



Technical and economic feasibility of photovoltaic energy adoption in a multifamily residential building

Murilo Anzanello Nichele¹, Paulo Reis Junior², Jairo Marchesan³, Mari Aurora Favero Reis^{3,*}

¹ Master's student in the Professional Master's Program in Civil, Sanitary and Environmental Engineering, Universidade do Contestado, Concórdia, SC, Brazil.

² PhD student in the Graduate Program in Environmental Science and Technology at Universidade Federal da Fronteira Sul (UFFS), Erechim, RS, Brazil.

³ Professor in the Professional Master's Program in Civil, Sanitary and Environmental Engineering, Universidade do Contestado, Concórdia, SC, Brazil.

*Autor para correspondência, E-mail: mari@unc.br

Received: 19 May 2028 | Accepted: 31 August 2026 | Published online: 02 September 2026

Abstract: Photovoltaic energy is widely recognized as a clean alternative capable of mitigating environmental impacts and reducing dependence on fossil-fuel-based electricity. Motivated by these factors, this study evaluates the technical and economic feasibility of implementing a photovoltaic system in a multi-family building in southern Brazil. The research was carried out in the *Vila Verde* Condominium, located in the municipality of Concórdia (Santa Catarina), where the choice of location was justified by the representativeness of its architectural and urban characteristics in the regional multi-family housing context. The methodology included an assessment of 12 months of electricity consumption, analysis of the physical installation environment using geolocation and aerial imagery, system sizing, and an economic comparison based on financing simulations. The economic analysis consisted of comparing the monthly cost of the photovoltaic system with the condominium's current electricity expenditure, demonstrating financial attractiveness through immediate monthly cost reduction rather than long-term assumptions or predictive simulations. The results indicate that the available roof area allows the installation of a 14.1 kWp system with an estimated average generation of 1,550 kWh/month. From a practical perspective, the system reduces energy expenses, shortens payback time, and decreases dependence on the conventional grid. The study contributes a replicable case for similar residential developments and supports the advancement of solar energy adoption in urban environments, aligning with Sustainable Development Goals (SDGs) 7 and 13.

Keywords: Photovoltaic; economic viability; energy efficiency.

1 Introduction

The global climate crisis, also driven by the intensive use of fossil fuels, has placed urban systems in the spotlight. This encourages structural transformations in lifestyles and, especially, in energy consumption patterns (Yu et al., 2022). Photovoltaic systems, for example, are a renewable energy source, converting sunlight into electricity, reducing greenhouse gases, and promoting environmental sustainability (Li, 2023; Reis and Serrano, 2022). In this context, urban sustainability depends on intersectoral policies, technological innovation, and cooperation between residents, governments, and the energy sector (Roberts, Bruce and MacGill, 2019).

Although the concept of near-zero energy buildings has advanced significantly in recent years, monitored case studies are still largely limited to single-family homes (Dermentzis, Ochs and Franzoi, 2021), public buildings (Reis, Reis Júnior and Perin, 2020), or commercial buildings. However, the challenges of sizing, operation, and monitoring remain more complex in multi-family developments, especially regarding the integration of photovoltaic (PV) systems and economic variability, a scenario that reinforces the importance of studies applied to collective buildings. In the Republic of Korea (Kwag, Kim and Hwang, 2024) and the European Union (Aste et al., 2024), photovoltaic systems can increase energy self-sufficiency in small-scale, low-rise multi-family buildings, which is similar to Brazilian cities. From a

social perspective, energy is crucial to the existence of any society; it becomes a need to be met, as well as a human desire (Akinyele, Rayudu and Nair, 2015).

The installation of photovoltaic systems in multifamily buildings can accelerate the transition to renewable energy and energy sustainability, producing more than half of electricity consumption (Monna et al., 2020). This is a fair and sustainable business opportunity for shared photovoltaic systems in distribution networks (Roberts, Sharma and MacGill, 2022). These factors justify analyzing the technical and economic feasibility of implementing solar energy in condominiums as a measure aligned with the principles of urban sustainability and the Sustainable Development Goals. The energy transition is a necessity in the development of sustainable cities. Technological advancements can contribute to the creation of more comfortable, resilient, and innovative urban environments (Cirella et al., 2021).

The energy transition in sustainable cities implies that the adoption of renewable energy systems and the implementation of demand management strategies are fundamental to the development of sustainable urban environments (Ren et al., 2021). The authors emphasize that the integration of solar energy, thermal energy storage, and demand management improves the energy efficiency of homes and contributes to environmental improvement and quality in urban contexts, balancing energy supply and demand in electricity grids, an essential aspect for the future of sustainable cities (Li et al., 2021; Ren et al., 2021).

In multi-family residential buildings, design practices that promote energy efficiency and indoor comfort can contribute to achieving the Sustainable Development Goals (SDGs) proposed by the United Nations (Rabaia et al., 2024; Aljaghoub et al., 2022). In this context, the adoption of solar energy systems helps reduce long-term operating costs, making energy more affordable for residents, which directly impacts SDG target 7.1, as it aims to ensure universal access to energy (Kobylarczyk, Marchwiński and Zielonko-Jung, 2020). The transition from fossil fuels to solar photovoltaic energy contributes significantly to reducing greenhouse gas emissions, an important action in mitigating climate change, and is therefore directly aligned with Sustainable Development Goal (SDG 13) – Climate Action (Nooman AlMallahi et al., 2024).

The impact of low-carbon city policies on China's energy transition highlights their importance for sustainable development, the transition to sustainable cities, and their role as a model for other developing countries seeking responsible growth (Lee, Feng and Peng, 2022). In the EU, solar energy plays a significant role in reducing energy consumption in the building sector, where buildings account for over 40% of final energy consumption, serving as a sustainable alternative to fossil fuels and contributing to energy efficiency and sustainability goals (Tsalikis and Martinopoulos, 2015). Therefore, there is an intrinsic relationship between the energy transition and the development of sustainable cities; the adoption of PV in multi-family residential buildings is essential for reducing carbon emissions and integrating distributed energy resources in urban environments (Roberts, Bruce and MacGill, 2019).

Buildings account for a large portion of energy consumption; the strategies previously discussed are vital for sustainable cities. However, their effectiveness depends on careful integration into design, considering economic, aesthetic, and behavioral factors (Kobylarczyk, Marchwiński and Zielonko-Jung, 2020). Solar energy is an important component in building a more sustainable infrastructure, helping to balance energy supply and demand and promoting more sustainable energy practices in residential environments (Ren et al., 2021). The lack of regulation for the sector, the absence of specific incentives for multi-family buildings, and the lack of public awareness still hinder progress in the energy transition (Roberts, Bruce and MacGill, 2019).

Vertical cities are compact and can be efficient with distributed energy generation when PV systems are incorporated. This requires well-designed systems to meet demands such as elevators and lighting, even when demand far exceeds production, contributing to the reduction of peak consumption, aligning with the goals of sustainable cities (Dermentzis, Ochs and Franzoi, 2021; Roberts, Bruce and MacGill, 2019). To maximize the benefits of photovoltaic energy generation in multi-family buildings, it is essential to invest in complementary solutions, such as local storage, smart metering, and efficient energy flow management, with greater self-sufficiency and environmental gains (Borodinecs, Lebedeva and Odineca, 2024).

This study aims to analyze the technical and economic feasibility of implementing a photovoltaic system in a multi-family building, including consumption data, generation simulations, and installation costs. The technical feasibility assessment prioritizes the analysis of the building's structural characteristics and the solar incidence curve (Yang, Xia and Mayer, 2024), integrated with an economic evaluation. For the economic analysis (Akinyele, Rayudu and Nair, 2015), the suppliers' proposals and the building's electricity consumption were examined in order to support the decision-making process for adopting a photovoltaic system in the condominium.

This study contributes by delivering an integrated assessment of the technical, economic, and environmental aspects of a photovoltaic system in a multi-family condominium, based on real consumption data, detailed solar analysis, and financial evaluation using market information. Additionally, the work provides a replicable model for similar residential developments and supports the expansion of renewable energy adoption in Brazilian urban environments, directly aligning with the Sustainable Development Goals (SDGs).

Despite the growing global literature on photovoltaic systems in residential buildings, studies addressing multi-family developments remain scarce, especially those that integrate real-world consumption data, detailed solar incidence analysis, and economic evaluation based on market conditions in the Brazilian context. Most existing work focuses on single-family homes or public buildings, leaving a clear gap regarding the technical and financial feasibility of shared photovoltaic generation in condominiums. To address this gap, the present study evaluates the feasibility of a photovoltaic system in a representative multi-family building, integrating structural, energetic, and economic dimensions. The work contributes a replicable methodological framework and empirical evidence to support decision-making and to promote the expansion of photovoltaic energy adoption in urban residential environments.

2 Materials and methods

Currently, there are different methodologies for sizing photovoltaic systems, which allow the calculation of technical and financial parameters for adopting this energy source (Milón Guzmán et al., 2020). In this study, a data-driven sizing approach was adopted, based on real electricity consumption and local installation conditions. The methodology combined: (i) analysis of 12 months of energy consumption; (ii) assessment of the physical environment using aerial imagery, drones, and geolocation data; and (iii) technical specifications and cost information provided by the company responsible for the photovoltaic installation. This approach enabled the estimation of system capacity, expected energy generation, and financial performance, supporting the assessment of technical and economic feasibility. Evaluating the possibilities of installing solar panels on rooftops at the initial design stage is essential for defining the most suitable surfaces for photovoltaic installation (Abu Qadourah, AL-Falahat and Alrwashdeh, 2022). Well-designed photovoltaic systems can significantly reduce energy costs and the carbon footprint, making residential buildings candidates for becoming energy self-sufficient communities (Borodinecs, Lebedeva and Odineca, 2024).

2.1 Study environment

The study was carried out in a multi-family residential building, *Vila Verde Condominium*, located in the urban area of the municipality of Concórdia, state of Santa Catarina, Brazil, situated between the geographic coordinates 27°14'24.83" S and 52°01'29.05" W. The Vila Verde was chosen due to its environmental and urban characteristics, which make it representative of most multifamily developments in the city of Concórdia. Located in an area with uneven terrain, the building imposes important characteristics for modeling and analyzing the solar curve, requiring the use of drones and tools to track the position of the sun.

The buildings in the blocks have fiber-cement tiles. The architectural characteristics of the block roofs, the use of fiber cement tiles, reflect the standard of multifamily housing condominiums in Brazil, making the study highly replicable and relevant for public policies and for the expansion of solar energy in urban environments. Fiber cement roofing, which is susceptible to weather events, acquires a certain resistance and retains the presence of the tiles. The garages located in front of the blocks have a metal structure, with aluminum/zinc tiles, which have important thermal characteristics to mitigate the effects on heat transfer through the roof (Reis et al., 2025).

The development consists of nine residential blocks, each with four floors and four apartments per floor, for a total of 16 housing units per block, or 144 housing units in total. The study considered the electricity used in the condominium's common areas. The usable area available for the installation of the photovoltaic system was mapped through technical inspections and analysis of aerial images (Figure 1), considering criteria such as slope, solar orientation, and the absence of shading. In addition to residential infrastructure, the condominium includes a green area - a Permanent Preservation Area composed of native plant species, measuring approximately 10,000 m².



Figure 1. Aerial view of the *Vila Verde* condominium.

The proximity to a Permanent Preservation Area reinforces the interest in sustainable, low-impact infrastructure solutions. Despite all the characteristics of the surroundings, the high incidence of sunlight at the site creates favorable conditions for evaluating the technical and economic performance of photovoltaic generation. The green area surrounding the condominium does not influence the installation of technology but reinforces the potential for the adoption of integrated sustainable solutions, such as clean energy generation.

2.2 Method for studying technical feasibility

Technical feasibility was assessed using the condominium's electricity consumption records and the physical characteristics of the installation site. Monthly electricity consumption data were obtained from the utility bills covering a 12-month period (May 2024 to April 2025) for the nine residential blocks. The historical consumption data, presented later in Table 1, were used to determine the annual energy demand and to estimate the required photovoltaic system capacity.

Table 1. Monthly electricity consumption (kWh) per block of the *Vila Verde* Condominium - May 2024 to April 2025

	2024						2025					
	May	June	Jul	Aug	Set	Out	Nov	Dec	Jan	Feb	Sea	Apr
Block A	550	487	640	467	509	516	434	497	475	434	499	465
Block B	209	223	228	168	194	196	207	225	213	186	198	169
Block C	200	202	197	158	193	218	201	184	200	156	190	175
Block D	79	75	78	69	80	75	68	81	86	80	82	72
Block E	88	88	84	78	85	90	81	93	94	81	96	86
Block F	97	93	96	82	95	99	88	99	94	84	85	80
Block G	85	83	86	77	89	98	78	93	87	82	91	85
Block H	55	72	74	64	66	61	44	47	44	40	45	49
Block I	100	96	102	92	101	106	90	105	96	87	94	89
T (kW)	1463	1419	1585	1255	1412	1459	1291	1424	1389	1230	1380	1270

The technical assessment also included an inspection of the installation site, considering the available roof area, roof type, orientation, slope, and possible shading. These characteristics were evaluated through on-site inspections, aerial drone images, geolocation data, and solar position analysis using SunEarthTools. Based on these data, the usable installation area was defined and the expected solar irradiation conditions were verified.

The photovoltaic system was then sized using the annual electricity demand, the local solar resource, and technical information provided by the installation company, including module specifications, inverter characteristics, estimated system losses (20%), and required installation area. The sizing process resulted in the definition of the installed capacity, number of photovoltaic modules, expected monthly energy generation, and occupied roof area.

The proposed system was verified for compliance with the current regulations of the Brazilian Electricity Regulatory Agency (ANEEL, 2021), particularly Resolution REN 1000/2021, as well as the applicable certification requirements for photovoltaic modules, inverters, protection devices, and metering equipment.

2.3 Method for studying economic feasibility

The literature indicates that the economic viability of solar PV systems on multi-family building rooftops is highly sensitive to the environment, roof characteristics, electricity demand, and system demand characteristics (Haegermark, Kovacs and Dalenbäck, 2017). After the assessment in the previous stages, an economic analysis was performed by comparing the system implementation costs with the financial benefits resulting from reduced grid consumption. Financing simulations and savings projections were used, considering different terms and average market interest rates.

The financial assessment in this study is not based on a predictive model requiring assumptions such as inflation, future tariff increases, or photovoltaic module degradation (Dos Santos et al., 2024; Reis, Reis Júnior and Perin, 2020). Instead, feasibility was demonstrated through a direct comparison of monthly expenditures: the monthly cost associated with implementing the system (as quoted by the specialized company) is lower than the condominium's current electricity bill. The photovoltaic system specifications were not arbitrarily selected by the authors but were obtained from the technical design and commercial proposal prepared by a specialized photovoltaic engineering company based on the condominium's electricity demand and installation conditions.

The photovoltaic system was sized based on the annual electricity demand, the available roof area, and the local solar irradiation conditions. The technical proposal considered a grid-connected (on-grid) photovoltaic system composed of high-efficiency bifacial photovoltaic modules (585 Wp), a 10 kW single-phase inverter (220 V), mounting structures, electrical protection devices, bidirectional metering, and monitoring equipment. The equipment was selected according to compatibility with the estimated load, installation conditions, manufacturer specifications, and compliance with Brazilian technical standards and ANEEL regulations.

Therefore, financial feasibility results from an immediate and observable reduction in monthly costs, rather than from long-term financial projections. Regarding the company that provided the budget figures, there is no conflict of interest, as the external company only supplied market-based cost estimates and did not participate in the analysis, interpretation, or writing of the study.

3 Simulation results for technical feasibility

Technical feasibility requires structural analysis, compatibility with roofing (or façade) materials, and compliance with technical standards (Bonomo et al., 2024; Maghrabie et al., 2021). The location selection considered collective energy consumption and the interest in adopting renewable energy sources, aiming to reduce operating costs and dependence on the conventional power grid. The historical electricity consumption data (Table 1) showed a total annual demand of 16,577 kWh for the study period (May 2024 to April 2025), for the nine residential blocks. The total annual consumption in this period was 16,577 kWh.

The data indicate that Block A has a higher electricity consumption than the average of the other blocks over the 12 months analyzed. This increase can be attributed to the inclusion of the electrical load of the guardhouse, lighting in common areas, and the main electronic gate, all connected to this block's power panel. Similarly, Blocks B and C also have high consumption, as they house party areas, whose lighting, ventilation, and cooling systems contribute significantly to the increased energy demand. Block I, in turn,

records higher consumption due to the secondary electronic access gate, whose load is also accounted for in its bill.

In contrast, Blocks E and H had the lowest average consumption levels during the period. This difference is primarily due to the partial vacancy of housing units, resulting in less foot traffic and, consequently, less use of common area lighting, which is controlled by motion sensors. Seasonal variations in consumption patterns were also observed, with an increase in the winter months (Figure 2). This behavior is related to the reduction in natural light on days with less sunlight, which leads to more frequent use of artificial lighting in common areas. The adoption of LED lighting control systems and motion sensors can mitigate this impact, although increased consumption in winter is still observed (Lee and Kang, 2024).

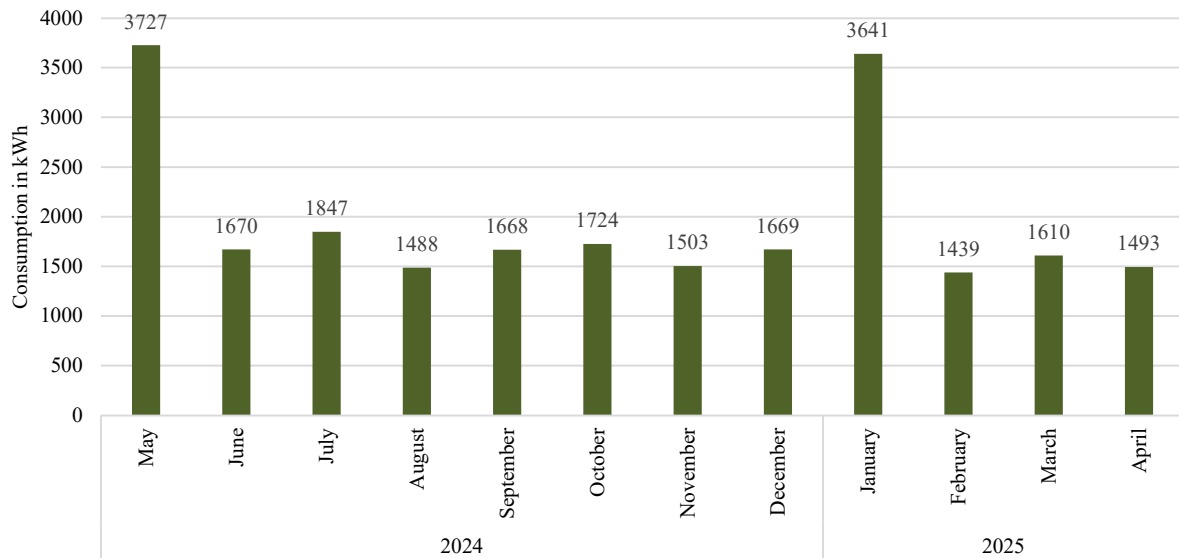


Figure 2. Historical data on energy consumption at the *Vila Verde* Condominium during the study period.

The condominium's energy consumption is predominantly used for the security system, which includes surveillance cameras and motion sensors for automatic lighting activation in the indoor and outdoor areas, as well as in the garages. It should be noted that the development does not have elevators. For the installation of the photovoltaic system, the use of the roof of one of the blocks, composed of fiber cement tiles, was considered, and the technical and structural feasibility for installing the modules was assessed.

To meet this energy demand, the project proposes the installation of a generating unit with an estimated average production of 1,550 kWh/month, using a system with an installed capacity of 14.1 kWp and assuming approximately 20% technical losses. The system will be installed on the roof of one of the residential blocks, occupying a usable area of 60 m² with 25 photovoltaic modules (Table 2). When the monthly consumption of 1,550 kWh is converted to a daily value (51.66 kWh/day) and compared with the system's rated capacity (14.1 kWp), the implied requirement is 3.66 peak-sun-hours per day. This value is fully compatible with typical Brazilian solar irradiation levels, which average around 5 peak-sun-hours per day even during winter. Therefore, the figures presented in the manuscript are technically consistent.

Table 2. Technical characteristics of the proposed photovoltaic system.

Features	Values
Recommended Energy Production, kWh	1550
Suggested power, kWp*	14.1
Approximate losses*	20.00%
Number of plates	25
Required area, m ²	60

The proposed photovoltaic system will use 585 Wp bifacial modules, with a fully automated manufacturing process and ISO 9001, ISO 14001, and OHSAS 18001 certifications, in addition to compliance with IEC 61215:2015. The inverter's nominal voltage and frequency are typically determined and requested prior to purchase (Hamid and Afifah, 2020). For this project, a single-phase 10 kW inverter for 220 V, certified and compliant with Brazilian standards, was considered. In addition to its residential-

friendly design, the system features Wi-Fi connectivity and protection devices against short-circuits, overloads, overvoltage, undervoltage, and polarity reversal, providing greater safety and efficiency.

To assess incident radiation in the condominium, it is necessary to evaluate the solar incidence on the building. Solar energy curve modeling, which seeks to map irradiance and meteorological variables in the shading analysis of photovoltaic panels, uses statistical and physical methods, or various types of software (Yang, Xia and Mayer, 2024). This study applied the tool for designers and consumers of solar energy (Anon), as in previous research (Reis, Reis Júnior and Perin, 2020), which helped assess the shaded areas and solar inclination in the condominium.

The solar incidence analysis followed four steps: (i) determination of the geographic coordinates of the condominium; (ii) insertion of these coordinates into the SunEarthTools – Sun Position software (Figure 3); (iii) generation of the annual solar path and shading diagrams; and (iv) interpretation of roof exposure and seasonal solar availability to verify the suitability of the selected roof for photovoltaic installation.

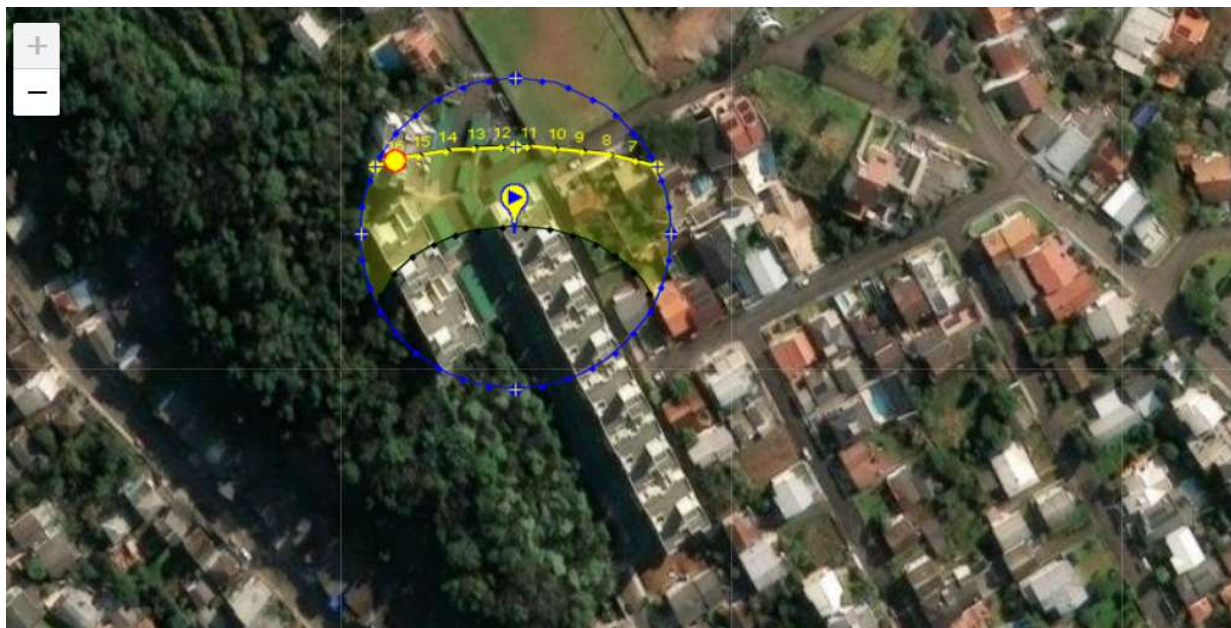


Figure 3. Solar incidence curve applied to the condominium building.

For the implementation of the photovoltaic system, the use of the roofs of the blocks, whose covering is composed of fiber cement tiles, was considered. The software automatically calculates annual solar geometry, hourly solar angles, irradiance on inclined planes, shading masks, and seasonal variations based on the geographic coordinates of the site. All irradiance-related parameters used in the feasibility study, such as effective irradiance, roof exposure, shading losses, and seasonal solar behavior, were obtained directly from the tool.

4 Simulation results for economic viability

Based on the energy demand, a technical and financial proposal was requested for the photovoltaic plant project in the *Vila Verde* condominium. The total budgeted value for the project was R\$34,383.00 (budgeted on June 9, 2025). The payment method was simulated at an interest rate of 1.6% per month, to be paid in 60 installments of R\$898.00 or 72 installments of R\$810.10.

Financing was considered in 60 installments of R\$898.00, distributed among the 144 housing units, with a unit price of R\$6.24 per month. This amount is lower than the cost of energy bill payments, demonstrating economic viability. According to the simulation diagram, the return on investment (ROI) for the project occurs in the third year after installation, two years before the initial investment is fully paid off (Figure 4). Our result was financially sound compared to another in Iran, where the total investment cost of the solar project for iron ore mines is paid back after 8.66 years (Magni, Marchioni and Baschieri, 2022).

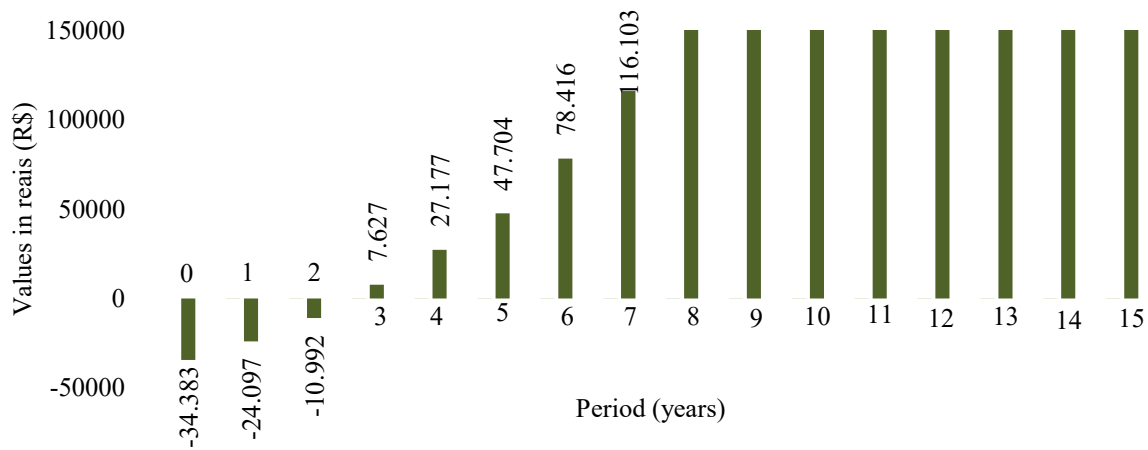


Figure 4. Return on investment (ROI) for the photovoltaic system.

The proposed solar photovoltaic plant design did not consider system maintenance costs, as it is an automatic generating station connected to the electricity distribution grid. The company responsible for installing the system guaranteed the generation capacity (80% of initial generation) for 30 years. The on-grid photovoltaic inverter, an essential piece of equipment for DC-AC current inversion (Abbassi, Aouiti and Bacha, 2023), is warranted for 10 years, and the photovoltaic panels are warranted for 12 years against manufacturing defects.

5 Study strengths and limitations

The applied study of photovoltaic technology demonstrated several strengths, such as the methodology, which combines technical, economic, and environmental analyses based on consumption data and geolocation tools. Still underrepresented in international photovoltaic research, the application of this technology in multifamily residential condominiums can contribute to urban sustainability. The proposal also demonstrates economic attractiveness, with a payback period in the third year and a low unit cost per apartment, directly aligning with SDGs 7 and 13.

However, some limitations must be acknowledged and may be considered as inferences for future research. The study is restricted to a single case study, which may limit its generalization to other contexts. The financial analysis did not include operation and maintenance costs, despite the fact that it is an automated (on-grid) system with low maintenance requirements. Regulatory and institutional barriers, although discussed, were not quantitatively assessed.

In addition, the simulations were based on only one year of energy consumption data, which may not fully capture seasonal and long-term variability. Finally, complementary technologies, such as energy storage and smart metering, were not implemented but only suggested for future developments, and they may contribute to the energy transition.

6 Conclusions

Given the current environmental situations and crises, particularly those related to energy and climate, the implementation of cleaner and more sustainable energy alternatives to mitigate environmental impacts is urgently needed. Investments and practices in photovoltaic energy, harnessing solar energy, are a growing possibility globally and in Brazil. This article, which stems from the "Sustainable Constructions" course in the Professional Master's Program in Civil, Sanitary, and Environmental Engineering, includes subsequent analyses by the authors, who sought to establish concrete relationships between the applicability of theoretical knowledge and engineering practice.

The study demonstrated that the adoption of photovoltaic systems in multi-family buildings, such as the *Vila Verde* Condominium, is technically feasible, economically advantageous, and environmentally more sustainable. The technical analysis confirmed the building's physical and environmental characteristics for system installation. The results of the economic feasibility studies demonstrated a return on investment in the third year of operation, reinforcing the financial attractiveness of the proposal. These findings confirm that the study's objective of "analyzing the technical and economic feasibility of implementing a photovoltaic system in a multi-family building" was achieved.

The project can directly contribute to reducing operating costs and dependence on the conventional electricity grid. Furthermore, adopting photovoltaic energy in residential condominiums represents a strategic advance toward the Sustainable Development Goals, especially regarding universal energy access (SDG 7) and climate change mitigation (SDG 13).

For initiatives like this to be scaled up, regulatory barriers must be addressed, such as affordable credit and resident awareness, which still limit the dissemination of this technology in multi-family developments. Therefore, we recommend that future studies advance on three main fronts: (i) exploring cooperative energy management models in condominiums; (ii) evaluating the impact of public policies and specific incentives for this segment; and (iii) analyzing the integration of photovoltaic generation with complementary solutions, such as energy storage and smart monitoring systems. Thus, this work, in addition to validating the feasibility of the practical application studied, can also pave the way for further research that strengthens the urban energy transition and the construction of more resilient and sustainable cities.

Acknowledgement

We acknowledge the financial support from the Santa Catarina State Research and Innovation Support Foundation (FAPESC) through the awarding of a master's scholarship to the lead author (Call for Proposals No. 18/2024).

References

- Abbassi, M., Aouiti, A. and Bacha, F. (2023). DC/AC Conversion Efficiency of Grid-Connected Photovoltaic Inverters with Sensorless MPPT. In: *2023 IEEE International Conference on Advanced Systems and Emergent Technologies (IC_ASET)*. 29 April 2023. IEEE. pp.01–06. [Online]. Available at: doi:10.1109/IC_ASET58101.2023.10150465.
- Abu Qadourah, J., AL-Falahat, A. M. and Alrwashdeh, S. S. (2022). Assessment of solar photovoltaics potential installation into multi-family building's envelope in Amman, Jordan. Pham, D. T. (Ed). *Cogent Engineering*, 9 (1). [Online]. Available at: doi:10.1080/23311916.2022.2082059.
- Akinyele, D. O., Rayudu, R. K. and Nair, N. K. C. (2015). Development of photovoltaic power plant for remote residential applications: The socio-technical and economic perspectives. *Applied Energy*, 155, pp.131–149. [Online]. Available at: doi:10.1016/j.apenergy.2015.05.091.
- Aljaghoub, H. et al. (2022). Solar PV cleaning techniques contribute to Sustainable Development Goals (SDGs) using Multi-criteria decision-making (MCDM): Assessment and review. *International Journal of Thermofluids*, 16 (October), p.100233. [Online]. Available at: doi:10.1016/j.ijft.2022.100233.
- ANEEL, A. N. D. E. E. (2021). *RESOLUÇÃO NORMATIVA ANEEL Nº 1.000, DE 7 DE DEZEMBRO DE 2021*. [Online]. Resolução Normativa 1.000/2021. Available at: <https://www2.aneel.gov.br/cedoc/ren20211000.html> [Accessed 29 April 2025].
- Aste, N. et al. (2024). The role of photovoltaic technology in achieving net zero energy target in residential buildings. *Energy Strategy Reviews*, 55, p.101543. [Online]. Available at: doi:10.1016/j.esr.2024.101543.
- Bonomo, P. et al. (2024). Comprehensive review and state of play in the use of photovoltaics in buildings. *Energy and Buildings*, 323, p.114737. [Online]. Available at: doi:10.1016/j.enbuild.2024.114737.
- Borodinecs, A., Lebedeva, K. and Odineca, T. (2024). Evaluation of household electricity consumption in multi-apartment buildings for optimization of rooftop PV systems. *Energy and Buildings*, 325 (November), pp.1–11. [Online]. Available at: doi:10.1016/j.enbuild.2024.114971.
- Cirella, G. T. et al. (2021). Energy Re-Shift for an Urbanizing World. *Energies*, 14 (17), p.5516. [Online]. Available at: doi:10.3390/en14175516.
- Dermentzis, G., Ochs, F. and Franzoi, N. (2021). Four years monitoring of heat pump, solar thermal and PV system in two net-zero energy multi-family buildings. *Journal of Building Engineering*, 43 (March), p.103199. [Online]. Available at: doi:10.1016/j.job.2021.103199.
- Haegermark, M., Kovacs, P. and Dalenbäck, J.-O. (2017). Economic feasibility of solar photovoltaic rooftop systems in a complex setting: A Swedish case study. *Energy*, 127, pp.18–29. [Online]. Available at: doi:10.1016/j.energy.2016.12.121.

- Hamid, M. I. and Afifah. (2020). Technical Design and Financial Feasibility Analysis of Off-Grid Photovoltaic Power Supply System for Residential Load. *IOP Conference Series: Materials Science and Engineering*, 846 (1). [Online]. Available at: doi:10.1088/1757-899X/846/1/012031.
- Kobylarczyk, J., Marchwiński, J. and Zielonko-Jung, K. (2020). Issues relating to the efficient application of passive solar protection in multi-family residential buildings. *Technical Transactions*, pp.1–16. [Online]. Available at: doi:10.37705/techtrans/e2020013.
- Kwag, B. C., Kim, G. T. and Hwang, I. T. (2024). Integration of Photovoltaic Systems for Energy Self-Sufficient Low-Rise Multi-Family Residential Buildings in Republic of Korea. *Buildings*, 14 (8), p.2522. [Online]. Available at: doi:10.3390/buildings14082522.
- Lee, C. C., Feng, Y. and Peng, D. (2022). A green path towards sustainable development: The impact of low-carbon city pilot on energy transition. *Energy Economics*, 115 (July), p.106343. [Online]. Available at: doi:10.1016/j.eneco.2022.106343.
- Lee, J. H. and Kang, J.-S. (2024). Study on Lighting Energy Savings by Applying a Daylight-Concentrating Indoor Louver System with LED Dimming Control. *Energies*, 17 (14), p.3425. [Online]. Available at: doi:10.3390/en17143425.
- Li, Y. et al. (2021). Residential demand-side management using integrated solar-powered heat pump and thermal storage. *Energy and Buildings*, 250, p.111234. [Online]. Available at: doi:10.1016/j.enbuild.2021.111234.
- Li, Z. (2023). Prospects of Photovoltaic Technology. *Engineering*, 21, pp.28–31. [Online]. Available at: doi:10.1016/j.eng.2022.07.008.
- Maghrabie, H. M. et al. (2021). State-of-the-Art Technologies for Building-Integrated Photovoltaic Systems. *Buildings*, 11 (9), p.383. [Online]. Available at: doi:10.3390/buildings11090383.
- Magni, C. A., Marchioni, A. and Baschieri, D. (2022). Impact of financing and payout policy on the economic profitability of solar photovoltaic plants. *International Journal of Production Economics*, 244, p.108338. [Online]. Available at: doi:10.1016/j.ijpe.2021.108338.
- Milón Guzmán, J. J. et al. (2020). Sizing methodology for photovoltaic systems considering coupling of solar energy potential and the electric load: dynamic simulation and financial assessment. Ta-Wei Lin, D. (Ed). *E3S Web of Conferences*, 181, p.02003. [Online]. Available at: doi:10.1051/e3sconf/202018102003.
- Monna, S. et al. (2020). A Comparative Assessment for the Potential Energy Production from PV Installation on Residential Buildings. *Sustainability*, 12 (24), p.10344. [Online]. Available at: doi:10.3390/su122410344.
- Nooman AlMallahi, M. et al. (2024). A path to sustainable development goals: A case study on the thirteen largest photovoltaic power plants. *Energy Conversion and Management: X*, 22, p.100553. [Online]. Available at: doi:10.1016/j.ecmx.2024.100553.
- Rabaia, M. K. H. et al. (2024). Enabling the circular economy of solar PV through the 10Rs of sustainability: Critical review, conceptualization, barriers, and role in achieving SDGs. *Sustainable Horizons*, 11 (October 2023), p.100106. [Online]. Available at: doi:10.1016/j.horiz.2024.100106.
- Reis, M. A. F. et al. (2025). Experimental study on the thermal performance of insulating materials for metal tiles. *Thermal Science and Engineering Progress*, 57 (November 2024), p.103127. [Online]. Available at: doi:10.1016/j.tsep.2024.103127.
- Reis, M. A. F., Reis Júnior, P. and Perin, D. L. (2020). Energy sustainability in public school. 11th ed. UNC (Ed). *MIX Sustentável*, 6 (3), pp.37–44. [Online]. Available at: doi:10.29183/2447-3073.MIX2020.v6.n3.37-44 [Accessed 2 April 2019].
- Reis, M. A. F. and Serrano, A. (2022). Teaching photoelectric effect with photovoltaic cells use in the physics laboratory. In: Graça S. Carvalho, Anastácio, A. S. A. and Z. (Ed). *Fostering scientific citizenship in an uncertain world*. (Iv). 2022. Braga: CIEC, University of Minho, Portugal.: ESERA 2021. pp.1305–1312. [Online]. Available at: <https://www.esera.org/wp-content/uploads/2023/02/CNF21-Complete-eProceedings.pdf> [Accessed 14 February 2023].
- Ren, H. et al. (2021). Improving energy flexibility of a net-zero energy house using a solar-assisted air conditioning system with thermal energy storage and demand-side management. *Applied Energy*, 285,

p.116433. [Online]. Available at: doi:10.1016/j.apenergy.2021.116433.

Roberts, M. B., Bruce, A. and MacGill, I. (2019). Opportunities and barriers for photovoltaics on multi-unit residential buildings: Reviewing the Australian experience. *Renewable and Sustainable Energy Reviews*, 104 (August 2017), pp.95–110. [Online]. Available at: doi:10.1016/j.rser.2018.12.013.

Roberts, M. B., Sharma, A. and MacGill, I. (2022). Efficient, effective and fair allocation of costs and benefits in residential energy communities deploying shared photovoltaics. *Applied Energy*, 305, p.117935. [Online]. Available at: doi:10.1016/j.apenergy.2021.117935.

Dos Santos, C. A. et al. (2024). Photovoltaic cells with transparency for glass coverage: case study in party space. *Latin American Journal of Energy Research*, 11 (1), pp.114–120. [Online]. Available at: doi:10.21712/lajer.2024.v11.n1.p114-120.

Tsalikis, G. and Martinopoulos, G. (2015). Solar energy systems potential for nearly net zero energy residential buildings. *Solar Energy*, 115 (2015), pp.743–756. [Online]. Available at: doi:10.1016/j.solener.2015.03.037.

Yang, D., Xia, X. and Mayer, M. J. (2024). A Tutorial Review of the Solar Power Curve: Regressions, Model Chains, and Their Hybridization and Probabilistic Extensions. *Advances in Atmospheric Sciences*, 41 (6), pp.1023–1067. [Online]. Available at: doi:10.1007/s00376-024-3229-4.

Yu, J. et al. (2022). Role of solar-based renewable energy in mitigating CO2 emissions: Evidence from quantile-on-quantile estimation. *Renewable Energy*, 182, pp.216–226. [Online]. Available at: doi:10.1016/j.renene.2021.10.002.

Sun position. [Online]. SunEarthTools.com. Available at: https://www.sunearthtools.com/dp/tools/pos_sun.php?lang=pt [Accessed 16 September 2025].