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**MULTI-OBJECTIVE OPTIMIZATION WITH AN ECONOMIC-
ENVIRONMENTAL FOCUS OF A HYBRID RENEWABLE ENERGY
SYSTEM IN AN ISOLATED COMMUNITY IN BRAZIL**

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Abstract. *In the development process of a hybrid renewable energy system (HRES), the net present value (NPC) is mainly established as a parameter for evaluating the economic viability of the project. However, since the use of HRES aims to reduce the environmental impact caused, mostly, by the burning of fossil fuels for energy generation, the importance of reducing the system's emissions is identified. In this way, the objective is to improve hybrid generation from renewable sources in an isolated location in Brazil, maintaining the economy of the project, in addition, minimizing the amount of carbon fuel dispersed in the atmosphere. For this, an HRES is made up of photovoltaic panels (PV), inverter (INV), Lithium batteries (BL) and backup generator (GD) was designed and optimized in both a multi-objective way (minimizing costs and carbon dioxide emissions) and a cost-optimizing way, using a double SPEA-2 algorithm, evaluating the set of equipment and the way of operation, allowing after processing the comparison of NPC and emission values after computational analysis. The results indicated a possible reduction in emissions by 8%, with an increase in NPC by 24.2%, comparing two solutions of the multi-objective optimization, the first valuing costs (M0) and the second focused on emissions (M1), while for the single-objective simulation (M2), there was a mirroring of the data found for (M0), since both prioritized economic variables. The initial investment values for M0 and M1 were identical, whereas for M2, there was a reduction, facing a different financial approach for the simulations or the need for longer simulation time.*

Keywords: SPEA-2, hybrid systems, renewable energy, Brazil.

1. INTRODUCTION

Currently, climate change is one of the major global concerns, prompting numerous research efforts and resulting in various changes in daily habits and responsibilities. From this perspective, carbon dioxide emissions have a significant impact on global natural activities, given that CO₂ is one of the most relevant contributors to the greenhouse effect. (Kwakwa, 2023).

Therefore, one of the ways to mitigate negative human interventions in nature would be through the improvement of energy supply by transitioning from high-emission energy generation systems to more sustainable ones, which are based on renewable sources for electricity production. Consequently, these systems are more appealing from an economic and socio-environmental perspective (Basnet et al., 2023).

Moreover, there are several aspects to be optimized in hybrid renewable energy system (HRES) projects, which comprise a combination of multiple renewable energy sources for power generation. Therefore, it is necessary to broaden the perspective when designing systems that are not only economically feasible but also have the lowest carbon dioxide emissions (Dufo-López et al., 2016).

In this way, it is possible to reinforce the existing disregard for the environmental impacts of HRES through Figure 1. Among the highlighted words, those related to the environment do not appear prominently, except for the resources themselves for energy production. The diagram presented also shows a significant presence of terms associated with costs and optimization.

Next, the available energy resources for power generation were explored, with reference to the data from NASA (2021), supported by estimates from the Global Solar Atlas (2023) and Global Wind Atlas (2023).

In this way, the determinations for modeling the suitable system were initiated. By using the iHOGA software (v3.4, 2023), it was possible to propose a hybrid system of the PV/WT/BL/GD type (WT stands for wind turbines), described by Figure 3. In this way, with the same initial parameters, it became possible to evaluate, through optimization using genetic algorithms SPEA-2, employed by iHOGA, the main energetic characteristics for the generation of the system with the lowest cost (M0) and the generation with the lowest CO₂ emission (M1), optimized in a multi-objective manner for both, as well as the projected estimations from a mono-objective simulation focused on minimizing the NPC (M2). Figure 4 depicts, in a simplified manner, how the three scenarios are characterized.

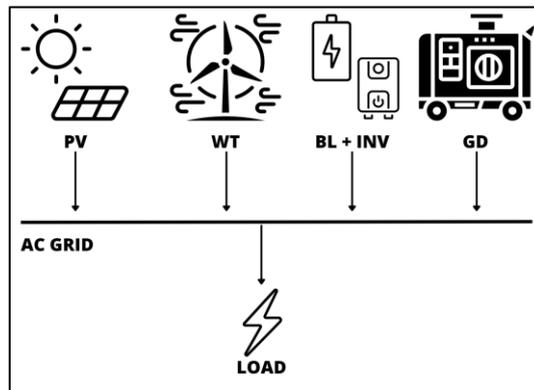


Figure 3. Basic scheme of the simulated system.

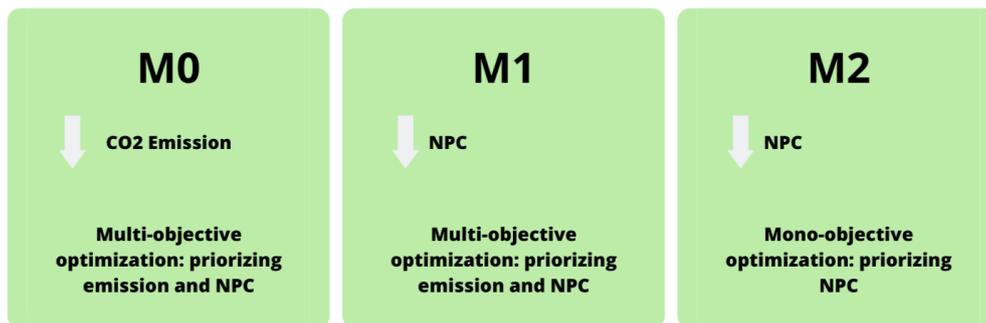


Figure 4. Three scenarios explored.

Finally, based on the outputs provided by iHOGA, a quantitative and qualitative comparison is made between the main differences of the optimal system with the lowest emissions and lowest NPC, optimized in a multi-objective manner, and the system optimized for cost individually. The advantages and disadvantages of both identified hybrid configurations are assessed and evaluated.

3. RESULTS AND DISCUSSIONS

Firstly, using the socio-economic information obtained about the (RESEX) Lago do Cuniã, it was possible to develop a theoretical demand profile with an average of 6.92 kWh/day, as shown in Figure 5, which was used as the primary input for the simulations.

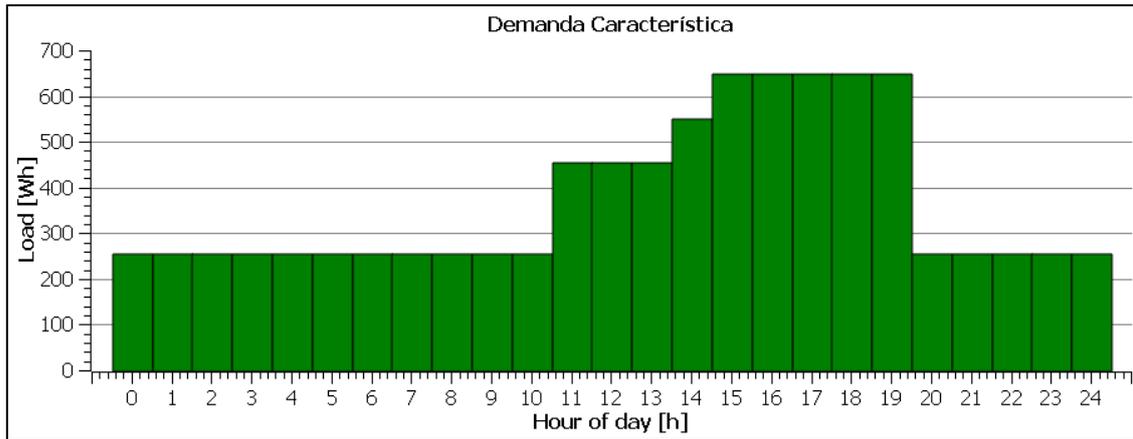


Figure 5. Distribution of demand throughout the day in the RESEX Lago do Cuniã.

In this way, it was possible to understand the energy usage patterns in the locality, identifying peak usage during the afternoon period, primarily due to the need for lighting and equipment used in a school. Additionally, during the business hours from 7 am to 6 pm, there is also higher energy usage, mainly related to economic and educational activities essential for local development. Furthermore, the existing demand during the late-night period (from 11 pm to 6 am) consists of the operation of freezers responsible for preserving the reserve's food and products.

Next, three systems of interest were determined to explore the project. The first two systems were obtained through multi-objective simulation, with one resulting in lower cost and the other in lower emissions. The third system focuses solely on cost and offers a different set of solutions. Table 1 provides a better understanding of the characteristics of each element.

Table 1. Definition of the different cases and their main characteristics.

Type of Optimization	Equipment	Emission	NPC
Multi-Objective ⁽¹⁾	PV/BT	146,8kgCO ₂ /yr	8091,3 \$
Multi-Objective ⁽²⁾	PV/BT/DG	135,86kgCO ₂ /yr	10047,3 \$
Mono-Objetive ⁽³⁾	PV/BT	146,8kgCO ₂ /yr	8091,3 \$

⁽¹⁾ Considering the lowest cost.

⁽²⁾ Considering the lowest carbon dioxide emission.

⁽³⁾ Considering the lowest cost.

In this case, it is possible to identify that the characteristics are mirrored between the optimal system with the lowest cost obtained from the multi-objective simulation (M0) and the one found by the simulation targeting cost reduction only (M2). However, when observing the hybrid system with emission reduction (M1), there is a change in equipment as well as a 24.2% increase in NPC and an 8.0% reduction in carbon dioxide emissions. All three systems agree on not using wind turbines, as there is high solar irradiation and low wind speed available at the location.

Another interesting analysis relates to the energy generated and consumed over the course of a year for the three systems. Figures 6 depict how this energy is distributed, allowing for the identification of new discrepancies among the observed hybrid networks.

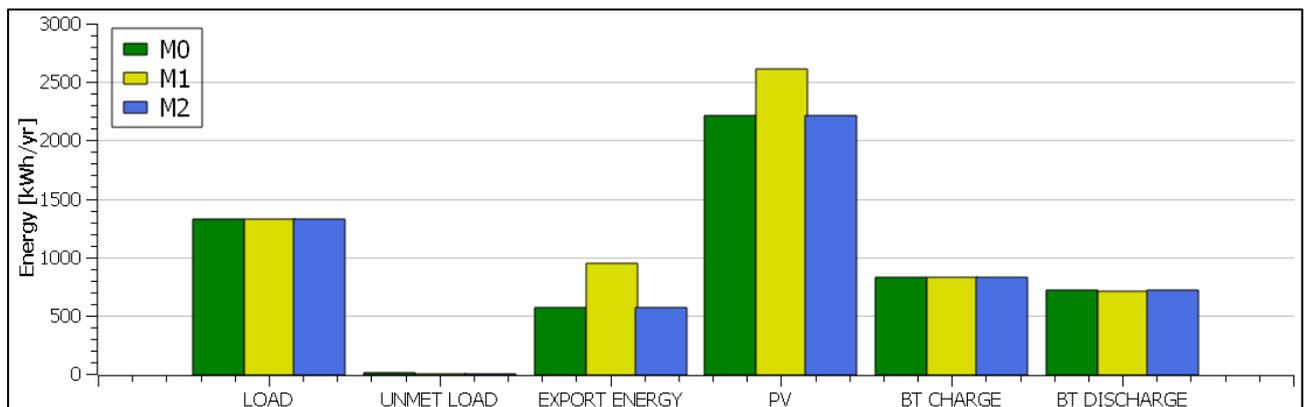


Figure 6. Data on energy consumption and generation over one year were collected for M0, M1 e M2.

Exploring the presented information, it can be observed that in Figures 3 and 5, there is a small fraction of unmet energy. Initially, this value may be negligible. However, in situations of extreme weather conditions, there could be instabilities in the system, making the presented hybrid models less reliable.

In Figure 4, there is no presence of unsustainable demands. However, it is noteworthy that the generators do not operate throughout the year, despite being a component of the system. This occurs because, considering the system's demand, it would be appropriate to have a backup energy source capable of operating essential elements in the studied locality, such as freezers for food preservation in a scenario where solar panels are undergoing maintenance, for example.

Finally, extending the analysis to the initial investment, a difference is observed between the M0 and M2 systems, despite the mirroring of most of their values. Figure 7 illustrates how the found values diverge.

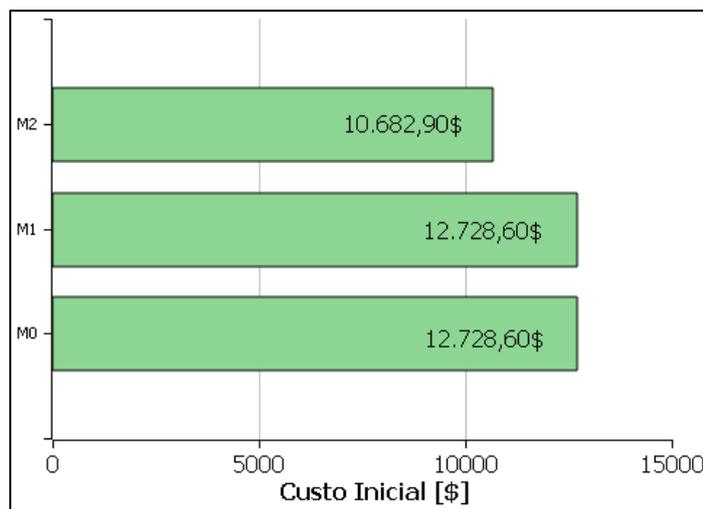


Figure 7. The initial investment for the different cases.

In this case, M0 and M1 showed the same initial cost, suggesting that the main expenses aiming to reduce emissions would be associated with equipment maintenance. Additionally, despite the similarities between M0 and M2, the initial investment of the latter is lower, even when using exactly the same economic parameters, indicating a possible discrepancy in the calculations performed by the software for defining investment terms in multi-objective and single-objective simulations.

4. CONCLUSION

When processing the same system in a multi-objective manner, it was observed, as expected, that reducing emissions would lead to an increase in total costs. Furthermore, when comparing the results with a single-objective analysis, it was possible to evaluate that both optimization approaches have the capacity to achieve similar values regarding economic parameters.

The found systems prioritize photovoltaic panels in conjunction with batteries, and it makes sense to be so, as the high irradiation in the isolated community allows for extended hours of solar generation. Similarly, due to the high surface roughness, thanks to the presence of forests in the Northern region of Brazil, wind energy is also relevant.

The systems, which do not consider the households in the RESEX Lago do Cuniã, can be improved by including them. Modifying the demand curve could lead to new proportions between costs and emissions, and it would be interesting to explore other renewable sources in the location. Being close to a watercourse, there is potential for the use of other types of renewable generators, such as hydrokinetic turbines, for example.

5. ACKNOWLEDGEMENTS

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7. RESPONSIBILITY NOTICE

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