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BALANÇO DA MATRIZ ELÉTRICA COM ÊNFASE NA PARTICIPAÇÃO DAS FONTES DE ENERGIAS RENOVÁVEIS

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RESUMO

Este artigo objetiva apresentar um panorama da participação das energias renováveis na matriz elétrica do RN, compartilhando dados quantitativos acerca dos empreendimentos de geração, com ênfase nas fontes renováveis. Estas informações podem subsidiar pesquisas acadêmicas ou estudos associados ao incentivo ao uso de fontes renováveis, características que motivaram e justificaram a opção por esta temática. O levantamento das informações reuniu e analisou dados relativos às fontes energéticas do RN disponibilizados pela plataforma SIGA/ANEEL. Acerca dos resultados, são apresentados mapas, tabelas e gráficos, ideados através da linguagem Python e bibliotecas Pandas e Plotly, representativos dos quantitativos de empreendimentos em operação, construção e com autorização para construção, classificados segundo múltiplos critérios, a saber: fonte, potências outorgadas e fiscalizadas, atuação e localização, dentre outras especificidades. Os resultados, em uma avaliação preliminar, atestam a tendência pela descarbonização, concluindo que a matriz potiguar está cada vez mais renovável, porquanto mitigando os efeitos da poluição ambiental.

Palavras-chave: balanço energético, empreendimentos de geração, energias renováveis, matriz elétrica, Rio Grande do Norte.

BALANCE OF THE ELECTRICAL MATRIX WITH EMPHASIS ON THE PARTICIPATION OF RENEWABLE ENERGY SOURCES

ABSTRACT

This article aims to present an overview of the participation of renewable energies in RN's electrical matrix, sharing quantitative data about generation projects, with an emphasis on renewable sources. This information can support academic research or studies associated with encouraging the use of renewable sources, characteristics that motivated and justified the option for this topic. The information gathering gathered and analyzed data relating to energy sources in RN made available by the SIGA/ANEEL platform. Regarding the results, maps, tables and graphs are presented, created using the Python language and Pandas and Plotly libraries, representing the quantities of projects in operation, construction and with authorization for construction classified according to multiple criteria, namely: source, powers granted and supervised, performance and location, among other specificities. The results, in a preliminary assessment, attest to the trend towards decarbonization, concluding that the Rio Grande do Norte matrix is increasingly renewable, as it mitigates the effects of environmental pollution.

Keywords: energy balance, generation projects, renewable energy, electrical matrix, Rio Grande do Norte.

1 INTRODUCTION

Renewable forms of energy, also called clean, have been gaining more and more space in the national electrical matrix due to the vast potential they have in different Brazilian regions, with greater projection in recent years for wind energy and photovoltaic solar energy (Fadigas, 2011). Numerous governments and companies have invested in renewable energy sources as a way of trying to minimize the effects of the energy crises that have occurred in recent years (Lima, Freire, Santos & Alburquerque, 2017). Gurgel, Lima and Sales (2023) defend the production of electrical energy from renewable energy sources (wind, solar, hydroelectric, biomass and geothermal, for example) as one of the ways to mitigate climate change. Within an increasingly demanding and competitive environment, these energy modalities are gaining more and more space and investments, consolidating themselves in the market, whether in centralized generation plants (installed power exceeding 3 MW), or in distributed generation systems, incorporated in urban and rural applications. Martins and Pereira (2022) argue that the growing ecological footprint in Brazil and the world has fostered increased awareness in society regarding environmental preservation, in addition to the need to take measures related to the diversification of the energy matrix. Therefore, the diversification of the matrix can be understood as the possibility of meeting the demand for electrical energy by making use of varied energy sources, not being held hostage to a single resource or energy source and, therefore, reinforcing energy security.

Celuppi (2017) argues that the use of renewable energy can be an alternative for reducing environmental impacts, as they meet demand in a more sustainable way without harming productive segments. From an environmental point of view, ensuring high sustainability for the regions where they are located, meeting their needs, is a way of ensuring that new generations can also be self-sustaining (Oliveira, Detomi & Meneghin, 2013). There has been much debate about environmental sustainability and ways to reduce greenhouse gases around the world. For Oliveira et al (2013) the main challenge is the use of alternative energy solutions to promote socioeconomic and technological development in order to make them economically viable. This article aims to present a general overview regarding the participation of renewable energy sources in the electrical matrix of Rio Grande do Norte, considering quantitative data associated with the generation plants that make up its matrix, based on consultation of series of data associated with the number of electrical energy generation plants (in operation, construction and authorized to start their works) in Rio Grande do Norte, with a time frame until December 2023. The information presented in this study comes from databases of the National Electric Energy Agency – Aneel, but specifically from its Generation Information System – SIGA.

Regarding the importance of the data published by this study, it is worth highlighting the intention to contribute to the debate in the scientific and/or technological context of the importance of encouraging the proposal of technological solutions that oppose the harmfulness of atmospheric pollution, climate change and of global warming. In this scope, we seek to highlight the relevance of encouraging the inclusion of renewable energy sources in the composition of the electrical matrix of Rio Grande do Norte. Regarding the originality of this study, a compilation of technical data is presented that, in the bibliographical review that preceded it, no similar scientific publications were found and, therefore, providing its contribution to the advancement of research in the field of studies of the energy generation matrix. electrical energy in the state of Rio Grande do Norte.

2 BIBLIOGRAPHIC REVIEW

This section is intended to present a brief theoretical discussion regarding concepts directly related to the subjects covered by this study, namely: renewable and non-renewable energy, wind and photovoltaic plants, small hydroelectric plants and thermoelectric plants. Finally, some aspects related to the relevance of adapting to the Sustainable Development Goals – SDGs, proposed by the United Nations – UN are commented.

2.1 Wind, photovoltaic, PCH’s and thermoelectric plants

Bianchin, Beck and Seidel (2020) describe that wind (moving air mass) is a direct consequence of the irregular heating of the Earth's crust. Lima, Freire, Santos and Albuquerque (2017) report that the energy available in air masses changes depending on the seasons, time of day, topography and soil roughness. Wind power plants make use of devices capable of converting the kinetic energy of the wind into electrical energy through the use of rotating electrical generators that are driven by the rotation of wind turbine blades (Campos & Moraes, 2012). In the case of power plants, there is a predominance of horizontal axis turbines, consisting of three blades, whose sweep area will depend on the nominal power and height of the respective wind turbine (Sá & Lopes, 2001). Only part of the power available in the wind is effectively converted by the wind turbines into electrical energy, this limit being associated with the turbine power coefficient and the Betz limit, which predicts a maximum theoretical use of approximately 59% (Borges Neto & Carvalho, 2012).

Optimization of wind capture is obtained through automated, electro-pneumatic or electronic systems that orient the blades and the wind turbine axis in the most favorable wind direction at different time intervals (Fadigas, 2011). According to Campos and Moraes (2012), less turbulent winds and consequently better wind generation are obtained in areas with fewer obstacles and at greater heights, aspects that justify the construction of wind farms in locations far from large urban centers and with mounted machines in towers with a height close to 100 meters. According to Campos and Moraes (2012), wind energy is more suitable for electrical generation in months when water inflow is lower, highlighting the complementarity between wind generation and generation from hydroelectric plants. Bianchin, Beck and Seidel (2020) defend wind energy as being the cheapest compared to other renewable energy sources.

Solar energy is energy radiated by the sun and reaching the earth (Tundisi, 2009). Borges Neto and Carvalho (2012) state that the Sun is the great primary source of energy on planet Earth, controlling the movements of tides, winds and water cycles, for example. Tundisi (2009) informs that there are multiple possibilities for using solar energy, whether directly or indirectly, namely:

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biomass production, energy from winds, tides, ocean thermal gradients or several others. Solar energy can be used as a source of thermal energy or as a source of electrical energy (Fialho Wanderley & Campos, 2013). Cavalcante, Lopes, Santos and Ribeiro (2022) report that solar energy can be used through two main methods: thermal and photovoltaic. In the case of thermal solar energy, usually called thermal solar system, the heat present in solar radiation is used. Its most common application is the heating of water systems (Cavalcante, Lopes, Santos & Ribeiro, 2022). Photovoltaic solar energy systems are those that produce electrical energy from solar radiation (Silva, Lana, Júnior & Talarico, 2022). In the context of its use as a source for generating electrical energy, solar energy is called photovoltaic solar energy.

According to Vilalva (2015), in the case of photovoltaic plants, they will be made up of large quantities of interconnected modules in different layouts, and the area and infrastructure necessary for their assembly must be evaluated, as well as their applicability in supplying energy for needs. locations (buildings or industries) or to complement generation from other sources. Fialho Wanderley and Campos (2013) describe that solar energy incident on the Earth's surface depends on atmospheric variables such as cloudiness and relative humidity. The forecast errors of the solar resource of a given location will be inversely proportional to the amount of information regarding the climatic aspects of that location, such as: temperature, humidity, radiation, among countless others (Borges Neto & Carvalho, 2012). Higher plant yields imply greater energy efficiency, making more sensible use of natural resources. The generation of electrical energy through the use of the sun can be considered inexhaustible from a human point of view, highlighting the extraordinary potential of photovoltaic energy compared to other energy sources (Silva, Lana, Júnior & Talarico, 2022).

Silva, Machado, Coelho and Carvalho (2020) report that a hydroelectric plant uses the force of water flow to produce electricity. Vilalva (2015) describes that the operating principle of hydraulic generation is based on the damming of water, followed by its subsequent flow through pipelines. Hydroelectric plants are made up of three main parts, namely: reservoir, speed regulator and generating unit. The regulator controls the flow of incoming water and therefore the amount of water that will flow through the turbine (Silva, Machado, Coelho & Carvalho, 2022). The displacement of the water will cause the turbine blades to rotate, the latter being coupled to an electrical energy generator. In the reservoir, the energy will be in gravitational potential form, and when it starts moving, the energy becomes kinetic and finally, at the generator terminals there is electrical energy (Vilalva, 2015). Silva and Campos (2016) point out as disadvantages of hydraulic generation the loss of productivity during periods of drought and the use of water for energy production, an input that, according to their point of view, should be prioritized for applications related to agriculture and human consumption.

Hydraulic use, resulting from the storage of water masses, on a small scale is called Small Hydroelectric Plant – PCH (Campos & Moraes, 2012). In these stations, the potential energy of the water is converted into rotational kinetic energy through hydraulic turbines coupled to rotating electrical generators designed to convert mechanical energy into electrical energy. For Campos and Moraes (2012), PCHs can be differentiated from large hydroelectric plants based on the analysis of two main aspects, namely: installed power and maximum flooded area. Other variables of interest in the operation of PCHs are the height of their dams and spillways, their turbine flow, in addition to the type of turbine they use (Peltron, Kaplan, Francis, etc.). Costa, Silva, Souza and Souza (2021) highlight, referring to the construction of hydroelectric installations, that hydroelectric projects are controversial when evaluated from the perspective of the environmental and social impacts they cause.

Hesse, Zonta, Amaral, Schuck and Zendron (2023) report that thermoelectric plants generate electrical energy from thermal energy provided by burning fuels. Thermoelectricity corresponds to the production of electrical energy associated with thermal processes that can vary depending on the type of fuel that will be burned. In a simplified way, its operating principle is based on the conversion of thermal energy into mechanical energy intended to drive electrical energy generators (Borges Neto & Carvalho, 2012). The primary source of heat required for the process comes from solar energy, fossil and non-fossil biomass, geothermal or waste incineration, among other possibilities. Oil, coal and natural gas are some of the main fossil fuels on which Brazilian thermoelectric plants operate. Hesse, Zonta, Amaral, Schuck and Zendron (2023) cite sugar cane bagasse, rice husk, elephant grass and black liquor, among others, as biomass fuels.

In the case of Rio Grande do Norte, its participation, as will be discussed later in this article, is modest compared to renewable sources, however in Brazil as a whole thermoelectricity has a significant participation, mainly complementing the hydroelectric generation that still predominates in our matrix. Borges Neto and Carvalho (2012) list that thermoelectric generation has as advantages the fact that, compared to hydroelectric and wind plants, it requires a smaller occupied area, as well as its high mobility capacity, since it can be demobilized, removed and installed in other locations and finally, and mainly, their high degree of service continuity. Allusive to the disadvantages Gurgel, Lima and Sales (2023) point out that the burning of fossil fuels for energy production, as occurs in fossil thermoelectric plants, contributes to the increase in emissions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), all harmful to the Earth's atmosphere.

2.2 Environmental aspects of renewable energy and sustainable development objectives

Society's concerns regarding environmental issues related to climate change have driven the academic-scientific debate on the issue of energy resource exploration (Silva et al., 2015). Gurgel, Lima and Sales (2023) highlight the increase in Greenhouse Gas (GHG) emissions as one of the main causes of climate change. The Sustainable Development Goals – SDGs, proposed by the United Nations, comprise the inclusion of economic, social and environmental dimensions, all mutually integrated, as can be seen in Figure 1 taken from Sena, Freitas, Barcellos, Ramalho and Corvalan (2016). The analysis of Figure 1 allows us to conclude that the theme of energy (included in Figure 1 as “energy for all”) is mainly integrated with the economic and environmental dimensions, while the fight against climate change is more associated with the social and environmental dimensions. . Alves and Fernandes (2020) refer to the publication of the SDGs as establishing a change of perspective in scientific debates related to sustainable development, leaving behind strictly technical and one-dimensional views, to adopt an increasingly procedural, multidimensional and transversal view, with highlighting the social and environmental spheres.

Figure 1: Integration of the SDGs into the economic, social and environmental dimensions.

The consumption structure of the population that constitutes the current modern society is characterized by its high dependence on electrical energy, a particularity that generates disastrous impacts on the environment (Celuppi, 2017). Toledo, Dutra, Zanesco and Moehlecke (2022) report that Brazil follows a global trend of increasing dependence on the use of electrical energy in multiple economic sectors. From the perspective of sustainability, measures must be taken that contribute to reducing environmental impacts and dependence on electricity, promoting more rationalized consumption. Taking this need as a basis, meeting the goals that make up the SDGs requires continuous, committed and effective government participation. Sena et al. (2016) highlight that, as proposed by SDG 7 – clean and affordable energy, increasing the share of sources based on renewable energy in the energy matrix by 2030 is a goal that will still require a lot of effort on the part of Brazil. Energy matrices based on renewable sources, such as the one in the state of Rio Grande do Norte, are in direct line with SDG 7. Full compliance with the provisions of the aforementioned SDG also goes beyond the need to provide universal and reliable access to electrical energy. This last attempt, both in Brazil and in Rio Grande do Norte, is unfortunately still far from being achieved.

3 METHODOLOGY

To achieve the objectives of this work, a methodological strategy was adopted based on carrying out bibliographical research related to the types of electrical energy generation, especially sources of non-fossil origin. This research supported the elaboration of the theoretical framework, as well as providing the foundations for critically evaluating the information available in the databases. Regarding the classification of the research in terms of its methodology, it can be classified as exploratory research, due to the purpose for which it was developed, namely: acquiring familiarity with the data collected and envisioning new insights into the use of information contained therein. Regarding the approach, this is quantitative research as it uses, manipulates and analyzes quantifiable elements. In relation to its nature, it is closer to applied research because it proposes to generate knowledge applicable in practice.

In relation to the materials used, the database consulted to develop the tables, maps and graphs that make up this study was the Aneel Generation Information System – SIGA/ANEEL. Such information is available on the aforementioned agency's web portal, publicly and free of charge, bringing together materials about Brazil's installed electricity generation capacity (Aneel, 2023). Regarding the methods and procedures used, it is reported that the SIGA data was downloaded through the Request function, present in the Python 3.9 programming language, and an Application Programming Interface – API made available by Aneel itself. In order to treat and examine the data available in SIGA, in order to filter them according to the specificities required for this study, data analysis and manipulation techniques (csv and xlsx) based on the Python language and Pandas libraries were applied. and Plotly, these three tools being the main software used in this study. The preference for using the Pandas library arises from its widespread and consolidated use in the area of data science, an aspect that allows broad access to documentation and examples of use in a multitude of scenarios and applications.

Regarding the methodology used to solve the problem, in the context of this study, the functionalities, structures and operations for manipulating numerical tables and time series made available by Pandas were used, with a view to building dataframes containing latitude and longitude data, type of action, classification of energy source, granted and inspected powers and municipality, among other data pertinent to the study. Once we had the generation data for the state of Rio Grande do Norte, already stored in Pandas dataframes, we sought tools that would facilitate the presentation of this information in a more intuitive way, in this sense we opted to use graphics. To achieve this goal, we decided to use the Plotly library. Its use in academic publications has been increasingly widespread due to the multiplicity of graphic formats available, the high degree of formatting available and the differentiated visual quality of the results it provides to its users. In this analysis, version 2.1.4 of Pandas and version 5.18 of Plotly, in its Python version, were used. Another aspect that supported the choice of the aforementioned computing tools was the fact that they are open source solutions (free software) and actively supported by an engaged community of developers, guaranteeing periodic updates and extensive compatibility with different operating systems.

4 RESULTS AND DISCUSSIONS

Regarding the characterization of the study site, it is reported that Rio Grande do Norte is made up of 167 municipalities that make up a total area of 52,809.601 km². The state's capital is the municipality of Natal located on the east coast of the state. Rio Grande do Norte is made up of 5 mesoregions, namely: Oeste Potiguar, Central Potiguar, Agreste Potiguar and Leste Potiguar. The discussion of the results begins by exposing, in Figure 2, a graph showing the total number of electrical generation projects in Rio Grande do Norte that are registered with SIGA until December

2023. Such plants are differentiated according to three classes: under construction, construction not started and in operation. Based on the data collected from Aneel, it is stated that Rio Grande do Norte currently has (December/2023) 326 electricity generation plants in operation. Figure 2 also allows us to glimpse, based on the analysis of the number of plants under construction or with construction not yet started, that over the next few years, another 347 generation projects should be added to the state, in order to constitute a generation park whose forecast is of at least 673 plants in operation. The projects to be added will cause a considerable increase in the installed load of the state's generation park. In view of the above, it can be seen that, if there are no sudden variations in the state's consumption profile over the next few years, the state is taking great strides towards consolidating its energy self-sufficiency.

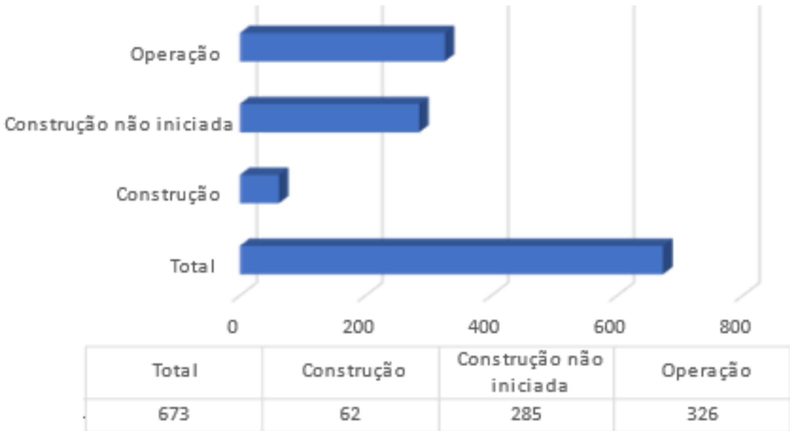


Figure 2: Quantity of electricity generation projects in Rio Grande do Norte, registered with SIGA/Aneel until December 2023.

Based solely on the information contained in Figure 2, it is not possible to assess whether the addition of the aforementioned plants represents a direction by the state matrix towards reducing environmental impact through the addition of non-polluting sources. For such an analysis to be carried out, it is necessary to verify the nature, renewable or non-renewable, of the projects already in operation and especially those that will be incorporated into the state electrical system. In order to encourage and support the beginning of the discussion on the types of projects, information regarding the number of thermoelectric plants currently in operation (December/2023) is presented in Table 1, classifying them into non-fossil (renewable) thermoelectric plants and fossils (non-renewable). The final fuel used to generate electrical energy is also explained.

Table 1: Number of thermoelectric plants in operation in Rio Grande do Norte until December 2023.

Origin	Number of projects	Final fuel	Number of projects by type of fuel
Biomass	2	Sugar cane bagasse	2
Fossil	34	Natural gas	6
		Diesel oil	28

Diesel oil A detailed analysis of Table 1 allows us to see a predominance of diesel oil thermoelectric plants (28 plants) over those that use sugar cane bagasse (2 projects), characterizing the thermoelectric matrix of Rio Grande do Norte as being almost entirely fossil fuel , a negative aspect in terms of environmental pollution generated by these forms of generation. Data related to thermoelectric plants under construction or with works to begin are not presented in Table 1, as a consequence of the fact that, according to consultation with SIGA/Aneel, the construction of projects of this nature is not planned in our state in the next few years. This peculiarity is quite representative, although it cannot be considered conclusive, of the trend towards gradual decarbonization of the generation park in Rio Grande do Norte in the coming years. In order to establish a counterpoint to the fossil predominance of generation from thermoelectric plants, one can analyze the data that constitute Table 2. In the latter it is clear that evaluating solely from the prism of quantity, that is, without taking Taking into account the respective installed generation powers, the total number of renewable projects (292 non-fossil plants in operation) is considerably higher than the 34 generation units of non-renewable origin corresponding to fossil fuel thermoelectric plants (natural gas and diesel oil). This superiority supports the argument in favor of reducing atmospheric pollution inherent to the use of renewables to the detriment of the use of thermoelectric plants.

Table 2: Profile of the state park for generation from renewable sources.

Origin	Number of projects	Phase	Number of projects per phase
PCH	1	Operation	1
Photovoltaics	256	Construction	23
		Construction not started	212
		Operation	21
Wind	382	Construction	39
		Construction not started	73
		Operation	270

An analysis based solely on the number of projects makes the discussion very vague, since the polluting potential will be directly related to the generation power of each unit. In this sense, the granted power (power declared for the purposes of regulating the plant's operation, representing the power at which the plant was authorized to operate) should be one of the pillars that will provide greater robustness to the study, and should therefore be evaluated. Following this line of reasoning, Figures 3 and 4 presented below highlight, respectively, the granted powers (MW) of wind and photovoltaic plants in the construction phase and with construction not yet started.

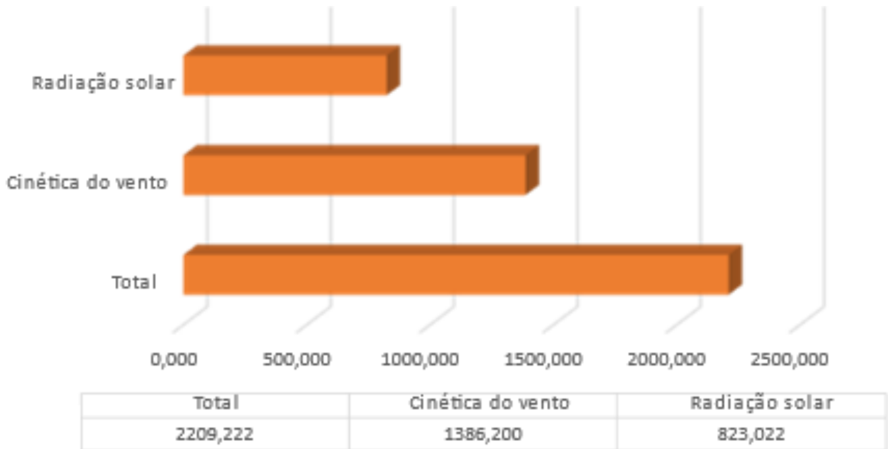
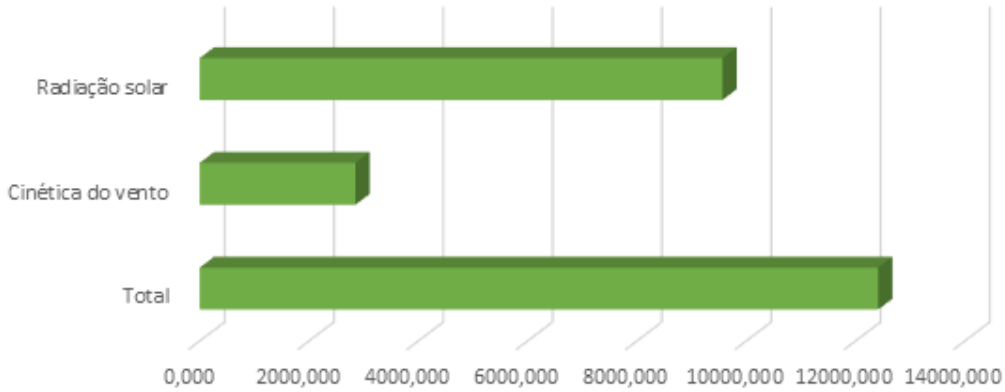


Figure 3: Granted power (MW), for wind (wind kinetics) and photovoltaic (solar radiation) sources, of projects in Rio Grande do Norte under construction.

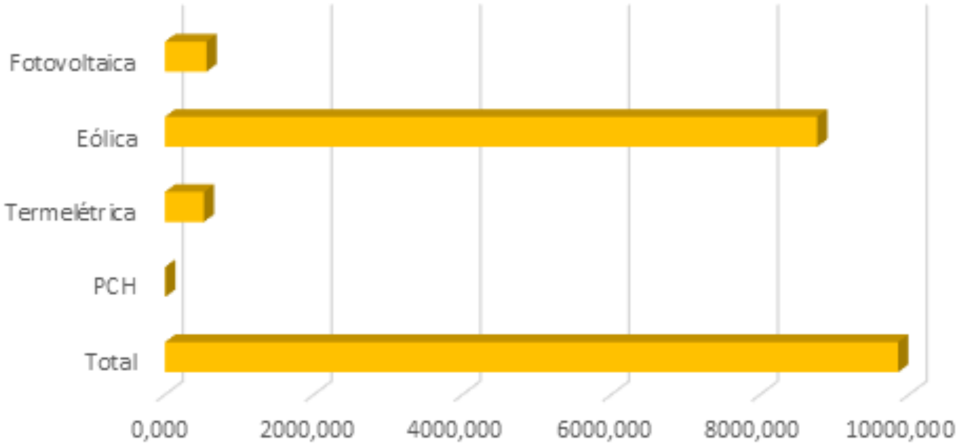


Total	Cinética do vento	Radiação solar
12415,130	2850,200	9564,933

Figure 4: Granted power (MW), for wind (wind kinetics) and photovoltaic (solar radiation) sources, of projects in Rio Grande do Norte in the construction phase that has not started.

In Figure 5 (including wind, photovoltaic, PCH and thermoelectric), you have access to the power of the plants that are already in operation. As previously described, thermoelectric projects, under construction or with work to begin, are not indicated in Figures 3 and 4 as they are not registered in Aneel's SIGA. There are also no plans to build PCHs, therefore they are not included in Figures 3 and 4. Checking Figure 3, it can be seen that a total of 2209.222 MW (2.20 GW) associated with renewable sources of wind and photovoltaic nature are under construction and, therefore, should come into operation in the state in the coming years. This power is associated with 39 wind farms and 23 photovoltaic projects, in line with the data described in Table 2.

In a similar way to the analysis in terms of quantities of generation establishments, the analysis centered on installed power once again brings light to the fact that in the coming years the Potiguar energy matrix will be increasingly renewable and therefore non-polluting, in this sense contributing to improvement in greenhouse gas concentration rates in the Rio Grande do Norte atmosphere. Repeating the analysis, but this time considering the information presented in Figure 4, the wind source, whose origin is associated with the kinetics of the wind, must begin works that will add 2850.2 MW of power, which when integrated into the 9564.933 MW of photovoltaic plants whose respective works are also scheduled to begin in the coming years, will provide approximately 12.41 GW of additional clean energy to the northern Rio Grande do Sul electrical system. Considering projects with construction not yet started and with construction started, the total additional power is estimated at 14.61 GW of energy practically free from adverse effects on the environment. Figure 5 below allows us to compare the installed powers of the projects, considering those that are already in the operating phase, thus providing a general overview of the installed powers of each energy source in Rio Grande do Norte.



Total	PCH	Termelétrica	Eólica	Fotovoltaica
9856,134	4,700	524,809	8768,336	558,289

Figure 5: Granted power (MW), for all sources that make up the energy matrix of Rio Grande do Norte, of the projects in Rio Grande do Norte whose operation is already active.

As widely reported in the media in general and especially in the specialized media, it is clear (Figure 5) the prevalence, in terms of generation capacity, of wind energy in Rio Grande do Norte, a particularity that undeniably demonstrates the predominance of sources not pollutants in our state's energy matrix in terms of number of projects or their respective generation capacities (granted powers). Still in line with Figure 5, for granted power values, a renewable power of 9331.325 MW (wind, PCH and photovoltaic) can be calculated as opposed to the 524.809 MW of installed capacity of a non-renewable nature. Therefore, in the territory of Rio Grande do Norte, fossil power corresponds to less than 10% of non-fossil power, confirming the renewable nature of the electrical matrix in the state of Rio Grande do Norte. A portrait of generation from thermoelectric projects in Rio Grande do Norte, by municipality, is presented in Figures 6 and 7, with Figure 6 associated with the granted power and Figure 7 referring to the supervised power. In them, the aforementioned thermoelectric plants are associated with their respective municipalities, allowing us to verify a predominance of fossil projects in the municipalities of Natal and Parnamirim.

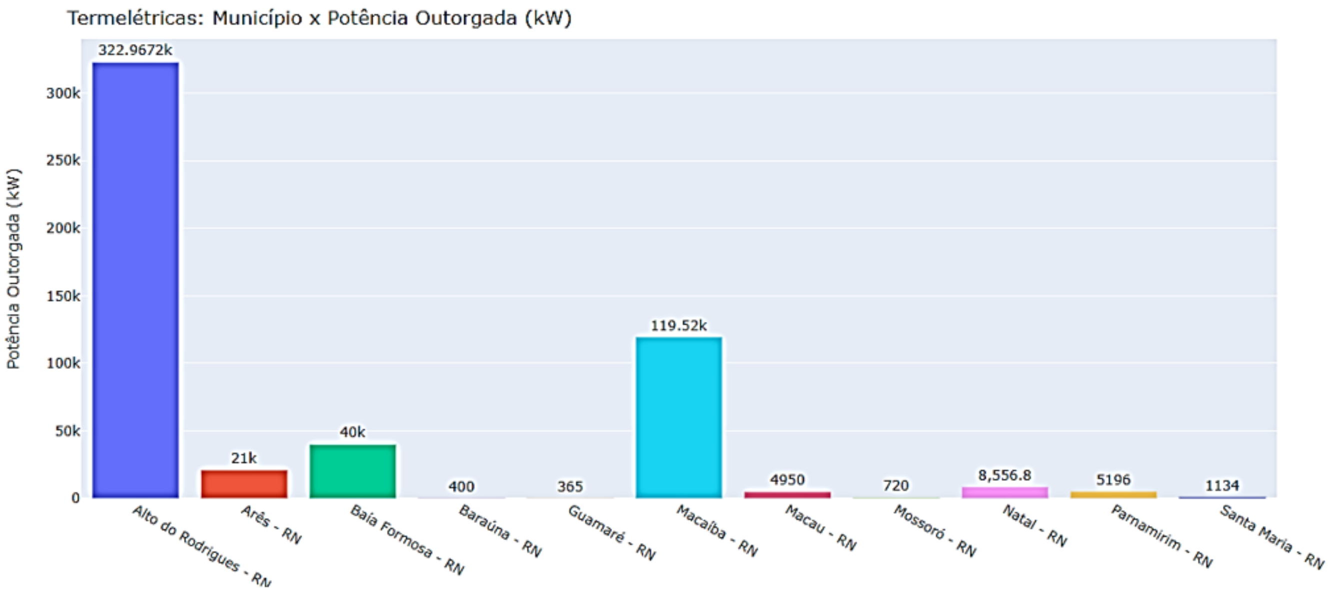


Figure 6: Power granted for thermoelectric generation and respective municipalities where the projects are located.

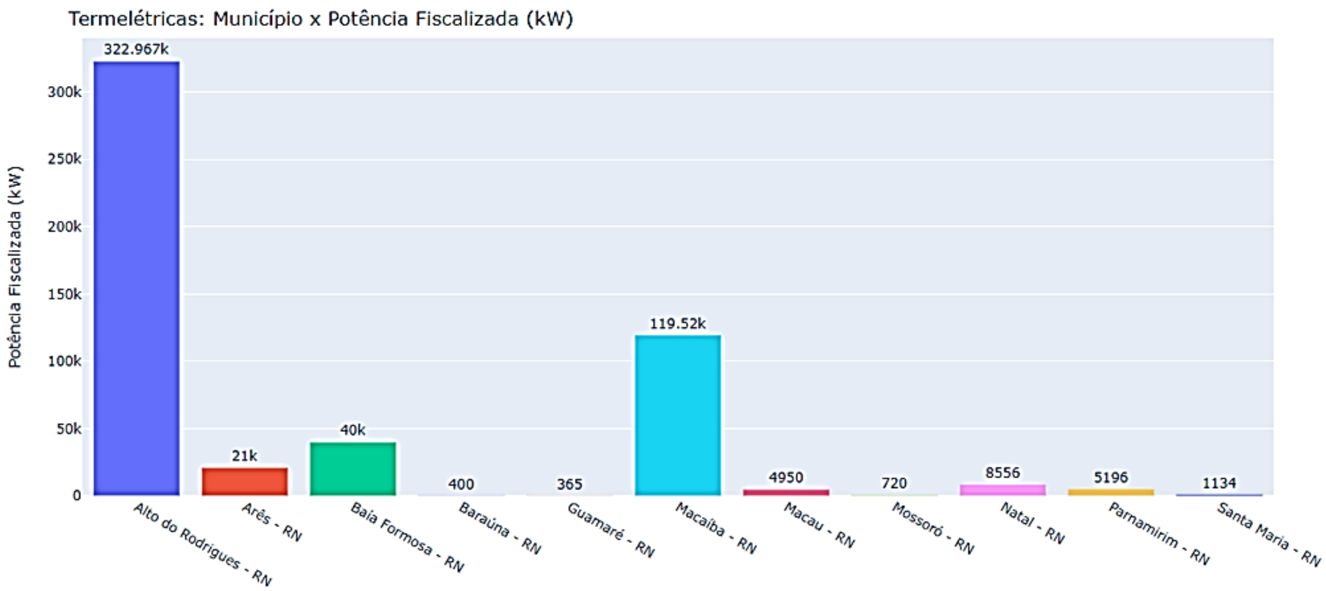


Figure 7: Inspected power referring to thermoelectric generation and respective municipalities where the projects are located.

As the renewable sources that the state has available, particularly wind and photovoltaic, require a vast area for their installation, the closure and replacement of thermoelectric plants located in the municipalities mentioned by renewable projects in regions in the interior of the state would be a possible solution for decarbonization of our centers urban. Figure 8 below provides an opportunity to visualize the geographical arrangement of thermoelectric generation projects on the map of Rio Grande do Norte. In a complementary way to what is presented in Figure 6, Figure 8 also provides information on the granted thermoelectric power of the Potiguar cities located along the state map. The analysis of Figure 9 makes it possible to conclude that, according to the physical layout, Rio Grande do Norte has a greater concentration of thermoelectric plants in the vicinity of the so-called Grande Natal (city of Natal, Parnamirim, Macaíba, Extremoz and São Gonçalo do

Amarante), with greater preponderance for the cities of Natal and Parnamirim previously mentioned.

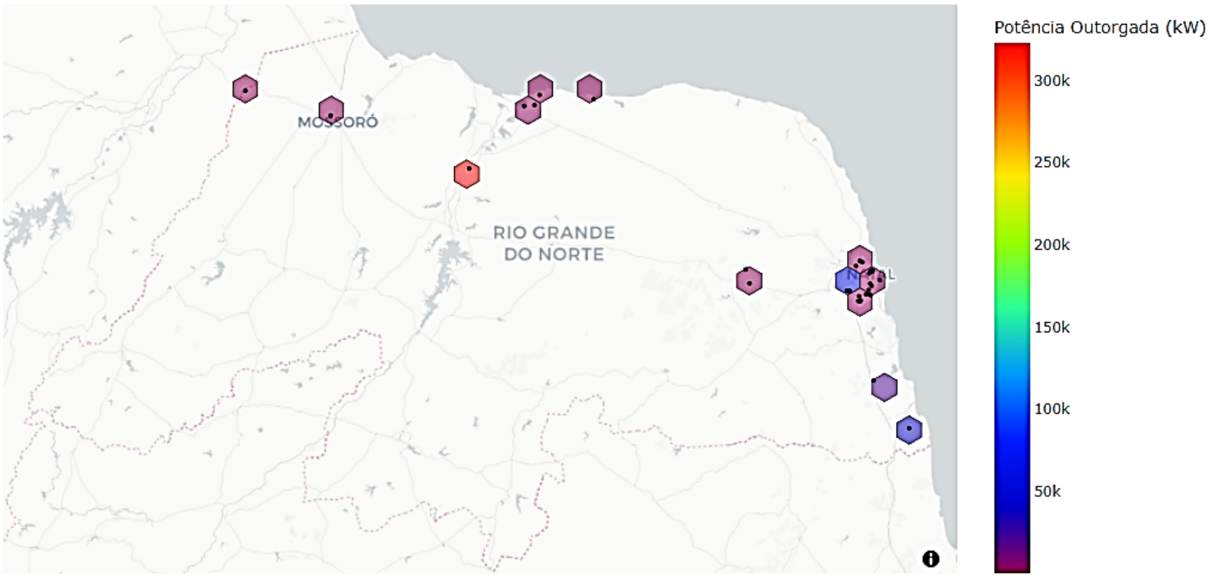


Figure 8: Geographical arrangement of thermoelectric generation projects on the map of Rio Grande do Norte, colored according to their respective granted powers.

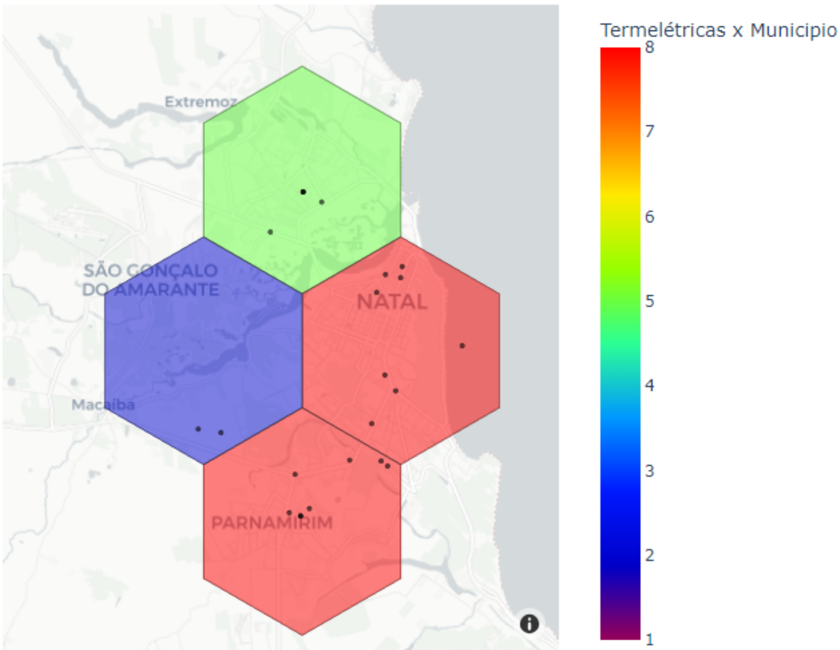


Figure 9: Geographical arrangement of thermoelectric generation projects around Greater Natal.

Continuing the analysis, directing attention to wind farms, Table 3 combines the values of power granted in MW relating to the sum of the powers of wind farms divided by municipality, including those that have wind farms in their territory. To construct Table 3, the wind farms were initially divided by municipality, later the respective sums of granted powers registered in SIGA were calculated, as the values reproduced in Table 3 can be understood as the wind power granted for each municipality, until December 2023. Some plants, due to their large dimensions, occupy more than one city, hence the combination of municipalities in some lines of Table 3. Figure 10 positions the wind plants along the map of Rio Grande do Norte.

Table 3: Wind farm in Rio Grande do Norte – granted power data (kW) registered with SIGA/Aneel.

County	Granted Power. (kW)
Afonso Bezerra	29400,00
Angicos	91200,00
Angicos, Fernando Pedroza	51300,00
Areia Branca	345570,00
Bento Fernandes, Riachuelo	130200,00
Bodó	282800,00
Bodó, Cerro Corá, Santana do Matos	279300,00
Brejinho	6,00
Caiçara do Norte	92300,00
Caiçara do Rio do Vento	321200,00
Caiçara do Rio do Vento, Riachuelo	63000,00
Campo Redondo	63000,00
Ceará-Mirim	145800,00
Cerro Corá	73600,00
Currais Novos	504000,00
Currais Novos, São Vicente	138600,00
Equador	27000,00
Fernando Pedroza	108600,00
Fernando Pedroza, Lajes	68400,00
Fernando Pedroza, Lajes, Santana do Matos	49500,00
Galinhos	118570,00
Guamaré	284450,00
Jandaíra	637290,00
Jandaíra, Lajes	27500,00
Jardim de Angicos	90400,00
João Câmara	741560,00
Lagoa Nova	92000,00
Lagoa Nova, Santana do Matos, São Vicente	16800,00
Lajes	1197500,00
Macau	200470,00
Monte das Gameleiras, São José do Campestre, Serra de São Bento	103500,00
Parazinho	629200,00
Parelhas	220500,00
Pedra Grande	353500,00
Pedra Grande, São Bento do Norte	21000,00
Pedra Preta	513600,00
Pedro Avelino	513200,00
Pureza	139500,00
Riachuelo	63000,00
Riachuelo, Ruy Barbosa	63000,00
Rio do Fogo	77300,00
Ruy Barbosa	121800,00

Santana do Matos	115500,00
Santana do Matos, São Vicente, Tenente Laurentino Cruz	46200,00
São Bento do Norte	605210,00
São José do Campestre	45000,00
São José do Campestre, Serra de São Bento	54000,00
São Miguel do Gostoso	584375,00
São Tomé	664200,00
Serra do Mel	1288320,00
Tenente Laurentino Cruz	28000,00
Touros	483515,00

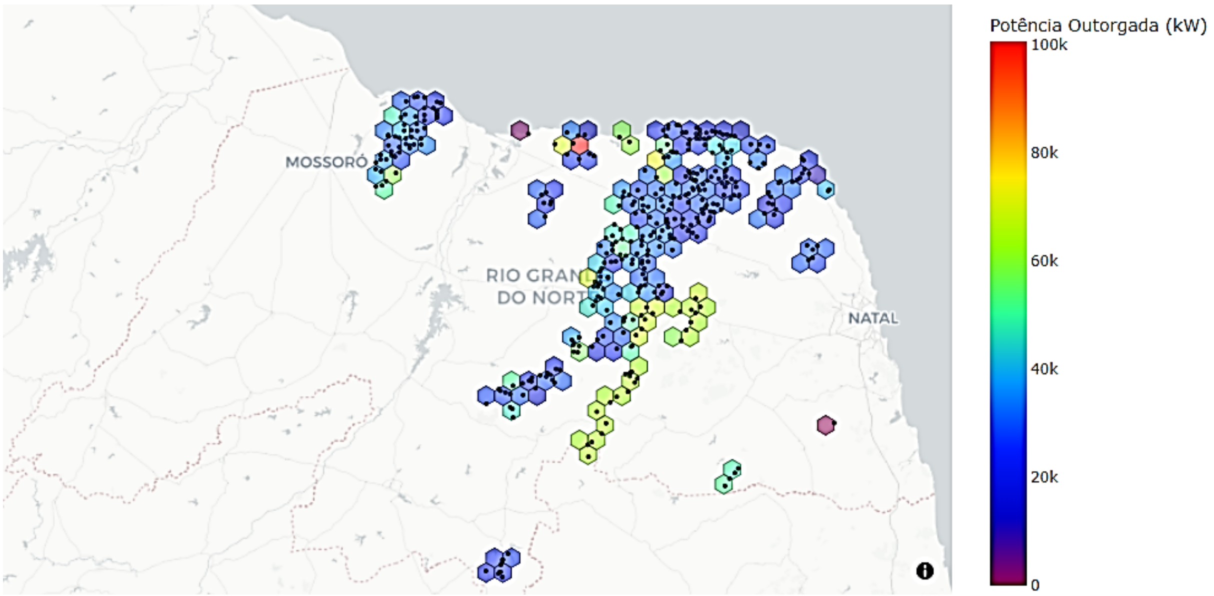


Figure 10: Geographical arrangement of wind generation projects on the map of Rio Grande do Norte, colored according to their respective granted powers.

According to Table 3, the highlight of wind power in the state of Rio Grande do Norte is the cities of Serra do Mel, Lajes and João Câmara, whose respective granted powers are 1.288 GW, 1.197 GW and 0.741 GW. For photovoltaic plants, analogous to previous analyses, their location in Rio Grande do Norte is illustrated in Figure 11, with a color scale based on the municipalities' granted powers (Table 4). The greatest prominence in terms of solar plants is the city of Açu with 4,304 GW of power granted to projects classified as photovoltaic plants. Just like in wind generation, the city of Serra do Mel also stands out in terms of photovoltaic generation, having, according to Aneel, 866.124 MW of photovoltaic power granted. In an intermediate power range, mention should be made of the cities of Ceará Mirim, Currais Novos and Galinhos, with values that vary between 570 MW and 708 MW of granted photovoltaic power.

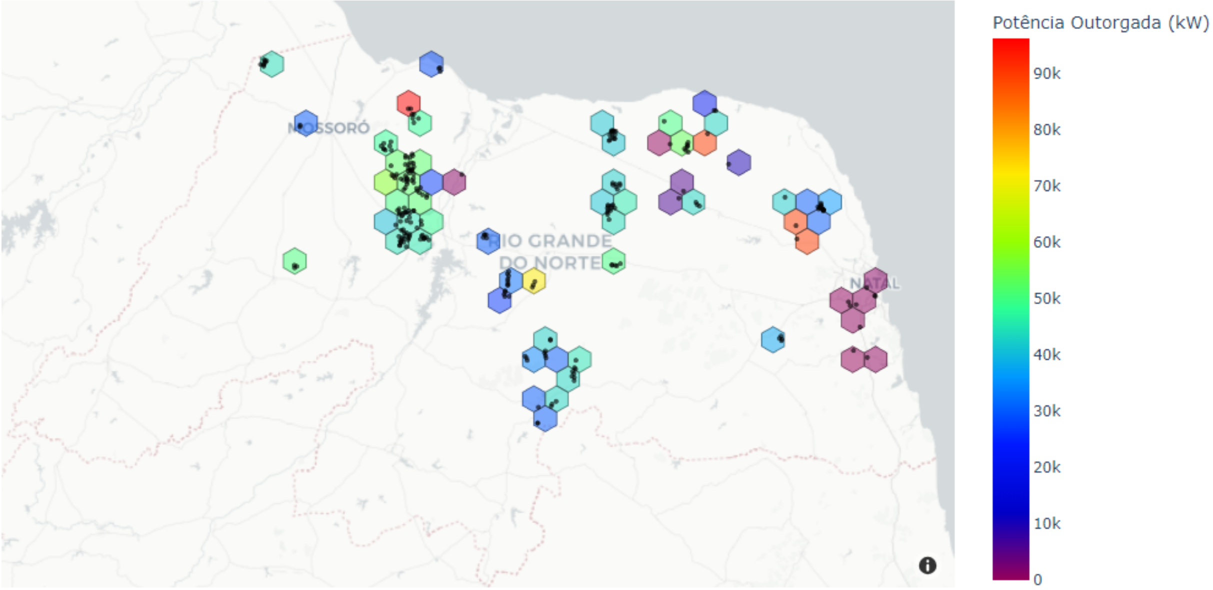


Figure 11: Geographical arrangement of photovoltaic generation projects on the map of Rio Grande do Norte, colored according to their respective granted powers.

Table 4: Photovoltaic project in Rio Grande do Norte – granted power data (kW) registered with SIGA/Aneel.

County	Granted Power. (kW)
Açu	4304992,00
Alto do Rodrigues	1100,00
Angicos	150000,00
Areia Branca	86000,00
Baraúna	354312,00
Bodó	118650,00
Bom Jesus	149985,00
Caraúbas	151848,00
Carnaubais	208000,00
Ceará-Mirim	708642,00
Currais Novos	570000,00
Galinhos	577416,00
Jandaíra	164673,39
João Câmara	141136,00
Lagoa Nova	204920,00
Lajes	338926,13
Macaíba	721,00
Mossoró	60000,00
Natal	2065,04
Parazinho	465000,00
Parnamirim	360,00
Pedra Grande	64548,00
Pedro Avelino	551811,13
Pureza	42000,00
Santana do Matos	602115,00

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São Bento do Norte	50000,00
São José de Mipibu	899,30
Serra do Mel	866124,00
Touros	10000,00

Concluding the discussions, Table 5 displays data on power granted, supervised (commercial operating power of the enterprise) and physical guarantee (capacity that the generator is capable of supplying) of the only generation enterprise of the Small Hydroelectric Power Plant type – PCH in the state of Rio Grande do Norte, located in the city of Açu.

Table 5: Table PCH development in Rio Grande do Norte – power data registered with SIGA/Aneel.

County	Granted Power (kW)	Supervised Power (kW)	Physical Guarantee (kW)
Açu	4700,00	4700,00	3200,00

Regarding the potential of the present study, for example, how and who could make use of the results presented here, it can be mentioned that the reading of the data contained here by companies wishing to geographically map their generation parks and/or the geographic scope of its consumers, companies interested in the state's generation profile in relation to the free energy market, in addition to data mapping by research institutions, research observatories and similar institutions. Regarding the limitations of this study, the results obtained evaluate generation projects classified, according to the criteria established by Aneel (Normative Resolution No. 482/2012), as power plants, that is, generating plants with an installed capacity greater than 3 MW. Therefore, the results obtained do not include information relating to minigeneration projects (installed power between 75 kW and 3 MW) and microgeneration (installed power less than 75 kW), a particularity that limits the scope of the study to a smaller number of projects and which does not provide a geographic scope and spread as large as that which would be obtained in a study involving microgeneration, for example.

5 FINAL CONSIDERATIONS

This work excelled in its objective and direct presentation, materialized primarily through the use of maps, tables and graphs, of a set of data about energy sources in Rio Grande do Norte. Reading it allowed us to have a general overview, considering the time frame of December 2023, of the electrical generation plants distributed in the different regions of the state, as some of the information is divided by municipality. Number of projects in operation, under construction and with authorization to start construction were some, among many others, questions presented and discussed during the course of this text. As presented and discussed, the vast energy potential available in that state has been progressively more explored, characterizing the growing tendency to make its matrix gradually cleaner. There was an increasingly increasing use of renewable energy sources in the electrical matrix of the state of Rio Grande do Norte. Solar photovoltaic and wind are examples of sources whose respective projects are already in operation or have obtained authorization to operate in the coming years, attesting that this trend towards cleaning the matrix should remain on a growth path within the energy context of Rio Grande do Norte.

In the meantime, it can be considered, in a preliminary assessment, that the Potiguar matrix is increasingly renewable, contributing decisively to mitigating the harmful effects associated with environmental pollution, since the use of renewable sources, to the detriment of fossil sources, brings as direct consequence of decarbonizing the atmosphere around the respective generation projects. Multiple challenges are still being faced, such as issues associated with environmental licensing, lack of specific legislation and distribution of employment and income in the municipalities that host these projects. Such questions were not the target of the present study, however, as suggestions for future work, the data presented here could, depending on their interpretation from another point of view, dialogue with these themes, either through data crossing or through the elaboration of trend charts. Still at the heart of future work, the aim is to evaluate the proportion of decarbonization of the electrical matrix in Rio Grande do Norte also considering systems with an installed power of less than 3 MW. Finally, it should be noted that in future work, a similar analysis to that proposed in this study could be replicated to cover other neighboring states or a specific region, for example the northeast region.

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