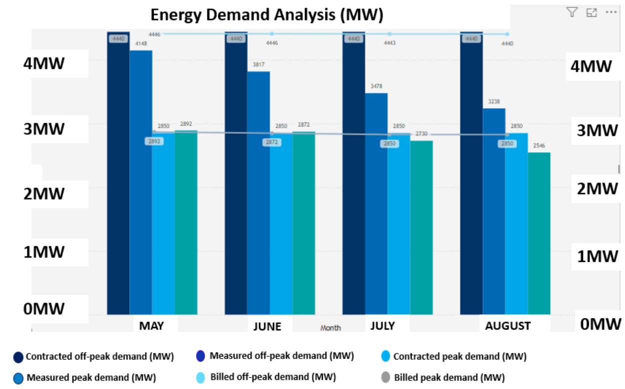


Fig. 9. Analysis of Monthly Energy Demand

Although off-peak demand measurements fall below the contracted values, a more in-depth data analysis is required to assess the feasibility of adjusting the contracts. This is because, like energy consumption, demand also exhibits seasonality throughout the year. Thus, it is possible that demand may increase or decrease further in other months of the year.

Regarding the FUP and FCE campuses, a similar reduction in demand can be observed. Since both units are subjected to the THV (Time-of-Use) tariff model, all hours are classified as off-peak and are subject to the same tariff. The FCE campus has the lowest recorded demand, only 409 kW, slightly lower than FUP's 474 kW.

Finally, the demand behavior at the FGA campus stands out. In contrast to the other campuses, the measured demand values remained relatively constant throughout the analyzed period. This fact may be directly related to the influence of the installed solar plants on the readings. Since a photovoltaic generation system requires a certain amount of power to operate, it is possible that the solar plants compensated for the expected reduction in demand due to the academic break period.

4. Proposed Report

To better analyze the implementation of the proposed indicators in the SIGE UnB, Microsoft Power BI® was used as the main tool for data display and analysis. Figures 10 and 11 show how the aforementioned indicators were present on the pages of the obtained report.

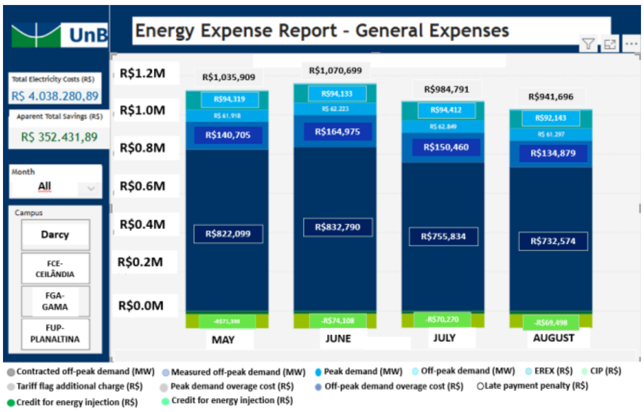


Fig. 10. General energy expenses page.

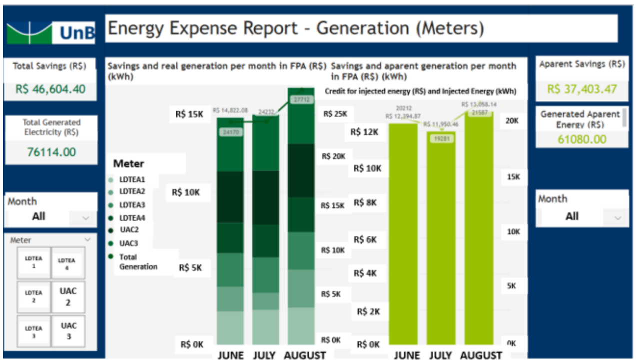


Fig. 11. Energy generation page.

Three report pages were created, each containing the analyses related to the three objectives presented in Section 3.1. Additionally, each page includes interactive filters that allow the user to select data for a specific month, campus, or meter, thus facilitating the analysis of individual scenarios.

5. Conclusions

This study motivation is to provide a tool to enhance energy efficiency and financial oversight while advancing sustainability goals. The proposed solution enables the monitoring of the photovoltaic system's energy consumption, as well as facilitating fault identification and predictive maintenance procedures.

The analysis of expense composition highlights energy consumption as the main component, revealing monthly variations influenced by seasonal factors, such as holidays. This understanding is crucial for anticipating fluctuations and optimizing consumption strategies.

Average consumption tariffs remain relatively stable on a monthly basis but vary between campuses. Notably, the Darcy Ribeiro campus benefits from lower peak tariffs due to its specific tariff modality.

The analysis of the actual generation from photovoltaic plants highlights significant savings, surpassing the energy injected into the grid. Generation variation reflects seasonal conditions, with a notable increase during months of higher sunlight.

The identification of penalties, especially excess reactive power at the Darcy Ribeiro campus, highlights areas of opportunity for optimizing the power factor. Targeted strategies can reduce costs and improve energy efficiency.

The analysis of demand contracts generally demonstrates efficient coverage of total demand. The variation in demand across campuses may indicate the need for contractual adjustments tailored to each campus.

Finally, the continuous implementation of energy efficiency measures, contractual adjustments, and the sustained generation of renewable energy are considered essential for cost reduction and the promotion of sustainability. In this regard, a contribution was made to understanding energy management performance on university campuses, demonstrating that the proposed SIGE provides a solid foundation necessary for informed decision-making, enabling UnB to strategically direct efforts to achieve its energy and environmental goals.

The platform can be implemented in different universities by adapting its structure to each institution's specific energy consumption patterns, regulatory frameworks, and financial management practices. Implementation would require integrating the platform with existing energy monitoring systems, ensuring compatibility with available data sources, and customizing indicators based on institutional priorities. Collaboration with administrative and financial teams is essential to refine the reporting model and optimize decision-making. Additionally, best practices from the University of Brasília's experience can serve as a guideline, helping other universities streamline energy efficiency efforts and improve cost management.

Acknowledgement

This research was partially funded in part by Universidade de Brasília (UnB), and in part by the Ministério da Educação (MEC)—Grant SIMEC-ted-pt-13285, and Fundação de Amparo à Pesquisa do Distrito Federal (FAPDF)—Grant SEI-GDF: 00193-00002423/2023-11.

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