

**COB-2023-0565**  
**DEVELOPMENT OF A HYBRID ENERGY GENERATION SYSTEM  
AIMED AT SERVING REMOTE AREAS WITH A FOCUS ON SYSTEM  
OPTIMIZATION**

**Thais Gonçalves Xavier** <sup>1</sup>

**Tarcísio Klein** <sup>2</sup>

Master's student at the Federal University of Itajubá - UNIFEI.

d2022100202@unifei.edu.br <sup>1</sup>

tarcisioklein@unifei.edu.br <sup>2</sup>

**Diego Mauricio Yepes Maya**

Prof. Dr. at Federal University of Itajubá - UNIFEI

diegoypes@unifei.edu.br

**Angie Lizeth Espinosa Sarmiento**

Prof<sup>a</sup>. Dr<sup>a</sup>. at Federal University of Itajubá - UNIFEI

angieespinosa@unifei.edu.br

**Abstract.** *In order to serve off-grid remote areas and hard-to-reach small communities in Brazil, the article aims to develop a hybrid system based on renewable energies to meet the needs of such areas, using the simulation software iHOGA. In this context, the article seeks to analyze the optimal configuration of the system, aiming to minimize CO<sub>2</sub> emissions and the total system costs (NPC). The study area, a Extractive Reserve called 'Barreiro das Antas', is located in the state of Rondônia, and its data were obtained from the georeferencing tool NASA POWER. Based on the literature and the developed state-of-the-art study, the average consumption of basic needs for the community was determined to achieve better accuracy in the demand to be met. Various models of components were inputted into the simulation to obtain the best combination for the location. Ultimately, through the simulations, a system composed of photovoltaic panels, batteries, a diesel generator, and inverters resulted in an NPC of €9499.45 and CO<sub>2</sub> emissions of 178.86 kg/year.*

**Keywords:** *hybrid systems; renewable energy; optimization; isolated areas*

## 1. INTRODUCTION

Quality of life is directly impacted by access to electrical energy, as it is one of the key factors for societal and economic development. The lack of access to electricity not only limits the socio-economic development of these communities but also hinders access to essential services such as lighting, refrigeration, communication, and medical care. However, it is important to consider sustainability and the environmental impacts that can be caused by the generation and use of this energy, and it is in this context that the development related to renewable energies is inserted.

Studies show that although renewable sources are an alternative to reverse this situation, it is necessary to use multiple sources simultaneously in order to increase reliability since their supply is dependent on natural resources, which can be disrupted and interrupted. This combination of energy sources is referred to as hybrid systems, and their proper development would be a solution for this scenario, capable of meeting the energy needs of these locations through renewable sources, contributing to sustainability and community development through clean and environmentally friendly energy.

The study conducted by Anoune et al. (2018) addresses the importance of solar and wind energies in electricity generation, emphasizing their renewable nature, reduced environmental impact, and widespread accessibility. The article highlights the benefits of combining these sources in remote areas, underscoring that using them separately can lead to high costs due to overcapacity. The author recommends the application of sizing and optimization techniques to ensure energy reliability and expense reduction in hybrid systems incorporating solar and wind energy. The research provides an updated review of literature and conventional approaches for sizing and optimizing photovoltaic and wind hybrid systems in remote regions, with the aim of balancing reliability and costs. Furthermore, the study compares various topologies used in these systems, presents a mathematical model of hybrid components, with an emphasis on reliability and costs. Finally, it discusses the software tools and algorithms used in optimizing the sizing of these systems.

In an effort to serve isolated areas, Shezan et al. (2016) developed a system to meet a community in Malaysia, aiming to minimize CO<sub>2</sub> emissions from a hybrid renewable energy system. In this regard, the research was conducted through simulations in a case study where the viability of Energy Cost and Net Present Cost (NPC) were also evaluated. The

results showed that 16 tons of CO<sub>2</sub> emissions per year could be avoided, and 29.65% of NPC could be minimized when compared to conventional power plants.

In order to propose a hybrid renewable energy system for the electrification of agriculture and irrigation in the Dongola region, Sudan, Elkadeem (2019) developed an integrative framework with technical-economic optimization to plan renewable energy systems, considering the combination of technologies such as photovoltaic solar energy, wind turbines, diesel generators, battery storage, and converters. The results indicate that the hybrid system is highly efficient, with reduced costs, minimal environmental impact, and a positive return on investment. The system demonstrated high performance, with lower costs, reduced environmental impact, and a positive return on investment of 39.94%; a significant reduction of approximately 95% in carbon emissions and fuel consumption compared to the baseline system.

In light of the aforementioned studies, areas with limited accessibility continue to be a cause for concern. Despite Brazil's abundant sources of electrical energy, as reported by the Institute of Energy and Environment – IEMA - (2019), approximately 990,103 thousand residents scattered across the Legal Amazon region lack access to electricity, representing roughly 250 communities. Among these communities is the *Barreiro das Antas* Extractive Reserve, situated in the state of Rondônia, which holds solar and wind energy potential for the implementation of a system.

In this regard, the present study aims to optimize a hybrid system using photovoltaic solar energy, wind energy, diesel generator, electrolyzer, and fuel cell to meet the isolated community of *Barreiro das Antas* Extractive Reserve.

## 2. METHODOLOGY

In this chapter, the methods and tools used in conducting the studies will be demonstrated, as well as the characterization of the locality, including available resources and the demand to be met. The data used in the simulation, parameters considered in the system development in the software, and the evaluation of the available resources will also be presented.

### 2.1 Characterization of the study location

The chosen study area is located in the municipality of Guajar-Mirim, in the state of Rondnia, as shown in Figure 1. Its extreme geographical positions are as follows: North 1122'04"S, 6448'06"W; South 1141'26"S, 6450'41"W; East 1134'28", 6421'08"; and West 1131'09"S, 6452'40"W (ICMBio, 2012).

According to the developed management plan (2012), there were a total of 360 inhabitants scattered across 20 locations in 2006. The houses have an average size of 25m<sup>2</sup> and use clay stoves for meal preparation. Access to the Extractive Reserve is via the Novo River, a tributary of the Pacas Novos River, and there is no source of energy in the community. For access to other activities such as health and education, residents travel to Guajar-Mirim. Communication between communities is done through solar-powered amateur radios located in Santa Isabel or battery-powered radios. The main economic activity of the community is cassava flour production and Brazil nut extraction, practiced by 42% and 92% of the families, respectively.

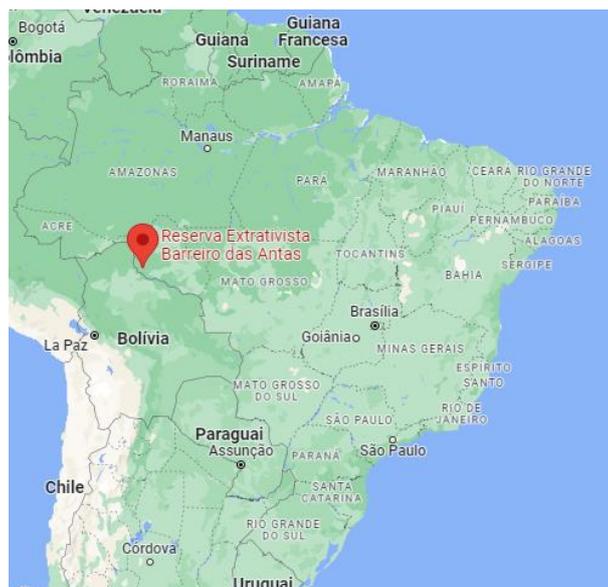


Figure 1 - Community Location. Source: Google Maps (2023).

### 2.2 Available Energy Resources

According to the Global Solar Atlas (2023), the average global horizontal irradiation in the region reaches 1902.7 kWh/m<sup>2</sup> per year, and the direct normal irradiation is 1433 kWh/m<sup>2</sup> per year. The average air temperature in the region is 25.7°C. The optimal tilt angle for photovoltaic panels is between 0° and 15°. For the simulations, the software determined an average daily irradiation of 4.82 kWh/m<sup>2</sup>, with a total annual irradiation of 1760.5 kWh/m<sup>2</sup>. The month with the highest irradiation calculated by the software was July, with 6.35 kWh/m<sup>2</sup>. No solar tracking was considered. According to Luque and Hegedus (2011) the average Earth albedo is 0.34 but can vary from 0.03 (for forests) to 0.8 (for clouds). The value used was 0.33, which is typical for dry soil.

Regarding wind potential, at a height of 50m, the wind speed in the region reaches 2.52 m/s, with a generation potential of 30 W/m<sup>2</sup> (Global Wind Atlas, 2023). The data adopted by the software, based on the location coordinates, indicate an average annual wind speed of 2.03 m/s, with August being the month with the highest wind speed at 2.35 m/s, also at a height of 50m.

### 2.3 Demand

A Management Plan for the region was developed by ICMBio (2012), which presents an optimal scenario to contribute to the community's development. In this regard, the demand was based on this document, aiming to meet the basic needs of the community as a whole. Individual households were not taken into account. The power of the equipment was taken from PROCEL - Brazilian Center for Energy Efficiency Information (2023) and the amount of equipment based on the study carried out by Mathyas (2018), carried out with the objective of proposing the regional development of extractive reserves spread across the Amazon with the dimensioning of energy consumption. With these data, Table 1 was obtained.

Table 1. Development of community demand.

<b>SCHOOL</b>		
<b>Equipment</b>	<b>Quantity</b>	<b>Total Power (kWh)</b>
Bulb	3	0.033
Freezer	1	0.066
Computer	1	0.063
Internet	1	0.006
<b>HEALTH CLINIC</b>		
<b>Equipment</b>	<b>Quantity</b>	<b>Total Power (kWh)</b>
Bulb	3	0.033
Freezer	1	0.066
Computer	1	0.063
Internet	1	0.006
<b>SLAUGHTERHOUSE</b>		
<b>Equipment</b>	<b>Quantity</b>	<b>Total Power (kWh)</b>
Bulb	1	0.011
Freezer	1	0.066

Source: PROCEL (2023), Mathyas (2018)

### 2.4 Simulation and Equipment

For the simulations, a series of components were selected, and regarding the photovoltaic panels, Table 2 shows the models that were used. As for the parameters related to efficiency, inflation rate, and cost variation, they were obtained through a literature review. Dantas et al. (2018) showed that the annual inflation rate for generation costs is 5%. According to Ruviaro et al. (2018), the efficiency coefficient of a photovoltaic panel can reach 80%. Additionally, Lotz (2015) reported that the maximum cost variation for panels is 36%. Therefore, these values were adopted in the system development. The exchange rate for the euro on the date of this manuscript, July 7, 2023, was 1.0899USD (European Central Bank, 2023).

Table 2. Model of Photovoltaic Panels.

<b>Photovoltaic Panels</b>	<b>Cost (€)</b>	<b>Power (Wp)</b>
SiP24-Atersa: A180P	201.0	180
SiP24-Atersa: A280P	234.5	280
SiP12-Atersa: A66P	100.5	66
SiP12-Atersa: A95P	115.91	95
SiP12-Atersa: A135P	128.64	135
SiP12-Atersa: A66P	100.5	66
SiP12-Atersa: A95P	115.91	95
SiP12-Atersa: A135P	128.64	135

(1)

Source: iHOGA, (López, 2023), European Central Bank (2023).

For the wind turbines, the models used are shown in Table 3. According Eras et al. (1982), considering the effect of temperature, the air density corresponds to 1.225 kg/m<sup>3</sup>, and regarding the surface roughness, a value of 0.1 m was used (in the software, Class 2). The operation and maintenance costs were set at 2% per year, and the depreciation value at 5% per year, according Custódio (2010, apud Fontanet, 2012). Additionally, a 26% reduction in the costs of wind turbines was considered (Irena, 2016).

Table 3. Wind Turbine Models.

<b>Wind Turbine</b>	<b>Cost (€)</b>	<b>Bus</b>
Bornay: 600	2850.85	DC
Bornay: 1500	3266.23	DC
Bornay: 3000	5061.85	DC
Bornay: 6000	8077.54	DC

Source: iHOGA, (López, 2023), European Central Bank (2023).

For batteries, a 39% annual cost reduction and a 6% depreciation were considered (Silva, 2022). Table 4 shows the battery models used.

Table 4. Model of batteries

<b>Battery</b>	<b>Cost (€)</b>	<b>Nominal Chain (Ah)</b>
OPZS-Hawker:TLS-3	65.09	180
OPZS-Hawker:TLS-5	119.26	270
OPZS-Hawker:TVS-5	110.48	390

Source: iHOGA, (López, 2023), European Central Bank (2023).

Regarding the inverters, the chosen models are detailed in Table 5 and they have a charging efficiency of 100%.

Table 5. Inverter model

<b>Inverter</b>	<b>Cost (€)</b>	<b>Power (VA)</b>
Generic: 1000	361.8	1000
Generic: 2000	703.5	2000
Generic: 3000	1072.0	3000

Source: iHOGA, (López, 2023), European Central Bank (2023).

The backup generator models are presented in Table 6. According to the operating regime, the wear factor and increase in the maintenance cost for activating less than 30% of the capacity was 1.25 and for generators operating at 100% was 1.25 1.5. The fuel for all models used is diesel.

Table 6. Model of generators

Generator	Cost (€)	Power (kVA)
Diesel 1.9kVA	536.0	1,9
Diesel 3kVA	703.5	3
Diesel 5.5kVA	871.0	5,5
Diesel 7kVA	1072.0	7
Diesel 10kVA	2479.0	10

Source: iHOGA, (López, 2023), European Central Bank (2023).

## 2.5 Economic analysis

In order to analyze the costs of the hybrid system over a period of 25 years, a real discount rate of 7.54% was used, derived from the nominal discount rate based on the SELIC (13.75% per year) (Banco Central do Brasil, 2023). However, the annual inflation rate for the same period, according to the IBGE (Brazilian Institute of Geography and Statistics) (2023), is 5.77%.

For the installation of the system, 25% of the initial value would be allocated to this phase. Along with the Pronaf (National Program for Family Farming Strengthening), it would be possible to finance 100% of the expenses at a lower interest rate (5% per year) for a period of 25 years, with equal installment payments, in the ABC+Bioeconomy modality (Banco Nacional de Desenvolvimento, 2023).

## 2.6 Optimization method

The optimization method used by the iHOGA software is SPEA-2. SPEA-2 is an enhanced version of SPEA (Strength Pareto Evolutionary Algorithm), a classic evolutionary algorithm used to solve multi-objective optimization problems. Through this strategy, SPEA-2 aims to improve problem space exploration and increase its effectiveness in searching for the optimal Pareto set of solutions (Rego, 2013).

The overall objective of the SPEA-2 method is to find high-quality solutions for multi-objective optimization problems. It achieves this by generating a set of candidate solutions and evaluating each of them based on their fitness. Fitness takes into account the multiple objectives of the problem and assigns a value to each solution based on how well it fulfills those objectives. Analyzing the information obtained about the SPEA-2 method involves assessing the quality of the solutions found, analyzing the external Pareto archive, and understanding the algorithm's characteristics. This information can be used to make decisions about the solutions to be implemented in the iHOGA software and to improve the optimization algorithm's performance (Shiheng et al., 2021).

To perform the optimization, iHOGA considers different variables and constraints related to the renewable energy system. This includes the availability and variability of renewable energy sources, energy demand, grid characteristics, and investment and operational costs.

At the end of the optimization process, iHOGA provides a set of results that represent the optimized configuration and operation of the renewable energy-based electric supply system. These results may include information about resource allocation and sizing, energy control and management strategies, and other relevant decision-making information.

In this regard, to define the best system, a multi-objective optimization was developed to mitigate CO<sub>2</sub> emissions and the Net Present Cost (NPC). The algorithm explored all possible combinations regarding the component models and operation strategies. When determining the best system, the three objective parameters were taken into consideration, aiming to find a scenario where the parameters are not excessively high and do not render the system infeasible.

## 3. RESULTS

With the optimization performed by the software, six different systems were obtained, yielding the following values presented in Table 7 below.

Table 7. Simulation Results

System	NPC (€)	CO <sub>2</sub> (kg/year)	Battery Life	Levelized Cost of Energy (€/kWh)
--------	---------	---------------------------	--------------	----------------------------------

1	9268.46	361.08	18 years	0.48
2	9499.54	178.86	18 years	0.50
3	9671.93	170.6	10.52 years	0.51
4	9971.80	166.92	10.84 years	0.51
5	10076.14	165.53	17.78 years	0.52
6	10354.06	161.05	17.78 years	0.54

Source: iHOGA, (López, 2023), European Central Bank (2023).

It should be noted that scenarios 1 and 2, 3 and 4, 5 and 6 are similar. In the simulation of the first system, with the chosen photovoltaic panel model, there is lower energy generation, and consequently, the use of the generator becomes more significant, resulting in a significant increase in CO<sub>2</sub> emissions. In the third and fourth scenarios, the battery used in the simulation significantly decreases its lifespan, making the system unfeasible in these two scenarios. In the fifth and sixth scenarios, the component models used did not yield significant results compared to the second system, except for the NPC, which had a higher value. However, since the remaining parameters are similar, the increase in NPC does not bring efficiency to the system.

Based on the above results, for the specific region, the hybrid system that best suits the requirements is System 2, composed of the equipment presented in Table 8. The wind turbine was not considered in any of the optimizations as the wind speed in the region did not favor the system, resulting in low potential for energy generation using this resource.

Table 8. Components considered in the chosen system.

Component	Model	Power
Photovoltaic Panel	SiP24-Atersa: A280P	280Wp
Wind Turbine	-	-
Battery	OPZS-Hawker:TVS-5	390Ah
Inverter	Generic: 1000	1000VA
Generator	Diesel 1.9kVA	1.9kVA

Source: iHOGA, (López, 2023)

The operation of this system would work as follows: If the energy produced by renewable sources exceeds the load, the excess energy is used to charge the batteries. If the energy produced by renewable sources is less than the load, the batteries would supply the remaining demand (if the batteries are not sufficient, the remainder would be provided by the generator).

The initial investment for this system would be €9909.63, with 99.57% coming from renewable energy sources. With this system, the generator would operate for 17.6 hours per year. Based on the obtained information, it is not possible to optimize CO<sub>2</sub> emissions since the usage of the generator is low.

Figure 2 shows the NPC of each component. It can be observed that the costs related to the photovoltaic panel, batteries, and inverters are similar. The high acquisition cost justifies the inclusion of batteries and inverters in this scenario.

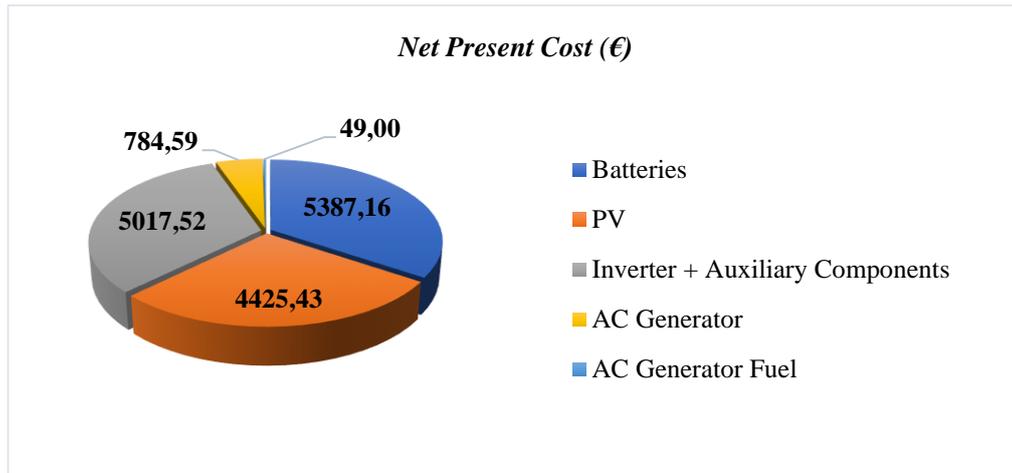


Figure 2. NPC distribution among elements. Source: iHOGA, (López, 2023)

Figure 3 demonstrates that the photovoltaic panel has the capacity to meet the load, justifying its high cost, as the high solar radiation in the area allows this energy source to fulfill the demand.

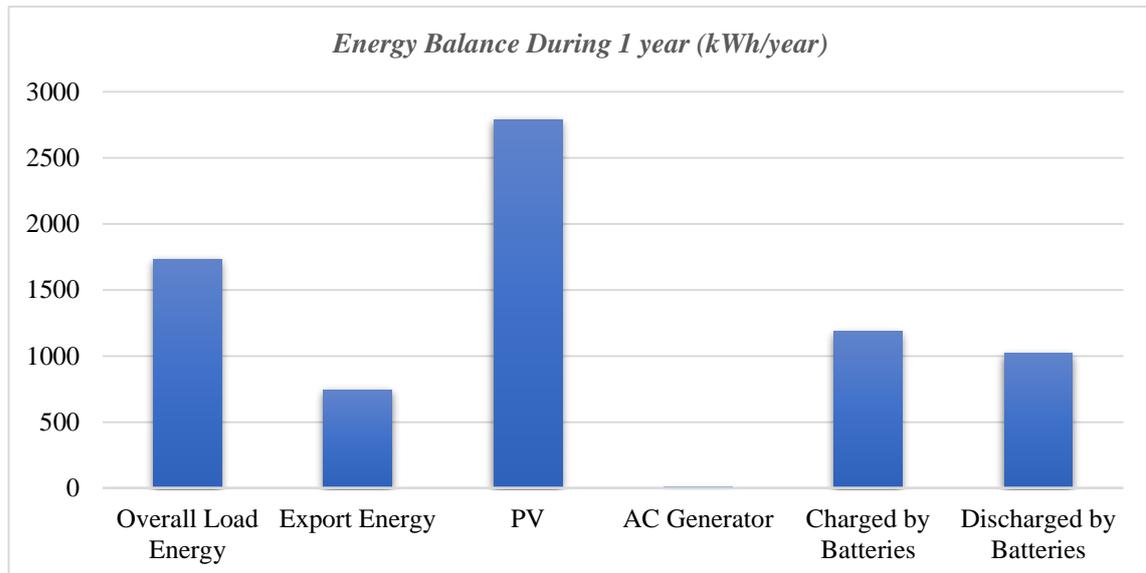


Figure 3. Energy produced per year. Source: iHOGA, (López, 2023).

The system described above consists of SiP24-Atersa panels (2 series x 6 parallel), Generic 1000 inverter, OPZS-Hawker:TVS-5 battery, and no use of a wind turbine. It is also worth noting that the total cost of the system for the period is €9,499.54 (cost of supplied energy at €0.50/kWh), and the total energy demand for the system is 1,734.5 kWh/year, with a total generated by the photovoltaic panels of 2,790.4 kWh/year. As mentioned earlier, in this scenario, 99.57% of the generated energy comes from renewable sources, with 735.7 kWh/year being excess energy generated.

It is evident that solar energy is capable of meeting the demand and charging the batteries with the surplus generated. In most situations, Li-ion storage is adequate to ensure a continuous distribution of electrical energy. Therefore, due to the function of the storage system, it represents one of the major impacts both in terms of costs and in the annual energy balance.

In summary, in terms of energy efficiency, it is possible to exclude the contribution of generators in the system to maximize the presence of renewable energies in the hybrid grid.

#### 4. CONCLUSIONS

With the obtained results, considering the NPC, it is important to conduct a more in-depth analysis to assess whether this cost is viable and justifiable in relation to the benefits provided by the system. Other factors need to be taken into

account, such as the system's lifespan, maintenance and operational costs over time, as well as potential energy savings and associated cost reductions.

Regarding CO<sub>2</sub> emissions, the value of 178.86 kg/year indicates a moderate impact. However, it is still important to consider environmental goals and regulations. Additional emission mitigation strategies may be implemented to further reduce the system's environmental impact.

It is important to emphasize that the conclusion regarding the viability and performance of the hybrid system should take into consideration the specific needs and characteristics of the isolated area in question. Additionally, it is recommended to perform a comparative analysis with other available solutions in the market that were not addressed in this article to determine if the proposed system is the best option considering the economic and environmental aspects. In summary, by considering all the characteristics of the Renewable Hybrid Energy System (SHER) obtained through the implementation of data in the iHOGA software, it would be possible to optimize it by exploring changes in energy storage methods and thus reducing system costs. Furthermore, to make the project more realistic, obtaining information about the actual consumption in the Barreiro das Antas Extractive Reserve would be possible.

## 5. ACKNOWLEDGEMENTS

The research team would like to thank Professor Rodolfo Dufo López, the principal investigator of the iHOGA software, for all the technical support. We also express our gratitude to the Minas Gerais State Research Support Foundation (FAPEMIG) for funding the project: "Simulation and Optimization of Isolated Hybrid Power Generation Systems based on Renewable Energies [PROCESSO APQ-01932-21]," carried out at the Federal University of Itajubá under the 001/2021 call - Universal Demand, DPI UNIFEI Registration No: PVDI208-2021. We also acknowledge the PPGEEN (Graduate Program in Energy Engineering) and the Federal University of Itajubá for their support.

## 6. REFERENCES

- Anoune, K., Bouya, M., Astito, A., & Abdellah, A. Ben. (2018). Sizing methods and optimization techniques for PV-wind based hybrid renewable energy system: A review. *Renewable and Sustainable Energy Reviews*, 93(April), 652–673. <https://doi.org/10.1016/j.rser.2018.05.032>
- Banco Central do Brasil. (2023). *Taxas de juros Bacisa - SELIC*. <https://www.bcb.gov.br/controleinflacao/historicotaxasjuros>
- Banco Nacional de Desenvolvimento. (2023). *Pronaf ABC+ Bioeconomia*. <https://www.bndes.gov.br/wps/portal/site/home/financiamento/produto/pronaf-bioeconomia>
- Da Mota, A., Br Fundo, M.-A. O., Para, M., Aurélio, N.-W.-B., & Souza, A. (2018). *ENERGIA SOLAR POTENCIALIZA PRODUÇÃO EXTRATIVISTA NA AMAZÔNIA*. [www.usinazul.com.br](http://www.usinazul.com.br)
- Dantas, S. G., & Pomper Mayer, F. M. (2018). Viabilidade econômica de sistemas fotovoltaicos no Brasil e possíveis efeitos no setor elétrico. *Ipea*, 1–42. [https://repositorio.ipea.gov.br/bitstream/11058/8400/1/TD\\_2388.pdf](https://repositorio.ipea.gov.br/bitstream/11058/8400/1/TD_2388.pdf)
- Elkadeem, M. R., Wang, S., Sharshir, S. W., & Atia, E. G. (2019). Feasibility analysis and techno-economic design of grid-isolated hybrid renewable energy system for electrification of agriculture and irrigation area: A case study in Dongola, Sudan. *Energy Conversion and Management*, 196, 1453–1478. <https://doi.org/10.1016/j.enconman.2019.06.085>
- Eras, D. G., Klein, S. A., & Duffie, J. A. (1982). *ESTIMATION OF THE DIFFUSE RADIATION FRACTION FOR HOURLY, DAILY AND MONTHLY-AVERAGE GLOBAL RADIATION* (Vol. 28, Issue 4).
- European Central Bank. (2023). *Currency Converter*. <https://data.ecb.europa.eu/currency-converter>
- Fontanet, F. A. (2012). *Avaliação de uma Opção de Espera de um Parque Eólico pelo Método de Opções Reais*. 90. <https://doi.org/https://doi.org/10.17771/PUCRio.acad.22813>
- Global Solar Atlas. (2023). *No Title*. <https://globalsolaratlas.info/map>
- Global Wind Atlas. (2023). *No Title*. <https://globalwindatlas.info/en>
- Google Maps. (2023). *No Title*. <https://www.google.com/maps>
- ICMBio. (2012). Plano de Manejo Participativo Reserva Extrativista Arapixi. *MMA-ICMBio*, 0–163.
- IEMA. (2019). *Um milhão estão sem energia elétrica na Amazônia, mostra IEMA*. <http://energiaambiente.org.br/um-milhao-estao-sem-energia-eletrica-na-amazonia-20191125>
- Instituto Brasileiro de Geografia e Estatística. (2023). *Inflação*. <https://www.ibge.gov.br/explica/inflacao.php>
- Irena. (2016). *The Power to Change: Solar and Wind Cost Reduction Potential to 2025*. [www.irena.org](http://www.irena.org)
- López, R. D. (2023). *Software iHOGA. Software de simulación y optimización de suministro eléctrico basado en energías renovables*. (EDU 3.4). <https://ihoga.unizar.es>.
- Lotz, C., Ottmann, J., Schneider, K., & Wilson, H. R. (2015). Fraunhofer Institute for Solar Energy System ISE. *Timo Sigurdsson P*, 6(1), 22. [www.ise.fraunhofer.de/www.ise.fraunhofer.de/en/press-and-media](http://www.ise.fraunhofer.de/www.ise.fraunhofer.de/en/press-and-media)
- Luque, A., & Hegedus, S. (2011). Handbook of Photovoltaic Science and Engineering. In *Handbook of Photovoltaic Science and Engineering*. <https://doi.org/10.1002/9780470974704>
- PROCEL. (2023). *Dicas de Economia de Energia*. <http://www.procelinfo.com.br/main.asp?View=%7BE6BC2A5F->

E787-48AF-B485-439862B17000%7D

- Rego, M. F. (2013). *Algoritmos Multiobjetivos para o Problema de Sequenciamento de Tarefas em Uma Máquina com Tempo de Preparação Dependente da Sequência e da Família*.
- Shezan, S. A., Julai, S., Kibria, M. A., Ullah, K. R., Saidur, R., Chong, W. T., & Akikur, R. K. (2016). Performance analysis of an off-grid wind-PV (photovoltaic)-diesel-battery hybrid energy system feasible for remote areas. *Journal of Cleaner Production*, 125(2016), 121–132. <https://doi.org/10.1016/j.jclepro.2016.03.014>
- Shiheng, H., Attux, R. R. de F., & Coelho, G. P. (2021). *Otimização Evolutiva Multiobjetivo : Implementação do Algoritmo SPEA2*. 1–5.
- Silva, R. D. de S. e. (2022). Novas tecnologias e infraestrutura do setor elétrico brasileiro – armazenamento de energia em baterias. *Texto Para Discussão*, 1–37. <https://doi.org/10.38116/td2746>
- Spat Ruviaro, R. (2018). *ANÁLISE DA VARIAÇÃO DA EFICIÊNCIA DO MÓDULO FOTOVOLTAICO EM FUNÇÃO DA TEMPERATURA*.

## 7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.