GREEN PARKING LOT IN THE AMAZON

Luiz Carlos do Nascimento Borges Filho[1], Ayrton Lucas Lisboa do Nascimento[1], Bruno Santana de Albuquerque[1], Maria Emília de Lima Tostes[1] and Carminda Célia Moura de Moura Carvalho[1]

1 Universidade Federal do Pará, Belém (Brazil)

Abstract

This study presents a photovoltaic carport project at the Guamá campus of UFPA, in the Amazon. The project demonstrates the three-dimensional modeling of the electricity generation system and the vehicle charging infrastructure. Thus, it is verified that there is better use of the available areas in the parking lot. This study also presents the economic feasibility via a simple financial return calculation of the project and an analysis of greenhouse gas (GHG) emissions reduction for the university. The results achieved show the technical efficiency of the installation and favorable economic feasibility, with an estimated return on investment in approximately five years. The project is part of an energy transition initiative by UFPA, which has been investing in electromobility, diversifying its energy matrix, and reducing GHG emissions. It aims to become a model in the region for Brazil in electromobility and low-carbon generation solutions, in line with the UN Sustainable Development Goals, thus demonstrating UFPA's commitment to technological innovation and the fight against climate change.

Keywords: Photovoltaic Systems, Photovoltaic Carport, Reduction of Greenhouse Gas Emissions, Electromobility.

1. Introduction

Currently, the energy transition has transformed the Brazilian electricity scenario, since these actions to replace a polluting energy matrix with a more renewable one are strongly correlated with the reduction of effects related to greenhouse gases [IPEA, 2019]. The energy transition is happening gradually, as implementation costs are still high, whether for obtaining some renewable sources, electric vehicles, or even in terms of the cost of purchasing fast electric chargers, which hinders universal access and also slows down the process. In Brazil, there have been several advances in the field of electric mobility, and despite national progress in recent years, the North Region still has a low density of charging stations and electric vehicles. In addition, there are few studies that integrate architectural designs, energy performance, and techno-economic analysis related to electric mobility in the Amazonian context.

The Federal University of Pará (UFPA) demonstrates its pioneering spirit through the implementation of electric mobility and renewable energy projects across its campuses. One example is the Amazon Multimodal Intelligent System (SIMA), which aims to apply distributed energy resources at the university, either through the use of photovoltaic systems or the addition of river and land modes of transport, as presented in [Tabora, 2021], [Albuquerque, 2024].

This study evaluates a photovoltaic carport integrated with eight fast charging stations (DC) on the Guamá campus of UFPA, near gate 3, an area with heavy foot and vehicle traffic. The study investigates: (i) the energy performance of the carport; (ii) economic feasibility

10.18086/swc.2025.03.32 Available at http://proceedings.ises.org

through CAPEX analysis, annual savings in local tariffs, and payback; and (iii) analysis of environmental benefits (emissions avoided compared to the emission factor of the electricity grid).

Organization of the article: section 2 summarizes the background and related work on photovoltaic carports and charging infrastructure in Brazil, especially in the North region. Section 3 describes the methodology applied. Section 4 presents the energy, economic, and emissions results. Section 5 presents the conclusions, discussing implications, sensitivity, limitations, and future developments.

2. Background

2.1. Overview of photovoltaic solar energy in Brazil

The share of photovoltaic generation in Brazil's electricity matrix has been growing rapidly in recent years, driven by falling costs, the expansion of distributed generation, and incentive policies. According to the Energy Research Company, in 2025, according to the report documenting the National Energy Balance, photovoltaic power and production showed significant growth compared to 2024, i.e., about 30.6%, as reported in [BEN, 2025], reinforcing the role of PV as a competitive alternative for reducing costs and emissions at the point of consumption. In this context, photovoltaic carports allow for better use of the installation area, since the area will be used as a place for renewable energy generation and for providing shade for cars.

Figure 1 shows the composition of the Brazilian electricity matrix in 2024, highlighting the predominance of hydraulic sources and the gradual advance of other renewable sources, such as solar and wind [BEN, 2025].

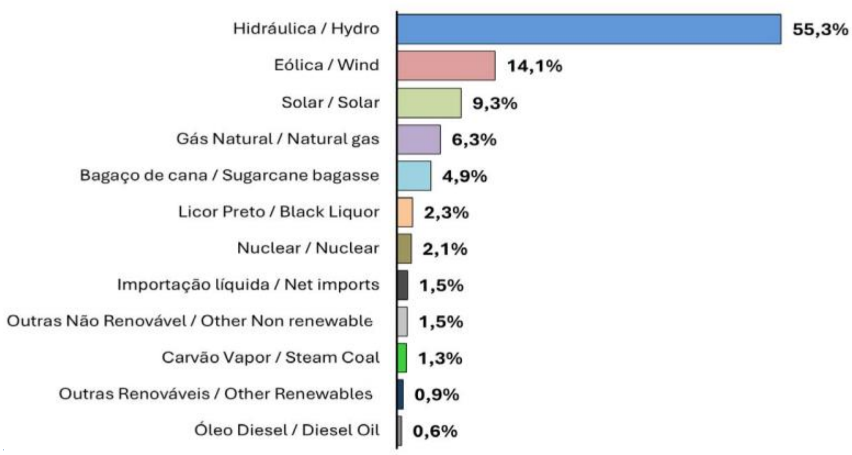

Figure 1: Brazilian Electrical Grid. Source: Empresa de Pesquisa Energética, 2025.

Looking at Figure 1, it can be seen that Brazil has a predominantly renewable electricity matrix, which implies low carbon emissions into the atmosphere. The Ministry of Science, Technology, and Innovation (MCTI) publishes monthly figures associated with greenhouse gas (GHG) emissions, considering all sources of electricity generation. For the Brazilian scenario, it is possible to make observations and verify that GHG emission values are low.

2.2. Universidade Federal do Pará

The Professor José Silveira Neto University City is located in the city of Belém, in the state of Pará, and is a major reference in Brazil in teaching, research, and extension, with a university population of more than 62,000 people, distributed across 12 campuses, including UFPA, 2025. The university campus offers more than 100 courses in a wide range of fields, as well as libraries, university hospitals, and green areas.

According to ABNT NBR ISO 37122:2020, 19 indicators determine smart cities, and UFPA has at least four of these smart city indicators, which are related to renewable energy, the environment, telecommunications, and transportation. This benchmark indicates the efficiency of processes that facilitate and improve the quality of development on university campuses. Whether in the modernization of engineering teaching practices, the improvement of energy efficiency measures, or the improvement of internal mobility conditions on campus, which are enjoyed by the entire population that frequents the university city.

2.3. Brazilian experiences

Brazil has a large set of initiatives in universities and public agencies that demonstrate the technical and institutional feasibility of the project, making replication attractive for universities:

UFSC – Florianópolis: Installation of a large solar parking lot, focusing on distributed generation and technological demonstration space, as presented in (Custódio et al. 2018).

Unicamp – Campinas: Demonstrated the expansion of PV generation on campuses with studies on integration with electric mobility and evaluation of institutional uses, through the charging of internal fleets and recharging logistics, as presented in (Machado et al. 2020).

UTFPR – Curitiba: R&D and charging pilot projects, with an emphasis on instrumentation and monitoring of energy quality and demand profiles in academic environments (Kulik et al. 2023).

It is important to note that there are several challenges related to the Amazonian context, which are due to environmental and operational constraints, such as heavy rains, high relative humidity, and high operating temperatures.

2.4. Electromobility in Brazil and regional asymmetries

Currently, recent data indicate accelerated growth in the EV fleet and charging infrastructure in the country, but with spatial asymmetry: the highest density of charging stations is found in the South and Southeast regions, while the North Region has a sparser network and a higher vehicle/charger ratio [ABVE, 2025]. In capitals such as the city of Belém, the supply of public charging points is limited, and a significant part of recharging still depends on the local power grid, which reduces the net environmental benefit when compared to scenarios with local photovoltaic supply.

In this context, university campuses are natural candidates for charging stations because they offer:

(i) large paved areas suitable for photovoltaic coverage;

(ii) predictable and concentrated demand during the morning and afternoon;

(iii) existing electrical infrastructure with the possibility of planned upgrades;

(iv) potential for a demonstration effect to induce a metropolitan-scale charging corridor.

Figure 2 shows the number of charging stations installed in the states of the North Region, with Pará (209) in the lead, followed by Amazonas (84) and Tocantins (50). Even so, there is a concentration in a few urban centers, resulting in low density per area. Figure 3 shows the number of charging stations in Brazil, demonstrating the disparity of charging stations by region, since the North region has 412 charging stations, while the Southeast region has a total of 8,035 charging stations.

The comparison shows the difference between charging infrastructures from two different perspectives, i.e., in a regional analysis and in a national analysis. It can be inferred that although Pará is the leader in the number of charging stations in the state, there is still a shortage when compared to other states in Brazil. In this scenario, the proposed photovoltaic carport contributes to expanding charging coverage and also to a significant increase in renewable energy generation, aligning with SDGs 4, 7, 9, 11, and 13.

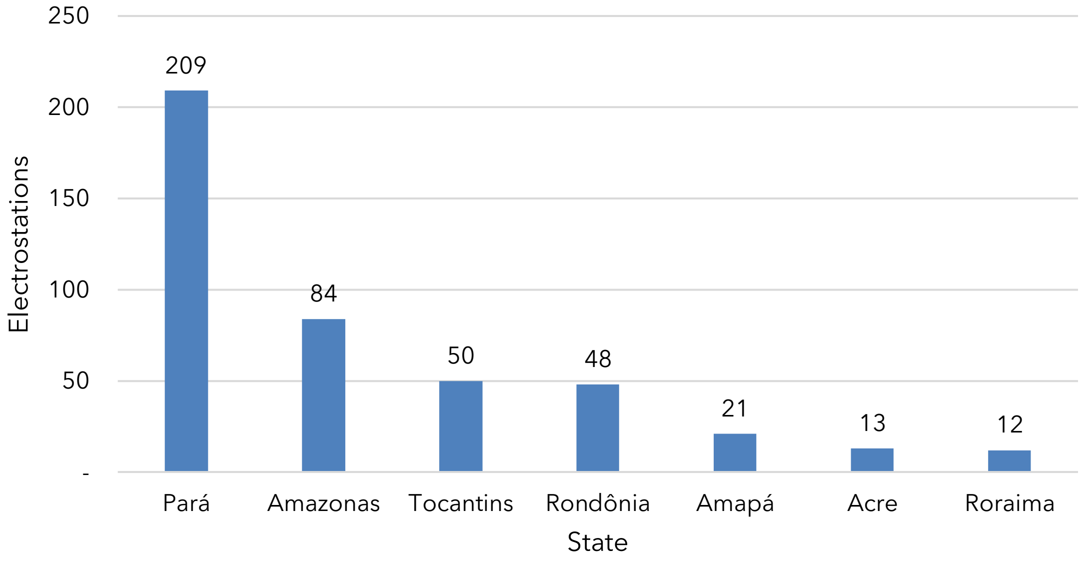

Figure 2: Electric charging stations in the northern region. Source: ABVE, 2025

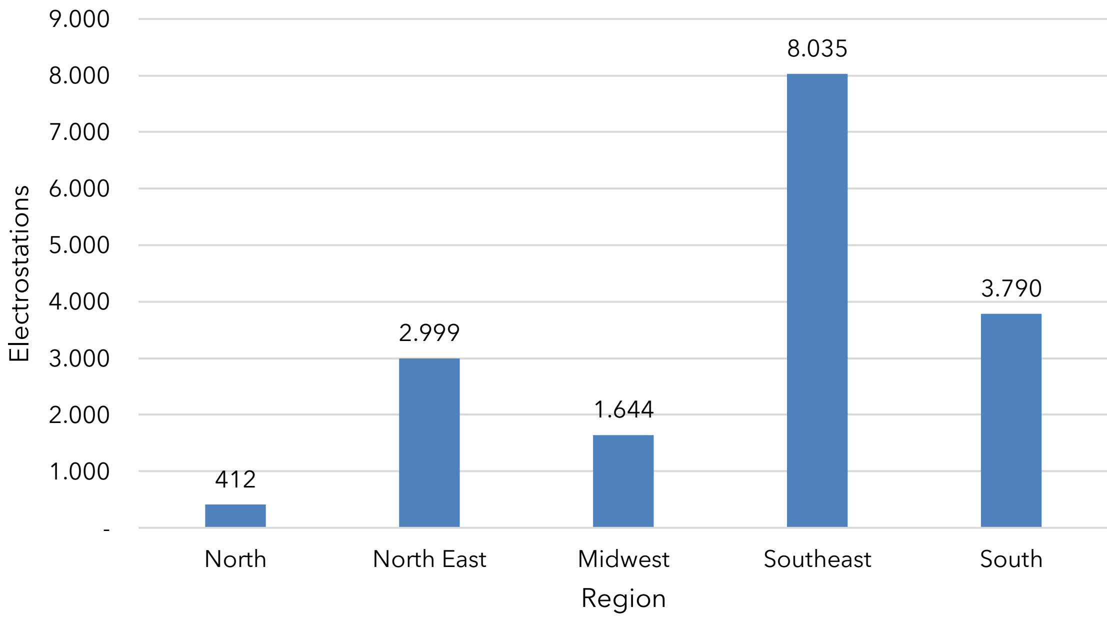

Figure 3: Number of electric charging stations in Brazil by region. Source: ABVE, 2025.

2.5. Sustainable Development Goals

The Sustainable Development Goals comprise the UN's 2030 Agenda, adopted in 2015 by Member States. There are 17 goals broken down into more than 160 targets, which guide public policies, investments, and projects until 2030, in social, economic, and environmental areas.

Figure 1 shows the complete set of 17 SDGs, each represented by an icon and color standardized by the UN to facilitate visual recognition in publications and reports. This paper highlights three SDGs, namely 4, 7, 9, 11, and 13, as they are directly related to photovoltaic generation, EV charging infrastructure, and greenhouse gas emissions mitigation.

Figure 4: Sustainable Development Goals.

• SDG 4 (Quality Education)

This goal seeks to ensure inclusive, equitable, and quality education, promoting learning opportunities for all. In the university context, the implementation of a photovoltaic carport represents a pedagogical and technological tool, allowing the academic community to experience concepts of sustainability, energy efficiency, and energy transition in practice. In addition, the system can serve as a living laboratory, integrating teaching, research, and extension, favoring interdisciplinary activities focused on innovation and the training of human resources committed to the principles of sustainable development.

• SDG 7 (Affordable and Clean Energy)

The function of this SDG is to ensure the expansion of renewable and affordable energy. The increase in the renewable matrix at the Federal University of Pará brings several benefits, and the greater participation of renewable energies ensures consumption close to the load, thus favoring self-consumption and the quality of electricity, since in this process there are no losses related to the transmission of electricity.

• SDG 9 (Industry, Innovation, and Infrastructure)

This SDG focuses on strengthening infrastructure, promoting inclusive and sustainable industrialization, and encouraging technological innovation. The implementation of a photovoltaic carport and its integration with smart charging infrastructure for electric vehicles reinforce the commitment to solutions that combine energy efficiency and environmental sustainability. Within the scope of UFPA, the project contributes to the development of resilient and technological infrastructure, incorporating energy monitoring, control, and management systems that can be replicated in other urban or institutional contexts.

• SDG 11 (Sustainable Cities and Communities)

This SDG is strongly correlated with the use of electric and sustainable modes of transport. The implementation of a photovoltaic carport encourages the increased use of electric vehicles, which are charged at charging stations that obtain electricity from less polluting sources. In addition, it makes use of areas that were previously underutilized, such as the parking lot, which has a large amount of untapped solar energy. The installation of the carport generates energy, providing thermal comfort for the parking lot and encouraging the use of electric vehicles with special parking spaces for vehicle charging.

• SDG 13 (Climate Action)

This SDG is based on actions against global climate change. Currently, Brazil's electricity matrix is one of the most renewable in the world, however, there is still a percentage of energy generated from polluting sources, such as thermoelectric plants.

The use of renewable energy sources close to the load reduces the use of non-renewable sources in the National Interconnected System (SIN), thereby reducing greenhouse gas emissions. As for electric modes of transport, most vehicles are internal combustion engines, which are powered by highly polluting energy sources, such as coal, oil, and derivatives. The use of these types of modes of transport contributes most to climate change worldwide.

The project represents the university's dedication to sustainable innovation and regional progress, demonstrating that energy change in the Amazon is not only viable but also essential and technically possible, despite the various regional difficulties present, marked by infrastructure issues, social inequalities, and low levels of government investment in the Amazon.

In addition, this project is also aligned with the ideals of the 30th Conference of the Parties to the UN Framework Convention on Climate Change (COP-30), which will be held in the city of Belém, in the state of Pará, from November 10 to 21, 2025. COP-30 is a historic event for the Amazon region, as it will be the first time that a city in the Amazon will host a global event, bringing together political, scientific, and social leaders for discussions on climate change mitigation and adaptation.

3. Methodology

This topic presents the methodology followed for this study, which presents the modeling and definition of the energy generation sectors, followed by the calculation formulas used..

3.1. Model

The area chosen for implementation was the parking lot on the Guamá campus of UFPA, near gate 3, which was divided into two sectors, A and B. This made it possible to allocate the eight charging points along the structures developed. The modeled structure is shown in

Figure 5.

For this study, we considered the availability of eight electric vehicle chargers, which could reach 16 charging points with dual-output connector equipment, allowing two vehicles to be served simultaneously per unit.

Based on the 3D modeling of the area and the support structures and photovoltaic modules, the modeling rendering is developed and subsequently presented for the better development of the design of the project under study.

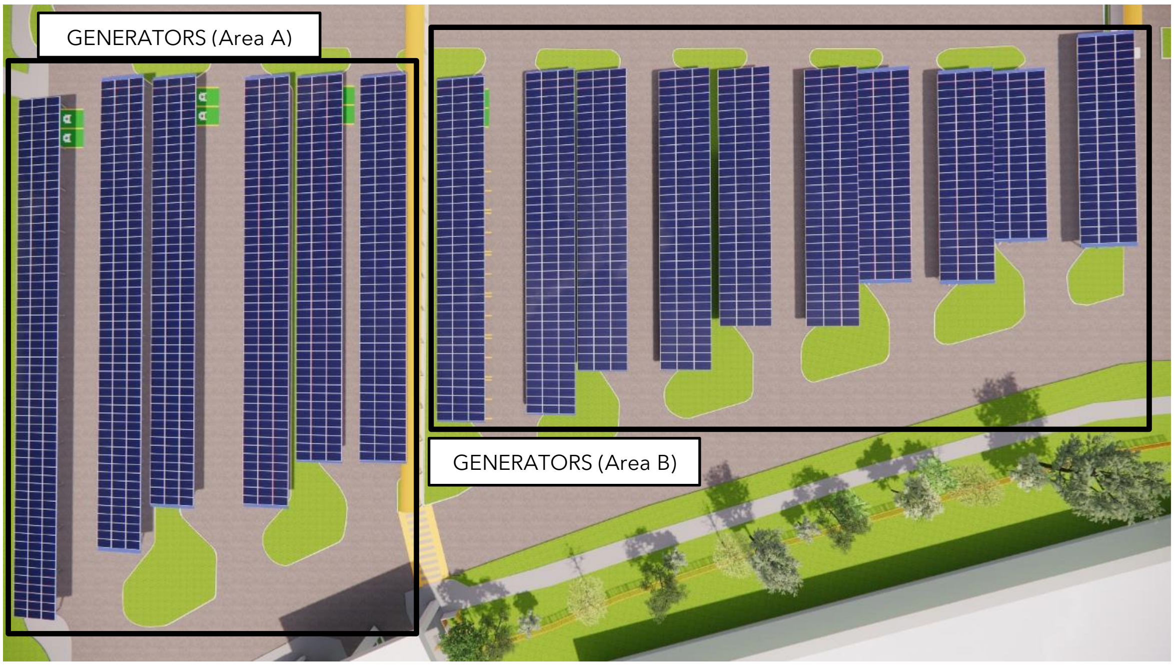

Figure 5: Top view of the green parking lot generated using Enscape software.

3.2. Calculation Methods

The energy potential of the photovoltaic carport was obtained through simulation, considering public climate databases. In this simulation, a value in MWh/year is obtained in each of the carport implementation sectors.

The initial energy generation results enable economic estimates based on local tariffs, making it possible to obtain annual savings and financial returns.

The methodology for calculating financial return is similar to that developed by [Nascimento, 2023], which considers losses due to degradation of the photovoltaic system over the years, equipment replacement during its useful life, and tariff increases over time. The GHG estimate considers the SIN emission value, which is 0.05 tons of CO2 per MWh.

$$E_{total} = E_{SetorA} + E_{SetorB} \tag{1}$$

$$Economia = E_{total} \cdot Tarifa \tag{2}$$

$$Payback = \frac{CAPEX}{Economia} \tag{3}$$

$$GHG = E_{total} \cdot Coef_{GEE} \tag{4}$$

4. Resultados

4.1. Power Generation

The initial values for the carport were obtained from the annual generation, with sector A generating 836,640 MWh/year and sector B generating 858,998 MWh/year, totaling 1,696 MWh/year for the parking lot.

4.2. Calculation Methods

From an economic standpoint, the exchange rate was set at USD 5.33/BRL, therefore, the electricity tariff adopted an average rate of USD 0.10/kWh for the first year and the total CAPEX for the carport (including photovoltaic coverage and associated infrastructure) was USD 819,638.3.

Conservatively, for the first year, considering the full use of the estimated annual energy on the campus itself. The gross savings result is “USD 169,563.8.”

Under these assumptions, the simple gross payback is approximately 4.83 years, with a gross return of about 20.7% in the first year.

From an environmental perspective, and according to the Methodology (Eqs. (2) and (4)), the reduction in greenhouse gas emissions was estimated based on the average emission factor of the Brazilian electrical system of 0.05 tCO_2/MWh/year. Applying this factor to the total annual energy and full utilization, 84.78 tCO_2/year avoided is obtained.

4.3. Three-dimensional modeling

Based on the model shown in Figure 5, a rendering was developed using Enscape software, allowing for a more detailed analysis of the project design, including the photovoltaic modules, carport structure, special parking spaces, and electric charging stations.

Figure 6: Electric vehicle charging stations generated using Enscape software.

4.4. Financial Return

The financial return analysis takes into account the initial cost of the project, which is “USD 819,638.3.” In the first year, an equivalent of “USD 169,563.8” is generated. Thus, Table 1 shows the financial return over the first six years of analysis, where it can be seen that the financial return occurs between the fourth and fifth years of the project. Figure 7 shows the financial return graph, which visually demonstrates the return for each of the sectors. In both cases, it was highlighted up to the sixth year of system operation.

Tab.1: Financial Return Over 6 Years.

Year	Area A	Area B	Full Carport
1	-USD 326.673,49	-USD 323.401,01	-USD 650.074,50
2	-USD 235.931,52	-USD 230.234,09	-USD 466.165,60
3	-USD 136.520,28	-USD 128.166,23	-USD 264.686,50
4	-USD 27.613,34	-USD 16.348,91	-USD 43.962,25
5	USD 91.694,32	USD 106.147,07	USD 197.841,39
6	USD 222.393,77	USD 240.339,29	USD 462.733,06

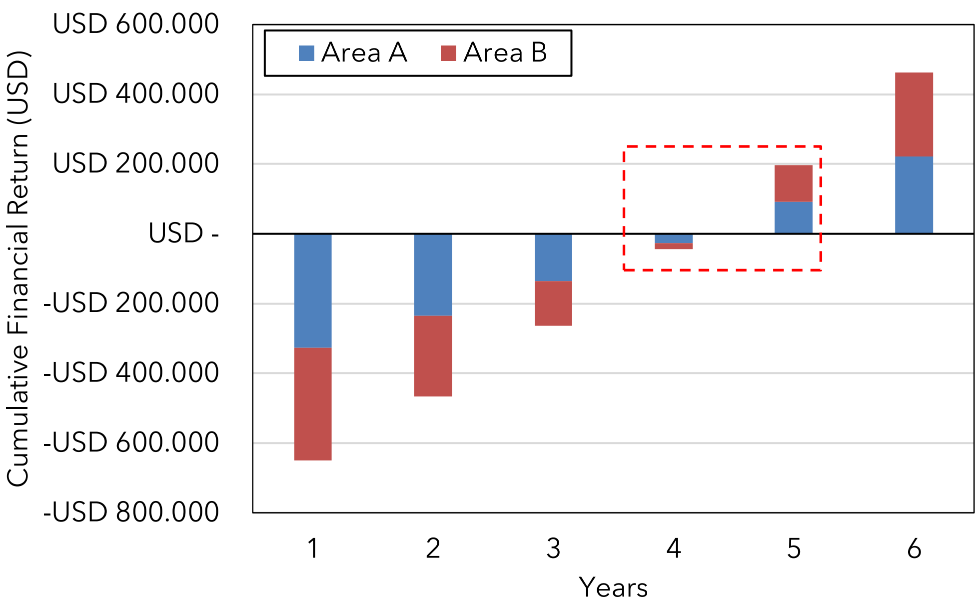

Figure 7: Carport Financial Return Chart.

5. Conclusion

This study highlighted the technical, economic, and environmental potential of implementing a photovoltaic carport in the Amazon region, particularly in northern Brazil, where climatic conditions and the availability of open areas favor the adoption of distributed generation systems. The proposal demonstrates that the system contributes directly to institutional sustainability and energy efficiency goals.

The results obtained pointed to an annual generation of approximately 1,696 MWh, associated with an initial investment of USD 819,639.30, with an estimated payback period of 4.83 years. This performance indicates economic viability and competitiveness compared to other types of energy investment. From an environmental standpoint, the system provides an annual reduction of approximately 84.78 tons of CO_2, representing a significant advance in emissions mitigation and the promotion of sustainable electric mobility.

The analysis also reinforces the project's adherence to the Sustainable Development Goals (SDGs 4, 7, 9, 11, and 13), integrating aspects of clean energy, technological innovation, urban sustainability, and climate action. In this sense, the photovoltaic carport is consolidating itself as a replicable model for other public and private institutions in the

Amazon, stimulating regional energy transition and the rational use of urban infrastructure.

Looking ahead, studies will be conducted to further integrate the charging stations with the photovoltaic system, considering scenarios of simultaneous charging of electric vehicles, hourly variation in demand, and smart energy management strategies. These analyses will make it possible to assess the impact of electric mobility on system performance, as well as contribute to the development of sustainable microgrid models and optimized energy dispatch strategies in the Amazonian context.

6. References

Ciobanu, I., Lazaroiu, C.G., Fulginei, R.F., 2024. Energy community with semi-public system of EV stations, carport and batteries energy storage. *International Conference on Environment and Electrical Engineering and 2024 IEEE Industrial and Commercial Power Systems Europe (EEEIC)*.

Custódio, I.P., Zomer, C.D., Schneider, K., Rüther, R., 2018. Critérios e soluções adotados em projeto de estacionamento solar de 1 MWp em Florianópolis - SC. *Revista Brasileira de Energia Solar* 4, 141–150.

Empresa de Pesquisa Energética – EPE, 2024. *Balanço Energético Nacional 2024: Ano base 2023*. Rio de Janeiro: EPE. 274 p.

Istók, R., Kádár, P., Reizer, L., 2021. Solar carport with energy storage capabilities. *IEEE 4th International Conference and Workshop Óbuda on Electrical and Power Engineering (CANDO-EPE)*.

Kulik, C.A., Rodrigues, A.M., Junior, U.J., 2023. Evaluation of solar photovoltaic carport associated with different electrical cars in the city of Curitiba, Paraná - Brazil. *15th Seminar on Power Electronics and Control (SEPOC)*.

Machado, V.M.G., Silva, S.L.J., Moreira, S.H., Vargas, N.T., Prym, S.C.G., Lima, P.G., Villalva, G.M., 2020. Estudo de caso de um sistema fotovoltaico instalado no campus da Unicamp em diferentes softwares de simulação. *Revista Brasileira de Energia Solar* 6, 124–131.

Nascimento, L.L.A., Albuquerque, S.B., Filho, R.O.E., Jorge, M.L.R., Carvalho, M.M.C.C., Tostes, L.E.M., 2023. Estimativa de payback de um sistema fotovoltaico híbrido para um prédio público educacional. *XV Conferência Brasileira sobre Qualidade da Energia Elétrica (CBQEE)*.

Pinto, A.X.G., Santos, O.D., Abreu, F.P.J., Hirassaki, V., Naspolini, F.H., Rüther, R., 2021. Perfis de demanda, potência excedente injetada na rede elétrica e fator de potência de unidade consumidora com geração fotovoltaica e veículo elétrico. *Revista Brasileira de Energia Solar* 7, 31–38.

Rodrigues, A.M., Junior, U.J., 2024. Performance analysis through merit indexes of a carport located in Neoville campus of the Federal University of Technology of Paraná. *16th Seminar on Power Electronics and Control (SEPOC)*.

SOS Mata Atlântica, 2025. *Calcule sua emissão de CO_2*. Disponível em: (acessado em 30 abril 2025).

Vidotto, C.L., Oliveira, V.K.A., Rüther, R., 2022. Estudo de viabilidade econômica do eBus do laboratório fotovoltaica UFSC: ônibus elétrico associado a energia solar e armazenamento de energia com baterias de segunda vida. *Revista Brasileira de Energia Solar* 8, 233–242.

Zielinska, A., Skowron, M., Bien, A., 2018. Cooperation of the process of charging the electric vehicle with the photovoltaic cell. *Applications of Electromagnetics in Modern Techniques and Medicine (PTZE)*.