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REGIONAL ANALYSIS OF RESOURCES FOR POSSIBLE HYBRID SYSTEMS IN ISOLATED REGIONS IN BRAZIL

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Abstract. *Brazil is the fifth country in terms of territory, which highlights the diversity of climate, fauna and flora. However, this characteristic hinders the arrival of basic resources, such as electricity, requiring other generation methods. In this sense, it is not possible to simulate a hybrid system in a region without previously collecting and analyzing the georeferencing information available in arbitrated databases and scientific literature. Also, this knowledge helps in assessing the energy potential, which depends on climatic resources such as solar radiation and wind, but which is dispersed among several sources. Thus, with the objective of classifying resources and simulating each region in the future, the main areas where isolated communities are concentrated were studied, using the computational tools Global Solar Atlas and Global Wind Atlas. As a result, a regional map was prepared, according to each studied resource, where the isolated communities of each area are also demarcated. From the results it was possible to conclude that there is an energy potential in the evaluated regions and also the possibility of implementing hybrid systems. Finally, it is expected that the analysis will help and encourage future research on the subject, in addition to concentrating information and facilitating the search.*

Keywords: *renewable energy, georreferencing, hybrid systems, simulation.*

1. INTRODUCTION

Brazil is the fifth largest country in terms of territorial extension (Bank, 2020), which highlights a great diversity of natural elements such as climate, flora, and fauna, as well as cultures and people. However, this aspect can hinder access to basic resources, such as electricity, in certain regions, as many areas can only be reached by waterways. Therefore, alternative methods of power generation are necessary.

Climate changes and the resulting diversities occur in all types of locations; however, isolated communities (those distant from the electrical grid) and regions with low-income populations are still the most affected (Adedeji *et al.*, 2014), increasing the vulnerability of these areas, which already suffer from geographic distance in relation to communities near urban centers.

In this sense, considering the difficulty in transporting resources, it is possible to think of a renewable solution that makes these communities more independent and resilient (IPCC, 2022), such as implementing a hybrid system that harnesses the natural resources specific to each region. To achieve this, it is necessary to collect and analyze key information about the community where the system will be implemented, such as georeferential data and the availability and quantity of resources, which can be found in curated databases and scientific literature. Furthermore, this knowledge about the region assists in evaluating the energy potential, which depends on climate resources such as solar radiation and wind speed, but is often dispersed among various sources or not publicly available, requiring contact with organizations and agencies that manage these locations.

Considering the context of energy resources and isolated communities, when examining studies on renewable energy resources analysis in Brazil, it can be observed, as shown in Fig. 1, that the most recent studies (from 2018 onwards, represented in yellow) address economic growth, renewable energy consumption, economy, and natural resources. Some of the most frequently encountered terms (represented by larger circles and font size) include "emission," "generation," "plant," and "renewable energy." However, there is no mention of isolated locations or regions of greater vulnerability, suggesting that the analysis of natural resources in communities isolated from the electrical grid is currently underexplored, highlighting the need for research on this subject.

In light of these circumstances, this study aims to classify resources in isolated regions from the interconnected energy system by using a map of Brazil. The objective is to facilitate future simulations of hybrid systems in these areas. The

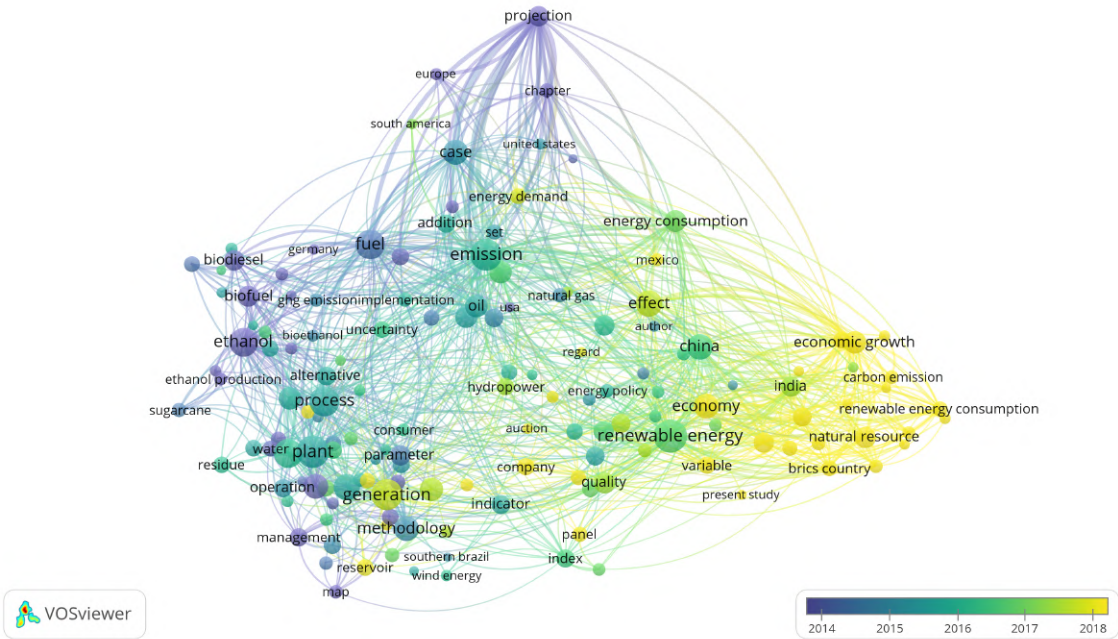

Figure 1. Bibliometric analysis carried out on June 23, 2023, with the keywords “analysis”, “renewable”, “resources”, “energy” and “brazil”.

analysis and classification were carried out based on data from the WEBMAP provided by EPE (Empresa de Pesquisa Energética) and evaluated using pre-defined quadrants. The resources considered were wind speed, global horizontal irradiation, and photovoltaic potential, analyzed using computational tools such as the Global Solar Atlas and Global Wind Atlas.

2. TOOLS AND METHODS

Next, the Global Solar Atlas and Global Wind Atlas tools will be presented, which were used for visualizing the photovoltaic potential, global horizontal irradiation, and wind speed resources. In addition to these tools, the open-source and free Geographic Information System (GIS) software QGIS was used for visualizing and editing map information. Finally, data from EPE (Energy Research Company) of Brazil regarding isolated locations and the creation of quadrants will be discussed, aiming to facilitate future simulations of hybrid systems in each region.

2.1 Global Solar Atlas

The Global Solar Atlas (Global Solar Atlas, 2023) is a geospatial mapping and analysis tool developed to provide detailed and accurate information about global solar potential. Built on reliable data and rigorous scientific methodologies, the platform aims to facilitate understanding and assessment of solar resource in different regions of the world.

Through the Global Solar Atlas, users have access to a wide range of data and analyses related to solar radiation, such as average annual solar irradiation, seasonal variation of solar irradiation, as well as information about solar energy production and photovoltaic generation potential in specific areas (Global Solar Atlas, 2023).

For this study, the maps of global horizontal irradiation and photovoltaic potential for Brazil, presented in Fig.2 and Fig.3 respectively, were utilized. The data from each map, available in Raster format, were manipulated in AAIGrid format and imported into the QGIS software, which will be further defined later.

2.2 Global Wind Atlas

The Global Wind Atlas (Technical University of Denmark (DTU Wind Energy), 2023) is an advanced and scientifically grounded platform that provides detailed information about global wind potential. Developed based on reliable data, the Global Wind Atlas aims to offer a comprehensive view of wind resources worldwide, assisting researchers, planners, and professionals in the wind energy sector in making informed decisions.

This platform integrates a wide range of data and tools, including climate models, historical wind data, topography, and geographic features. From this information, accurate estimates of wind energy-related parameters can be obtained, such as average wind speed, prevailing wind direction, and spatial distribution of wind resources in different regions of

Figure 2. Horizontal solar irradiation resource map of Brazil according to Global Solar Atlas (2023).

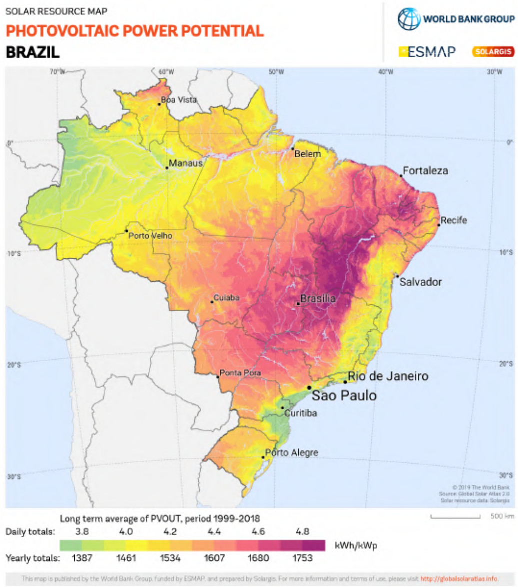

Figure 3. Photovoltaic potential map of Brazil, according to Global Solar Atlas (2023).

the world (Technical University of Denmark (DTU Wind Energy), 2023).

In this study, the map of average wind speed at a height of 50m for Brazil, presented in Fig. 4, was used. The data from this map, available in Raster format as a .TIF file, were manipulated and edited and imported into the QGIS software, which will be further defined later.

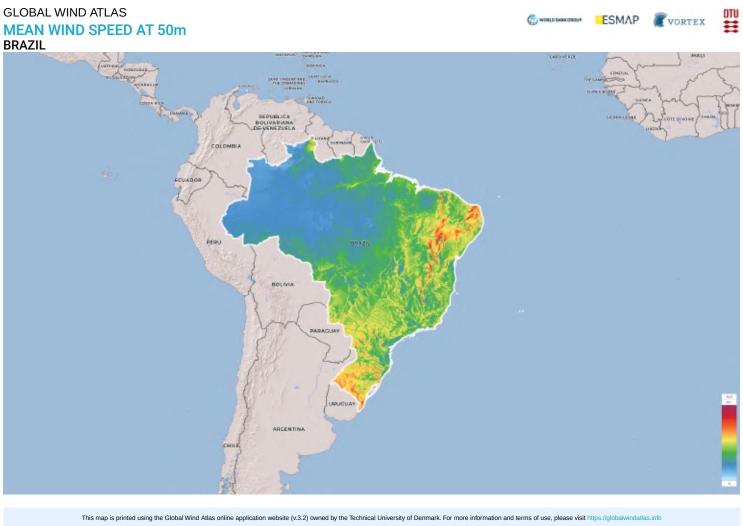

Figure 4. Mean wind speed at 50m map of Brazil, according to Technical University of Denmark (DTU Wind Energy) (2023).

2.3 QGIS

QGIS (Quantum Geographic Information System) is an open-source and free geographic information system developed with the aim of providing a robust and accessible environment for the analysis and visualization of geospatial data. Designed to meet the needs of researchers, scientists, and industry professionals, QGIS offers a wide range of features and functionalities that allow for the manipulation, interpretation, and representation of geographic information accurately and efficiently (QGIS Development Team, 2023).

QGIS adopts a layer-based approach, where geographic data is organized into different layers representing real-world elements such as points, lines, polygons, and raster images. These layers can be imported from a variety of formats, including shapefiles, raster files, spatial databases, and web services, allowing users to work with heterogeneous datasets and visualize them in an integrated manner, according to QGIS Development Team (2023).

For this study, QGIS was used to create the resource maps based on isolated regions and quadrants defined using its layer approach. All the maps were overlaid and edited within the software to improve visualization.

2.4 Isolated Communities

EPE (Empresa de Pesquisa Energética), in Brazil, provides a Webmap that aims to offer access and visualization of geospatial data related to the energy sector in the country. Based on scientifically grounded information and technical analysis, this webmap offers an interactive interface that allows users to explore and analyze a variety of geospatial information relevant to energy resource planning and management in Brazil.

Furthermore, the platform covers various aspects of the energy sector, including the location of energy generation plants, transmission and distribution infrastructure, areas with potential for renewable energy development, energy consumption data, among others. Through overlaid geospatial data layers on an interactive map, users can gain insights into the spatial distribution of this information, assisting in decision-making related to expanding the energy matrix, infrastructure planning, and environmental impact mitigation strategies.

As mentioned earlier, data from communities with isolated energy systems, available in 2022, were used. Based on this data, the communities were placed on the map of Brazil to visualize the resources according to their locations. The map can be seen in Fig. 5, exported from QGIS.

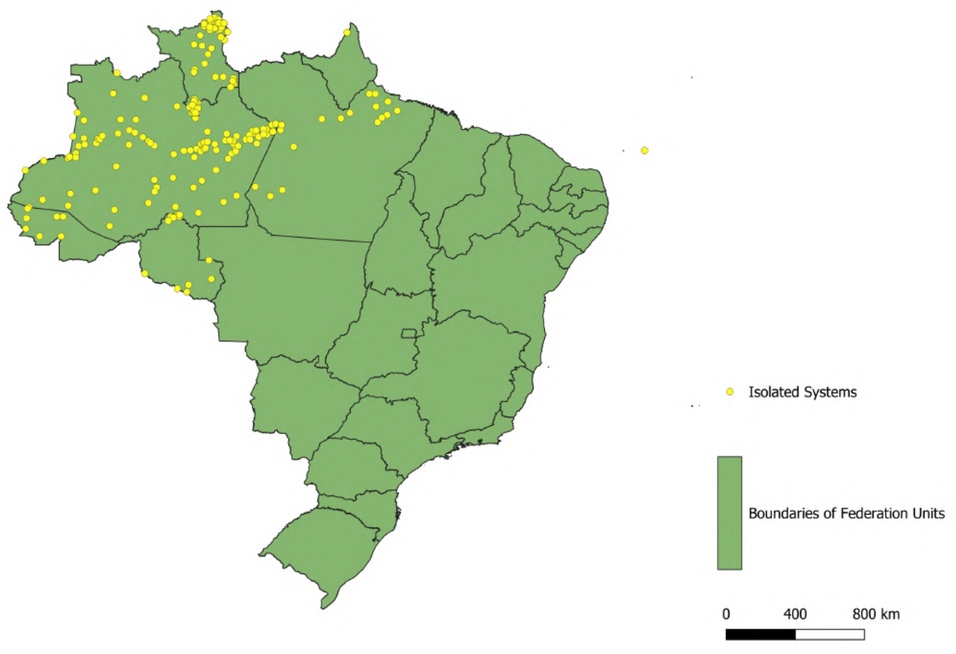

Figure 5. Map of systems isolated from the electrical grid, in Brazil, according to the data available in the Empresa de Pesquisa Energética (EPE) (2022).

2.5 Quadrant Definition

According to EPE (2022), there are approximately 212 locations isolated from the electrical energy system, and as shown in Fig. 5, it is evident that most of these areas are located in the northern part of the country. Therefore, considering that some communities are in close proximity to each other, in order to improve data acquisition efficiency, a division into quadrants was proposed. This division takes into account the geographic location, which can provide insights into climatic and georeferencing characteristics.

Furthermore, the division into quadrants can facilitate future simulations, as it would not be necessary to simulate each nearby community separately, assuming that the available renewable resources would be similar. This approach can expedite the process and subsequent analyses, enabling a larger number of isolated regions to be addressed.

Based on this concept, Fig. 6 presents a map with the defined quadrants. A grid was overlaid on the map of communities, and each quadrant was designated alphabetically.

Thus, it becomes possible to analyze the isolated regions according to their resources and infer their energy potentials

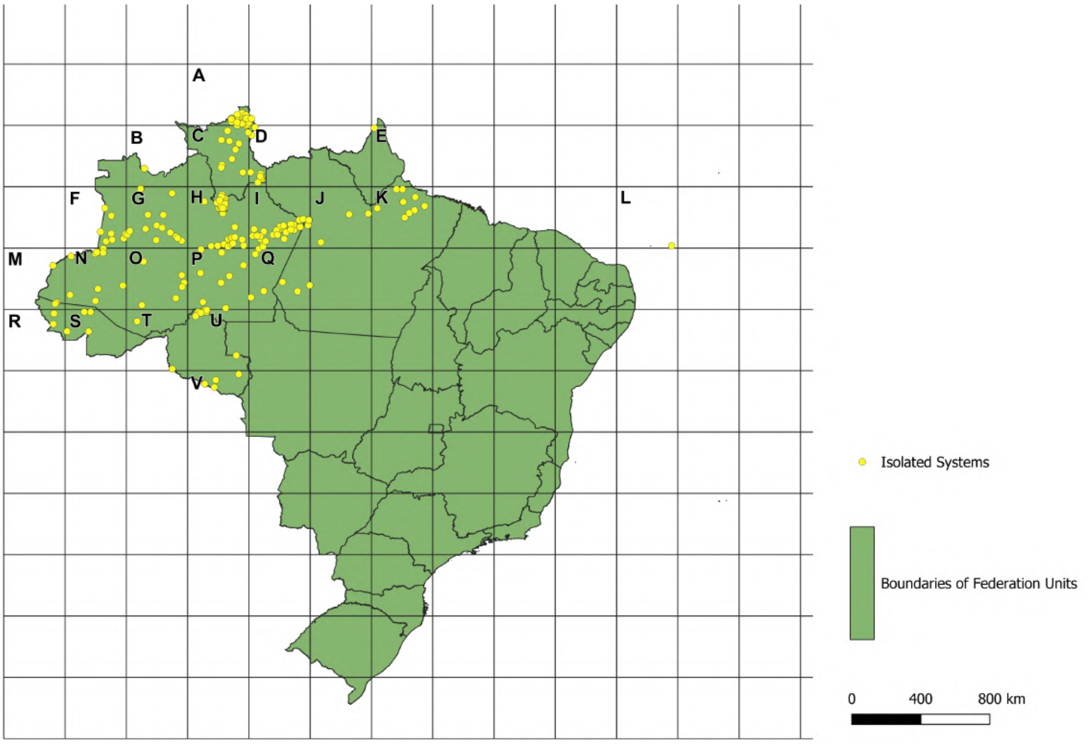

Figure 6. Map of isolated systems, divided by quadrants.

for simulations and potential implementations of hybrid systems in these areas.

3. RESULTS

From the available maps in each tool, three maps were created, which present the following resources: global horizontal irradiation in kWh/m^2 (M1), photovoltaic potential in kWh/kWp (M2), and average wind speed at 50m altitude in m/s (M3), all based on annual values. The elaborated maps can be visualized in Fig. 7, Fig. 8, and Fig. 9, respectively, and the analyses that could be made from these will be presented.

3.1 M1 - Global Horizontal Irradiation (Annual) (kWh/m^2)

In M1, according to the colors present in the map, it can be observed that the region where the isolated communities are located (yellow dots) has values ranging from 4.89 kWh/m^2 to 5.38 kWh/m^2 per day, and approximately 1784.85 kWh/m^2 to 1963.70 kWh/m^2 per year (Global Solar Atlas, 2023), and it is colored orange in quadrants F, G, and N, for example, and yellow in quadrants C, D, and K, for example, which corresponds to the higher values according to the map legend.

From this, we can infer that there is a high solar irradiation in these areas, as the values approach the areas with the highest irradiation in Brazil, present in the northeastern region of the country (more yellowish regions on the map), according to Pereira *et al.* (2017).

3.2 M2 - Photovoltaic Potential (Annual) (kWh/kWp)

From M2, by observing the colors, it can be seen that the region where the isolated localities are mostly located has a color closer to purple, which represents lower values, such as in quadrants F, M, and N, with some smaller areas showing a more yellowish color, like in quadrants C, D, and J, indicating good photovoltaic potential. The areas present values ranging from 3.89 kWh/kWp per day, corresponding to 1419.85 kWh/kWp per year, to 4.26 kWh/kWp per day, corresponding to 1554.90 kWh/kWp per year (Global Solar Atlas, 2023).

From this, it can be stated that there is photovoltaic potential in the area, although it may not be the highest in the country, according to the coloration on the map, but it still allows for the utilization of resources for energy generation.

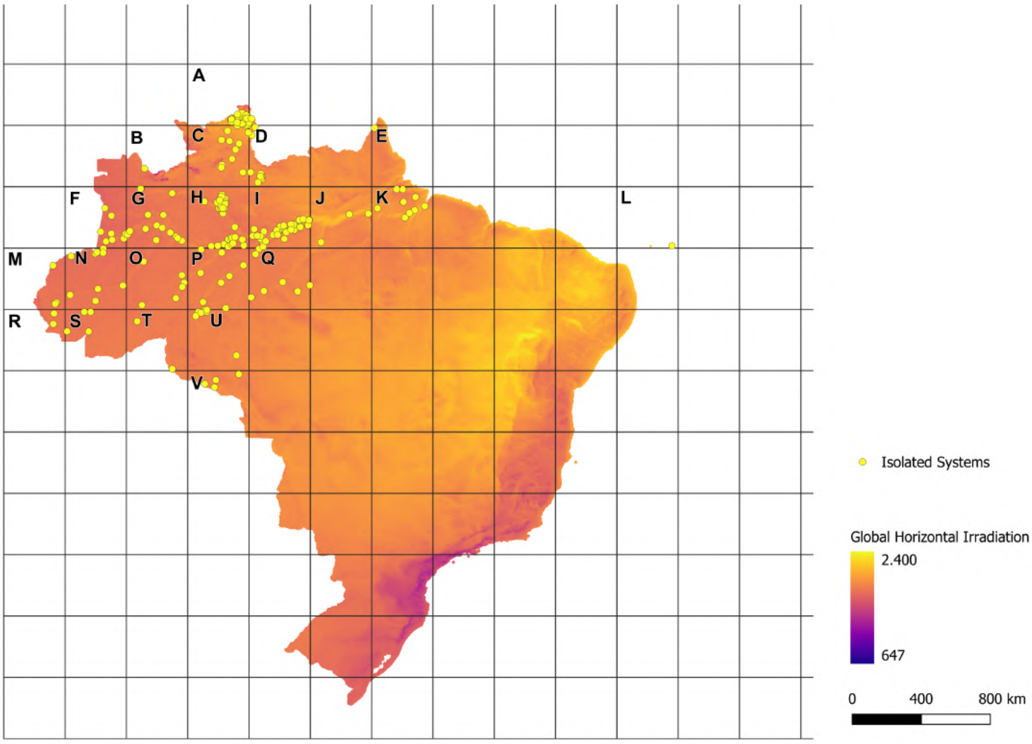

Figure 7. Horizontal solar irradiation resource map of Brazil, divided by quadrants, in kWh/m^2.

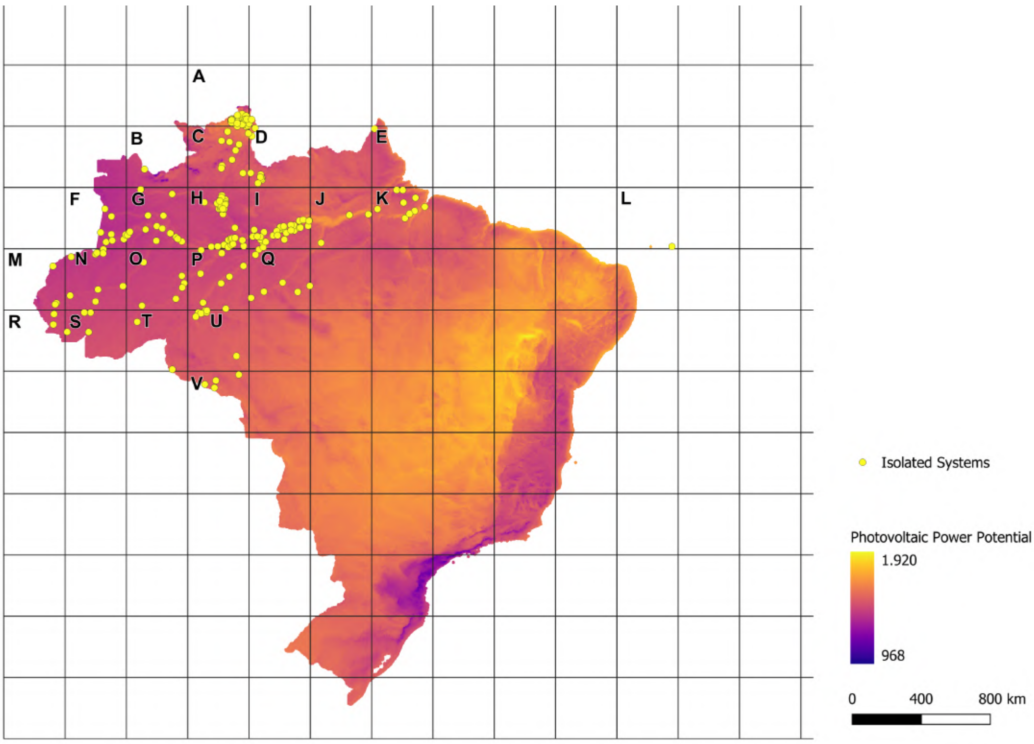

Figure 8. Photovoltaic potential map of Brazil, divided by quadrants, in kWh/kWp.

3.3 M3 - Average Wind Speed at 50m (Annual) (m/s)

Upon analyzing M3, it can be observed, based on the coloration of the areas where the isolated communities are located, that the average wind speed at 50m is low in a large part of the region, with some lighter points that approximate the median value in quadrants C, E, J, K, and L, according to the map legend. Based on the data from Technical University of Denmark (DTU Wind Energy) (2023), in these regions, the speeds range from approximately 2.69 m/s to 4.93 m/s, with the latter being present in only 2

Thus, M3 highlights the low wind potential in the region, indicating that the resource can be harnessed in a limited number of areas.

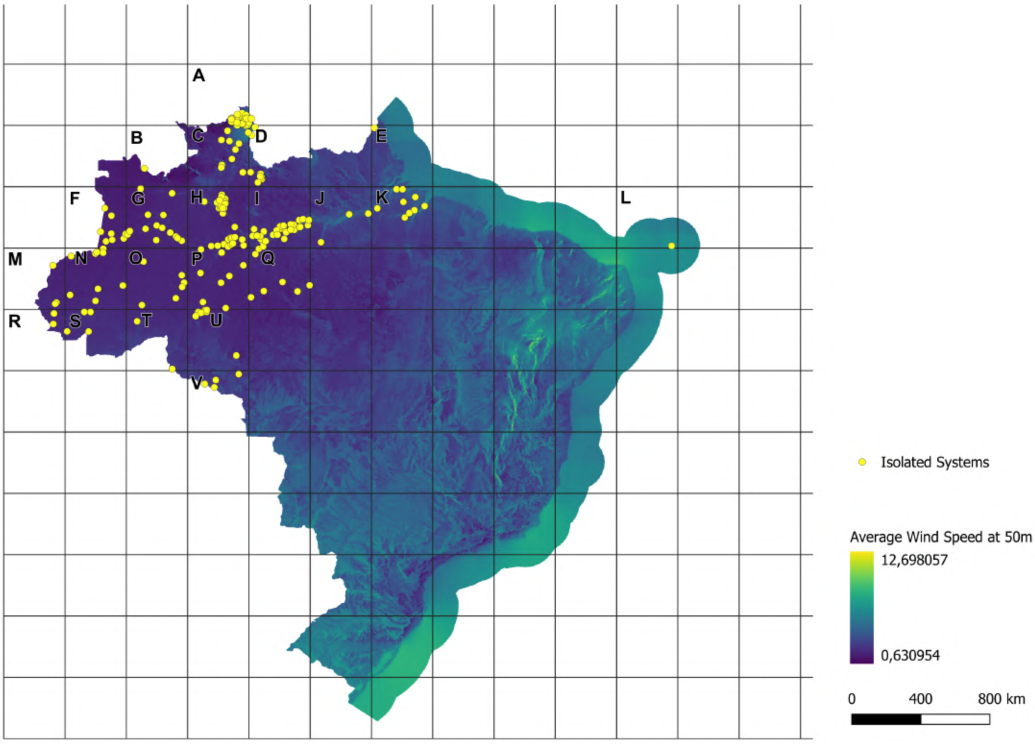

Figure 9. Mean wind speed at 50m map of Brazil, divided by quadrants, in m/s.

4. CONCLUSIONS

Based on the study results and the generation of the maps, it can be concluded that there is a significant solar potential in all quadrants, both in terms of global horizontal irradiation and photovoltaic potential, as depicted in maps M1 and M2. This highlights the possibility of harnessing these characteristics by implementing a hybrid system in the study area, with photovoltaic panels being one of its components.

However, map M3 revealed that the wind potential is limited to a few communities, as the average wind speeds were found to be lower compared to the rest of the country. Nevertheless, it is still feasible to utilize this resource in quadrants where it shows promise, although a more in-depth analysis of each community's characteristics is necessary.

In this context, it is anticipated that this classification will contribute to future research on the energy deficiency in isolated regions by facilitating the search for information and analysis of energy resources and potentials. Furthermore, it opens up opportunities for the classification and analysis of other aspects as well.

5. ACKNOWLEDGMENTS

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