Technical-economic feasibility of installing a photovoltaic generation plant: a case study in a public university

Viabilidade técnico-econômica de instalação de uma usina de geração fotovoltaica: estudo de caso em uma universidade pública

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ABSTRACT
The energy compensation system has attracted the interest of several sectors, including the public sector. In this context, this work presents a technical dimensioning and techno-economic feasibility of installing a photovoltaic generation plant, considering the service to a Brazilian public university campus. Four systems were designed using NREL's PVWatts and SAM tools with the NSRDB database, analyzing 6 economic viability situations. The results show a payback of 6 years and 3 months for a 545kWp system without energy storage and 10 years and 5 months for a 180kWp system with energy storage. The variations in the results depend on the implementation considerations of each of the proposed systems, such as the energy availability demand contract and the savings on the bill made possible by the implementation method.

Keywords: Photovoltaic Power Generation, Techno-Economic Feasibility, Sizing System.
RESUMO
O sistema de compensação de energia tem atraído interesse de diversos setores, incluindo o setor público. Nesse contexto, este trabalho apresenta um dimensionamento técnico e uma viabilidade técnico-econômica de instalação de uma usina de geração fotovoltaica, considerando o atendimento a um campus de uma universidade pública brasileira. Foram dimensionados 4 sistemas por meio das ferramentas PV Watts e SAM da NREL com base de dados NSRDB, além de analisadas 6 situações de viabilidade econômica. Os resultados obtidos demonstram um payback de 6 anos e 3 meses para um Sistema de 545kWp sem armazenamento de energia e de 10 anos e 5 meses para um Sistema de 180kWp com armazenamento de energia. As variações obtidas nos resultados dependem das considerações de implantação de cada um dos Sistemas propostos, como contrato de demanda de disponibilidade de energia, bem como economia na conta possibilitada pela forma de implantação.

Palavras-chave: Geração Fotovoltaica, Viabilidade Técnico-Econômica, Dimensionamento.

RESUMEN
El sistema de compensación energética ha atraído el interés de varios sectores, incluido el sector público. En este contexto, este trabajo presenta un dimensionamiento técnico y factibilidad tecnoeconómica de la instalación de una planta de generación fotovoltaica, considerando el servicio a un campus universitario público brasileño. Se diseñaron cuatro sistemas utilizando las herramientas PV Watts y SAM del NREL con la base de datos NSRDB, analizando 6 situaciones de viabilidad económica. Los resultados muestran una amortización de 6 años y 3 meses para un sistema de 545kWp sin almacenamiento de energía y de 10 años y 5 meses para un sistema de 180kWp con almacenamiento de energía. Las variaciones en los resultados dependen de las consideraciones de implementación de cada uno de los sistemas propuestos, como el contrato de demanda de disponibilidad de energía y el ahorro en la factura que posibilita el método de implementación.

Palabras clave: Generación de Energía Fotovoltaica, Factibilidad Tecno-Económica, Sistema de Dimensionamiento.

1 INTRODUCTION

The increasing diversification of energy sources is observed year after year in the National Energy Balance reports. In 2020, whose base year is 2019, the share of renewable energy in the Brazilian matrix was 83%, a share much higher than that observed in the rest of the world (22%). It can be seen that the share of solar energy
corresponds to 1% of the matrix and 2.8% of the group "Other renewables", and that there was a growth of 92.2% compared to the previous year 2018 (EPE, 2020). In the 2023 report, this figure reaches 87.9% in renewables, with a representation of 4.4% in solar energy, corresponding to a growth of 452% in 4 years (EPE, 2023) and 79.8% compared to 2021.

In this context, the number of distributed generation units has grown with the incentive of the National Electric Energy Agency (ANEEL, 2020a) to promote microgeneration (≤ 75kW) and minigeneration (between 75kW and 5MW) since NORMATIVE RESOLUTION No. 482, OF APRIL 17, 2012 (ANEEL, 2012) and its updates, through the Electric Energy Compensation System. It is observed that the amount of electricity generated has almost quadrupled and the annual number of connections has tripled, when comparing 2019 with 2018 (ANEEL, 2020c). In 2019, Brazil surpassed 1GW of installed capacity in micro and minigeneration (ANEEL, 2020d). As of September 2020, the number of registered photovoltaic systems (UFV) was 288,757, corresponding to almost 3.5GW of installed capacity and 360,263 consumer units benefiting from credits, according to (ANEEL, 2020b). This number increases to 3,282,683 in December 2023, with 25.4 GW of UFV, according to (ANEEL, 2023).

Economic incentives, which attract the attention of consumers from residential to commercial and industrial, aim to reduce electricity bills, as presented in (Ruviaro et al., 2018), allowing them to invest in other sectors of interest. This interest in incentives can also be seen in the increase in the number of connections from consumers in the A4 voltage group, for example, which almost tripled between 2019 and 2018 (ANEEL, 2020c).

For example, Valory et al. (2019) present an analysis of the feasibility and potential of photovoltaic generation for new installations at the Vitória-ES airport, showing a short payback period (6 years) for the company. In turn, Rocha et al. (2017) perform a stochastic economic analysis for microgeneration with photovoltaic systems in Brazil, based on incentives through tax exemption, which can be variable depending on the state. Economic studies, such as (Yamamoto, 2012) and (Tan and Chow, 2016), have
been carried out adapting to the tariff collection model of each country, which can vary and sometimes includes the possibility of buying and selling the energy generated.

Governmental connections represented a small number of annual connections, with 2 connections in 2013, 81 connections in 2017 and 72 connections until September 2020, a total of 326 generations today (ANEEL, 2020c). The government also encourages these sectors to pay attention to energy efficiency in the public sector, for example through the Procel Edifica programs, so that the buildings built require less energy consumption.

In the same way, public institutions, such as institutes and universities, have also awakened to the applicability in their contexts. The energy generated by the photovoltaic system of the Solar Energy Research Center of the UFSC has made it possible to satisfy the energy needs of the building with 13% of the generation and to have a surplus of 87% to be used as compensation for other consumer units of the same university, as can be seen in the work of (Zomer et al., 2017). As also shown in (Ruviaro et al., 2018), the economic feasibility study for the Federal University of Santa Maria (UFSM) shows a financial return obtained in about 6 years, also analyzing the possibility of adjusting demand contracts. Another study looks at the return on investment based on energy compensation for the North Wing UCSI University Campus in Malaysia, with a payback period of around 16 years, and compares it to another type of public policy-based incentive, "feed-in tariff", which would reduce the return on investment to around 11 years (Tan and Chow, 2016).

In turn, for the technical design, the use of computational tools that allow the specification of the components and the simulation of the system, as well as the analysis of the results, is verified in the literature. Among the software found, we can mention PVsyst (Lacchini et al., 2017) (Zomer et al., 2017), System Advisor Model (SAM) - NREL (Lacchini, 2017), HOMER (Ruviaro et al., 2018), CREARRAY associated with RADIASOL (Peraza, 2013) developed by the Labsol research laboratory at UFRS. An important feature is the loading of the solarimetric database, which can be provided by the software itself or uploaded by the user. Among the databases available are, for
example, INPE, NASA, NREL, Meteonorm, Openei-SWERA, as compared in (Zomer et al., 2017) and (Lacchini et al., 2017).

This paper aims to present the technical-sizing and the technical-economic feasibility of the installation of a photovoltaic generation plant for the university campus in the northern region of Minas Gerais, considering the scenario 2022, before the change of the legislation in 2023\(^1\).

The remaining sections of this paper are organized as follows. Section II presents the methodology of the work, and Sections III and IV describe the data from two case studies. The results and analysis are presented in Section V. Finally, Section VI presents the conclusions and points out future work.

2 METHODOLOGY

The methodology of this study can be divided into the following steps, as shown in Figure 1: (i) Consumption analysis; (ii) Initial Sizing of the system; (iii) Technical sizing; (iv) Feasibility Analysis and Results and, finally, (v) the definition of the proposal for the implementation of the photovoltaic generation plant.

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\(^1\) In 2023, Resolution 482 of 2012 was revoked with the implementation of Resolution 1059 of February 7, 2023.
In the first stage, Consumption Analysis, the energy bills are analyzed, and the main necessary data are obtained, such as Active Demand kW HFP, Excess kW HFP, Active Energy kWh HFP, Active Energy kWh HP, Municipal Public Lighting Contribution. In addition, the analyzed accounts present information on taxes such as IRPJ, PIS/PASEP, COFINS, CSLL.

The next stage of the initial sizing aims to obtain a more global estimate of the system, without going into the technical aspects of the equipment to be used in the generation system. So that it can be used as a starting point for the next step.

In the third step, the objective is the technical dimensioning, i.e. it is intended to design a real physical system composed of modules and inverters and to carry out a simulation based on the technical specifications of the chosen equipment. With the simulation it is desired to verify the performance of the designed system under conditions close to reality. For this design, this work uses the SAM NREL software.

The cost analysis of the system was based on data from the Strategic Study for Distributed Generation for the first half of 2020 in Brazil, prepared by (GREENER,
2020). For the economic feasibility analysis, the data of the current tariffs of the energy concessionaire that serves the locality for the type of consumers studied are considered, a percentage of annual consumption increase is considered, and a percentage for tariff adjustment is considered.

Finally, based on the analysis of the results obtained, considerations of implementation costs and payback time, it may be necessary to resume and evaluate alternative solutions until a proposal is obtained. It may also lead to a conclusion of infeasibility.

2.1 CASE STUDY 1

The first case study of this work considers an unnamed public university campus in the northern region of Minas Gerais. Data from the years 2018 and 2019 were collected and summarized in Figure 2, but only data from the last 12 months were needed for the sizing. The following main data are summarized:

- Classification: Class: Federal Public Power;
- Green THS A4 tariff modality;
- 90kW demand contract;
- Average Peak Demand (HP): 176kW;
- Average Off-Peak Demand (HFP): 252kW;
- Average HFP Active Energy Consumption: 72,117.5 kWh/month;
- Average Active HP Energy Consumption:
  - 7,700 kWh/month;
- HFP: from 8 pm to 5 pm;
- HP: from 5pm to 8pm (3 hours);
- Annual HFP consumption: 865,410.00 kWh/year;
- Annual HP consumption: 92,400.00 kWh/year.

These data are considered for the initial and technical dimensioning of the systems identified as 1 and 2, considering the hypothesis of using the energy compensation system
for the HFP consumption, since for the campus this portion represents the highest annual consumption and the highest cost of the energy bill. System 1 would be connected to the private network of the campus and System 2 would be connected to the network of the concessionaire CEMIG.

Figure 2. Consumption history for the years 2018 and 2019 of the Consumer Unit - University Campus.

Source: Authors (2023).

For a comparative study, a second alternative was considered (systems identified as 3 and 4), with energy storage through a battery bank and injection of the energy generated during peak hours, when the tariff is more expensive, to increase the compensation and reduce the size of the generation system. In this case, the energy consumed in HP and HFP was considered, as well as the proportionality within a year of working days and weekends and holidays to take into account the tariff difference. System 3 would be connected to the private network of the campus and System 4 would be connected to the network of the concessionaire CEMIG.
Thus, based on the location data of the Campus, it was initially estimated that a power of 478kWp would be needed for Systems 1 and 2, and 160kWp for Systems 3 and 4, considering:

- average hours of full daily sunshine data by SAM NREL software: 5.95kW/m²/day;
- solarimetric data source NSRDB;
- 20% total losses;
- module type: Standard\(^2\);
- type of arrangement: Fixed;
- Tilt angle: 20°
- angle relative to North Array Azimuth 0° (North-facing system)
- the remaining data were considered the standard values: losses: 14.08%, inverter efficiency: 96% and the DC to AC Size ratio of 1.2.

For the technical design of Systems 1 and 2, we chose the WEG inverter model SIW500H ST060 with a nominal AC active power of 60kW, manufacturer's efficiency of 98.7%, considering a factor between DC power and DC/AC AC power equal to 1.14. It is therefore proposed to use 8 inverters, each with 6 MPPT (Maximum Power Point Tracking) inputs, for a total nominal AC power of 480kW and a maximum of 528kW\(^3\).

For the technical design of Systems 3 and 4, we chose the WEG inverter model SIW500H ST040 with a nominal AC active power of 40kW, manufacturer's efficiency of 98.8%, considering a factor between the DC power and the DC/AC AC power equal to 1.14. Thus, it is proposed to use 4 inverters, each of the inverters with 4 MPPT (Maximum Power Point Tracking) inputs, for a total nominal AC power of 160kW.

For the photovoltaic module, the model KUMAXCS3U-355P of the Canadian manufacturer was chosen, of the polycrystalline type, 355Wp, with an efficiency of 17.89%. The specification data were also loaded into the software, considering the

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\(^2\) Input data used in the PVWatts tool.
\(^3\) The SAM software does not allow simulation with more than one inverter with multiple MPPT inputs, having a limit of 4 MPPT inputs to simulate. Thus, the system was divided, using the simulation with 1 inverter with half the power, with the same specification data and 3 MPPT inputs.
arrangement adopted for standardization, which was an equal number of modules per inverter.

For Systems 1 and 2, each inverter was configured with 192 modules, for a total of 1536 modules. There are 32 modules for each MPPT input, with two parallel strings of 16 modules each. For simulation purposes, 96 modules were loaded for the 3 MPPT inputs of the inverter.

For Systems 3 and 4, each inverter was configured with 128 modules, for a total of 512 modules. The MPPT input configuration was the same as before, but the inverter was simulated with the 4 MPPT inputs. Since the inverter datasheet did not include the equipment consumption, the data suggested by the SAM was used. The loaded losses were 1% for AC losses in the conductors, 0.5% for transformation losses, 0.5% for transmission and AC losses differentiated by MPPT of 0.5%, 1.0% and 1.5%, respectively, to account for the difference in distance between the modules and the inverter. On the other hand, the transformation and transmission losses have been included considering that to connect this system to the grid, it will be necessary to transform the low output voltage of the inverters to the medium voltage of 13.8kV of the distribution grid.

In addition, for Systems 3 and 4, a system efficiency of 92% and a depth of discharge of 70% for lithium-ion batteries were used to estimate the size of the battery bank. An integrated system based on converters, transformers, switchboards and containerized battery banks was considered.

Therefore, the cost reference estimates as average values R$ 2.46/Wp for a 500kWp photovoltaic system and R$ 2.48/Wp for a 150kWp size on the ground and R$ 1.22/Wp and R$ 1.28/Wp for the system integration value, respectively for a 500kWp and 150kWp size. The cost of the protected substation and the cost of R$ 2.65/Wh for the storage system were included. Therefore, the total value of the system considered in this analysis was R$ 2,285,130.40 for Systems 1 and 2 and R$ 4,313,078.85 for Systems 3 and 4.

For the economic feasibility analysis, we considered the current tariff data of the energy concessionaire CEMIG, which serves the State of Minas Gerais, for the year 2020
for the consumer type A4 2.3kV to 25kV, green tariff, without taxes. The accounts analyzed show tax deductions since they belong to the government. The value of the tariff adjustment considered was 4%, a value close to the inflation rate. Moreover, this value was adopted for a more conservative study.

As it is noted that for the implementation of the plant, it depends on the readjustment of the demand contract for Systems 1 and 3, the effect of this modification is considered in the feasibility study, which will increase the portion of the energy bill that refers to the demand, however, on the other hand, it will eliminate or reduce the value of the demand overrun portion. For System 1, contract demand would be 545kW and for System 3 it would be 180kW. Consumption growth is expected to be 2% per year. On the other hand, for Systems 2 and 4, the need for a new demand contract with CEMIG with the same values of Systems 1 and 2 is considered, but the costs related to the contract demand and exceeding the demand of the Campus consumer remain the same.

2.2 CASE STUDY 2

In order to provide an alternative solution for the implementation of the photovoltaic system on campus, a second case study was considered, a building called Building 1, belonging to the Campus, but connected to the CEMIG network, whose estimated data are:

- Classification: Class: Federal Public Power;
- Green THS A4 tariff modality;
- 120kW demand contract;
- Installed capacity: 500kVA;
- Average HFP active energy consumption: 16,000 kWh/month;
- Average HP active energy consumption: 4,000 kWh/month;
- HFP: 8 pm to 5 pm;
- HP: 5 pm to 8 pm (3 hours);
- Annual HFP consumption: 192,000 kWh/year;
- Annual HP consumption: 48,000 kWh/year;
The initial design data is the same as in the first case study, except for:

- type of arrangement: Fixed (roof mount);
- Tilt angle 10°
- angle relative to North Array Azimuth 1st Subgroup 62° and 2nd Subgroup 242°

System 5 is an energy balancing system for HFP consumption, limited to the maximum contract demand for the installed power in Building 1, which is 460kW. System 6 is an energy storage system with a battery bank and injection of the energy generated in the HP. In this case, the energy consumed in HP and HFP was considered, as well as the proportionality, within one year, of working days and weekends and holidays, to consider the tariff difference of both consumer units, Campus and Building 1.

For the technical design of System 5, we chose the inverter from the manufacturer WEG model SIW500H – ST0100 HV with a nominal AC active power of 100kW, manufacturer efficiency of 99%, with 2 inverters to divide the two subgroups, considering a factor between the DC power and the DC-AC power equal to 1.19 for the 1st Subgroup and 1.11 for the 2nd Subgroup. Thus, it is proposed to use 4 inverters, each of the inverters with 6 MPPT (Maximum power point tracking) inputs, totaling a nominal AC power of 400kW and a maximum of 420kW.4

For the technical design of System 6, the same inverter of System 5 was chosen, and the same configuration of the 1st Subgroup of System 5, were selected, with a total nominal AC power of 200kW and a maximum of 210kW.

In addition, for System 5, each inverter in the 1st Subgroup was configured with 336 modules, resulting in a total of 672 modules. There are 56 modules for each MPPT input, with two parallel strings of 28 modules each. For simulation purposes, 168 modules were loaded for the 3 MPPT inputs of the inverter. The 2nd Subgroup was configured with 312 modules per inverter, resulting in a total of 624 modules. There are 52 modules for each MPPT input, with two parallel strings of 26 modules each.

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4 It is worth mentioning that the SAM software does not allow simulation with more than one inverter with multiple MPPT inputs, having a limit of 4 MPPT inputs to simulate. Thus, the system was divided, using the simulation with 1 inverter with half the power, with the same specification data and 3 MPPT inputs.
In turn, System 6 has the same configuration as the 1st Subgroup of System 5. And to estimate the size of the battery bank, a system efficiency of 92% and depth of discharge of 70% for Lithium-Ion batteries were considered. The first case study was also considered as an integrated system based on converters, transformer, electrical panels and battery bank stored in containers.

The cost reference estimates as average values R$ 2.28/Wp for a photovoltaic system of the size of 500kWp on the roof and R$ 1.22/Wp the value of system integration of the same size and cost R$ 2.65/Wh for the storage system. Also included is the cost for low voltage transformer, 380V to 220V, due to the inverter output voltage of 100kW for System 5. Therefore, the total value of the system considered in this analysis was R$ 1,660,960.00 for System 5 and R$ 5,267,315.41 for System 6.

Therefore, considering the economic feasibility analysis, the same conditions are provided for the first case study. As it is noted that for the implementation of the plant, it depends on the readjustment of the contract of the demand of Building 1, the effect of this modification is considered in the feasibility study, change from 120kW to 460kW for System 5 to 238kW for System 6. In both cases, the costs of contract demand and overrun on campus are still present.

3 RESULTS

The technical sizing resulted in a 545.28kWp plant for Systems 1 and 2, with an annual generation capacity of 918MWh; 181.76kWp for Systems 3 and 4, with an annual generation capacity of 303MWh; 460.08kWp for System 5, with an annual generation capacity of 731MWh and 238.56kWp for System 6, with an annual generation capacity of 391 MWh, as shown in Table I.
Table I – SUMMARY OF TECHNICAL SIZING – SYSTEMS 1 TO 6.

<table>
<thead>
<tr>
<th>System</th>
<th>Ability</th>
<th>Annual Generation</th>
<th>N of Panels</th>
<th>Investors</th>
<th>Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 &amp; 2</td>
<td>545kWp</td>
<td>918MWh</td>
<td>1,536</td>
<td>8 x 60kW</td>
<td>2 strings in parallel w/ 16 panels for each MPPT</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8 x (6 MPPT) WEG SIW500H – ST060</td>
<td></td>
</tr>
<tr>
<td>3 &amp; 4</td>
<td>180 kWp</td>
<td>303MWh</td>
<td>512</td>
<td>4 x 40kW</td>
<td>2 strings in parallel w/ 16 panels for each MPPT</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4 x (4 MPPT) WEG SIW500H – ST040</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>460 kWp</td>
<td>731MWh</td>
<td>1,296</td>
<td>1st subgroup: 2 x 100kW WEG SIW500H – ST100</td>
<td>1st subgroup: 2 strings in parallel w/ 28 panels for each MPPT</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2nd subgroup: 2 x 100kW WEG SIW500H – ST100</td>
<td>2nd subgroup: 2 strings in parallel w/ 26 panels for each MPPT</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>HV</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>238 kWp</td>
<td>391MWh</td>
<td>672</td>
<td>2 x 100kW WEG SIW500H – ST100</td>
<td>2 strings in parallel w/ 28 panels for each MPPT</td>
</tr>
</tbody>
</table>

Source: Authors

Table II SUMMARY OF THE FEASIBILITY STUDY – SYSTEMS 1 TO 4.

<table>
<thead>
<tr>
<th>System</th>
<th>Photovoltaic power</th>
<th>Generating Capacity (annual)</th>
<th>Investment</th>
<th>Payback</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 – Campus on the private network</td>
<td>545 kWp</td>
<td>918MWh</td>
<td>Rs 2.285.130,40</td>
<td>6A and 3M</td>
<td>Available land area, Reduction of demand overrun payments</td>
<td>Required cubicle for inverters, meters, protections, transformer Dependence on Campus network conditions Demand increased Required</td>
</tr>
<tr>
<td>2 – Campus in the network CEMIG</td>
<td>545 kWp</td>
<td>918MWh</td>
<td>Rs 2.285.130,40</td>
<td>8A and 9m</td>
<td>Available land area, Independence of the conditions of the Campus's private network</td>
<td>Demand overshoot remains in the Campus network New demand contract required, new SE.</td>
</tr>
<tr>
<td>3 – Campus w/1290kWh storage on private grid</td>
<td>180 kWp</td>
<td>303MWh</td>
<td>Rs 4.313.078,85</td>
<td>9A and 5M</td>
<td>Available land area, Reduced demand overrun in HP Autonomy gain in the absence of CEMIG's power The transformer included in the storage system Reduction of the generation system (energy value in HP)</td>
<td>Cubicle required for inverters/meters and guards Dependence on Campus network conditions Demand increase required, although less than System 1 Demand overshoot remains HFP, albeit lower than current Higher Cost</td>
</tr>
</tbody>
</table>
Injection of power into the grid at a less overloaded time

<table>
<thead>
<tr>
<th>System</th>
<th>Photo voltaic power</th>
<th>Generating Capacity (annual)</th>
<th>Investment</th>
<th>Payback</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 – Campus in the CEMIG network w/ 1290kWh storage</td>
<td>180 kWp</td>
<td>303MWh</td>
<td>RS 4,313,078,85</td>
<td>10A and 5M</td>
<td>Available land area</td>
<td>Demand overshoot remains in the Campus network It will not bring autonomy, depending on the connection topology Required new contract of new demand SE.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Independence of the conditions of the Campus's private network Reduction of the generation system (energy value in HP)</td>
<td></td>
</tr>
</tbody>
</table>

Table III SUMMARY OF THE FEASIBILITY STUDY – SYSTEMS 5 AND 6.

<table>
<thead>
<tr>
<th>System</th>
<th>Photo voltaic power</th>
<th>Generating Capacity (annual)</th>
<th>Investment</th>
<th>Payback</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 – Building 1</td>
<td>460 kWp</td>
<td>731MWh</td>
<td>RS 1,660,960,00</td>
<td>7A and 4M</td>
<td>Existing Energy Measurement Cubicle (SE 500kVA) Existing roof area Physical space for installation of existing equipment CEMIG Network Spare bay for existing traffic for expansion</td>
<td>Required increase in contract demand for system connection (estimated contract 120kW) Demand overshoot remains in the Campus network Limitation of generation in the value of the maximum contract demand 460kW for existing substation.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>area for the installation of the photovoltaic plant. The Campus has free non-built areas</td>
<td></td>
</tr>
<tr>
<td>6 – Building 1 w/ storage 1670kWh</td>
<td>238 kWp</td>
<td>391MWh</td>
<td>RS 5,267,315,41</td>
<td>8A and 11m</td>
<td>Available floor and roof area Gain of autonomy of Building 1 in the event of a power outage Reduction of the generation system (energy value in HP) Area and capacity available for expansion of generation and service to other consumer units (e.g. Villas)</td>
<td>Demand overshoot remains in the Campus network There is no autonomy for the Campus Higher cost</td>
</tr>
</tbody>
</table>

Source: Authors
that allow the implementation of a ground type system of the dimensioned size that would occupy an approximate area of 3041.6m² for the installation of photovoltaic panels.

For the technical feasibility analysis of Case Study 2, it was also verified that there is a physical area of roof coverage for the installation of the photovoltaic plant. System 6 would require an approximate area of 2,566m² for the installation of photovoltaic panels and Building 1 has a floor area of approximately 2,818.8m².

Tables II and III present a synthesis of the six systems studied to solve the economic feasibility proposal. The advantages and disadvantages of each solution are presented. System 5 presented the lowest cost, but did not present the lowest payback. It is considered that this is because the system was not able to generate all the necessary consumption (campus + Building 1), due to the limitation of the installed power, thus reducing the savings in energy bills. System 6 had a higher cost, but had a lower payback than Systems 3 and 4 with energy storage. This is probably because System 6 was able to generate more savings by generating energy in HP with a higher compensation value and was able to supply not only the campus consumption but also that of Building 1.

System 1 had the lowest payback. However, it is noted that there is a technical difficulty that needs to be better studied, which would be the implementation of the system in the private network of the campus (Systems 1 and 3). Because of the network is very old, there are difficulties in maintaining maintenance by the institution and there is an ongoing process of donating this network to CEMIG. With the same cost, System 2 had a payback almost 3 years higher due to the new demand contract required and the permanence of the cost on the campus.

The same can be observed in System 4 compared to System 3, with a payback of 1 year more. In this case, however, the difference was smaller because the system designed with energy storage also supplied the HP consumption, and System 3 only partially reduced the demand overrun.

Finally, the proposals for Case Study 2 are considered more feasible (Systems 5 and 6). Because they present an independence from the state of the campus network and because they already have a protected substation, unlike Systems 2 and 4, where there is a need to build the substation. It is worth mentioning that the study of Systems 5 and 6
included the consumption of Building 1, a larger building not included in the studies of Systems 1 to 4.

4 CONCLUSION

This work presented 4 technical dimensions that could be explored in 6 feasibility analysis for the implementation of a photovoltaic generation plant in a university campus in the northern region of Minas Gerais.

In addition, it was found that the inclusion of the battery system reduces the size of the photovoltaic system, which is important when there is little area available for the installation of the panels. The campus did not present a problem of available area, making it attractive to evaluate all possible implementation considerations.

There was a slight increase in the payback time of the investment compared to other feasibility studies (Greener, 2020), mainly because the facility is tax exempt.

Future work includes:

- Technical dimensioning of Systems 2 and 3, adding the consumption of a large building 1 of the campus to increase the scope of the analysis;
- Improve the calculation of the consumption of Building 1, which was estimated today at 200% of the current consumption value, as the building is undergoing renovations to increase space utilization;
- Improve the cost estimate of the storage system, which was based on a portion of a quote for a larger system (3MWh), and in the case of System 6 could be slightly reduced since it only requires the low voltage transformer, since the high power one can use the substation transformer;
- Re-analyze the payback, considering the new Resolution 1,059 of 2023;
- Improve the calculation of the actual generation capacity of Systems 3, 4 and 6, including the consumption of the storage system in the technical sizing study;
- Technical sizing of the proposed battery banks.
REFERENCES


