Environmental and financial optimization: Hybrid generation (wind-PV) with battery energy storage

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Abstract. This study proposes a multiobjective optimization to identify the best combinations for renewable hybrid generation (wind-PV) with the use of battery storage systems, at a residential level for the Brazilian scenario. The objectives of this optimization are to maximize the Net Present Value (NPV) and minimize the emission of CO_2eq - GHG (CO_2equiv/KWh) - Carbon footprint, using the Response Surface Methodology (RSM) to model the objective functions. The Normal Boundary Intersection (NBI) method was used to generate the Pareto frontier with the optimal points and the LCOE variable was used to select the best optimal solution on the frontier. The method will consider one of the possibilities of the Brazilian tariff model, the white tariff, which is an hourly billing modality. First, the regression models generated for each selected city were significant by the ANOVA p-value test, being less than 0.05. In addition, the R^2 and adjusted R^2 values were also expressive, with results above 80%, indicating a high degree of explainability of the modeled process. As main findings, on the national scene, the cities that presented the best results are located in the northeast region, which by far was the region with the best results both in the environmental and financial aspects. Only one city outside the northeast region was financially viable, which was the city of Búzios - Rio de Janeiro. These regions presented excellent wind speed regimes, consistent with other studies in the literature [1,2] which indicated that in the case of small turbines, only regions with excellent environmental conditions would be financially viable. On the other hand, cities like Manga - Minas Gerais, Pirenópolis - Goiás and Uiramutã - Roraima, which presented low wind speed regimes, resulted in low participation of wind energy and in economically unfeasible investments. These cities had a higher proportion of photovoltaic energy, which forced the system to use a larger amount of batteries to balance itself. The battery is still a very expensive element in the system, bringing worse financial results, in addition to worse environmental results due to the fact that the greater number of batteries, linked to a greater proportion of photovoltaic energy, which has a worse environmental performance when compared to wind energy.The advantages of the hybrid generation pointed out by some authors [3,4] were proven in some cities of this study. The cities of João Pessoa - Paraíba, Petrolina - Pernambuco, Florianópolis - Santa Catarina, Búzios - Rio de Janeiro and Uiramutã - Roraima presented proportions at the chosen Pareto optimal points (based on the lowest LCOE), between 42 and 58% of wind energy in the generation. This is directly related to the advantage of the complementarity of photovoltaic and wind energy, which in some scenarios can, for example, reduce the number of batteries to balance the system. As

for the choice of batteries, in all cities the lithium-ion battery was considered the best option, both in terms of the environment and the economy. These results can be explained by the characteristics of the lithium-ion battery, which has high energy efficiency, high power density and is environmentally sustainable [5], consistent with other results in the literature [5–8]. The Scenario Type variable responded to the hypothesis at national level, whether it would be advantageous to make an investment considering only the highest tariff value (peak/intermediate), of the white tariff modality. The optimization results showed that in none of the selected cities would it be advantageous to generate energy to consume considering only peak/intermediate times. This may be directly related to the greater proportional need for batteries in scenarios of this type, as it would be necessary to store energy throughout the day and consume it only in the peak/intermediate ranges. Basically, it forced the system to need more storage capacity. Furthermore, the generation of PV at peak/intermediate times is very low, practically nil, as these bands are closer to the beginning of the night (generally between 4:30 pm and 9:30 pm).

Keywords: multi-objective optimization, hybrid generation, batteries, Normal-Boundary Intersection.

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