A proposal for renewable energy viability and environmental conservation in the Caatinga: Challenges and Opportunities

Toni Alex Reis Borges[1,4] *, Filipe Cardoso Brito[2,4], Hugo Saba[3,4], Aloísio Santos Nascimento Filho[2,4]
[1] *Instituto Federal da Bahia - IFBA, Departamento de Computação, Feira de Santana, Bahia, Brasil*
[2] *Universidade SENAI CIMATEC, Departamento Stricto Sensu, Salvador, Bahia, Brazil*
[3] *Universidade do Estado da Bahia – UNEB, Departamento de Ciências Exatas e da Terra, Salvador, Bahia, Brazil*
[4] *Núcleo de Pesquisa Aplicada e Inovação—NPAI, Salvador, Bahia, Brazil*
**Corresponding author: toni.arb@gmail.com*

Abstract: The need to preserve the Caatinga, characterized by a semiarid climate, high temperatures and low humidity with long periods of drought, while considering methods that could utilize these characteristics to minimize their adverse effects, poses a challenge. Despite this need, climate change has sparked significant global concern through the reduction of CO2 emissions. Given this scenario, clean energy generation presents an important alternative to overcome climate challenges. This study seeks to bridge these two needs by sharing resources from irrigation systems developed under the Integrated Development Region strategy. To this end, it seeks to integrate the use of renewable energy supported by a clustering model, grouping different municipalities to ensure the implementation of irrigation infrastructure with democratic participation. The research locus is the state of Ceará, the only state 100% located in this Caatinga region. The solar energy potential of the Northeast region represents a major economic investment in the short term, but with a reduction in the medium and long term. Furthermore, its technical feasibility requires local energy infrastructure and, from a socio-environmental perspective, can foster cooperative and associative work through the sharing economy due to the subdivision of solar panels. Based on this scenario, the results suggest that the use of optimal location points can contribute to the development of more resilient and sustainable energy solutions, benefiting both the environmental preservation of the Caatinga region and the generation of clean energy, the latter supported by the region's solar energy potential.

Keywords: Caatinga, Distributed Energy Generation, Clustering.

1. Introduction

The Caatinga is one of the biomes found in Brazil. Although the characteristics of a semiarid climate, with high temperatures, low humidity, and long periods of drought, are not exclusive to the country, the Northeast region has the highest concentration of Caatinga. (1)

Considering drought as a target of public policies to advance Brazil's development is an important element to be observed (2). With this in mind, Public Irrigation Projects, originated under the strategy of the Integrated Development Region, were adopted by the Brazilian government with a focus mainly on the semi-arid region, aiming at the implementation of an irrigation infrastructure with democratic participation around a group of small, medium and large producers; through the sharing of resources of irrigation systems. (3).

According to the Brazilian Government, represented by the Ministry of Integration and Regional Development, one of the main obstacles to the development of this shared culture was the availability of electricity on the properties for irrigation systems (3).

This lack of energy availability contrasts with the region's energy potential. According to the

Brazilian Solar Energy Atlas (4), direct solar radiation levels occur largely in Northeast Brazil.

According to the Atlas, in addition to photovoltaic technology, electricity generation through thermal use of solar energy may be the main requirement to make the use of this generation technology viable in the region (4).

Investment in solar energy provides a greater economic return in the short term and a reduction in the medium and long term. Its technical viability requires local energy infrastructure and, from a socio-environmental point of view, it can foster cooperative and associative work through the sharing economy due to the division of solar panels (5).

When we look at the Northeast, we have that, according to the Caatinga Association, the caatinga covers the states of Piauí, Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, Sergipe, Bahia and the northern strip of Minas Gerais (1) and, among these, Ceará corresponds to the only state 100% inserted in this region of the caatinga.

A study developed with clustering models to mitigate the impacts caused by climate change, used the concept of distributed microgeneration to enable collaborative production using optimal location points, called centroids (6).

The study mapped the division of municipalities into clusters for the state of Bahia, aiming to form alliances to combine efforts focused on expansion. This study used the k-means algorithm to divide the state into subgroups, which can be representative of the application of a distributed microgeneration approach for the state of Ceará.

Based on the above information, this study seeks to develop a proposal for renewable energy viability and environmental conservation for the Caatinga region, focusing on the state of Ceará. Using clustering models, the study aims to identify optimal locations to support the region's development through the availability of electricity on properties, targeting irrigation systems.

2. Methodology

The methodological approach used in the construction of the clustering process was divided into three phases: Mapping of municipalities in the state of Ceará, Identification of an optimal number of clusters and Grouping of municipalities.

2.1. Mapping of Municipalities in the State of Ceará

According to the Instituto Brasileiro de Geografia e Estatística (IBGE) (7), the state of Ceará has a territorial area of 148,894.444 km² distributed among its 184 municipalities.

The mapping of these municipalities within the state was performed using the *geobr* library of the R programming language (8). The *geobr* package allows access to data from the IBGE.

The points on the map are represented by the latitude and longitude coordinates of the municipalities that comprise the state of Ceará.

2.2. Identification of an Optimal Number of Clusters

The optimal number of clusters is identified by the model's representative points. For this identification, the Elbow model was used to select an optimal output, considering the Euclidean distance between the latitude and longitude coordinates defined in the identification of the municipalities representative points.

2.3. Grouping of Municipalities

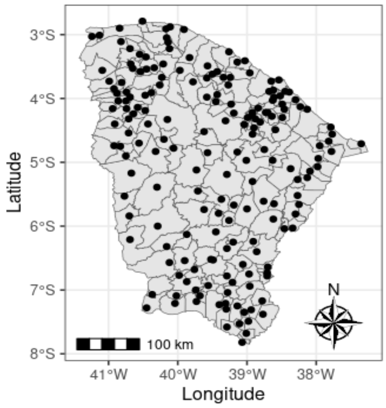
To identify the municipalities that constitute their respective groups, the K-means algorithm was used. The K-means algorithm is the most widely used algorithm and serves as the basis for other clustering techniques used. (9). Still about the author, the algorithm uses simple principles, is easily adaptable and has good performance in real-world scenarios (9).

Among the identified deficiencies, already mentioned in item 2.2, also highlighted by the author, was the randomness of the process which, as a consequence, makes it impossible to guarantee an optimal number of clusters and which was overcome with the integration of the Elbow model.

3. Results

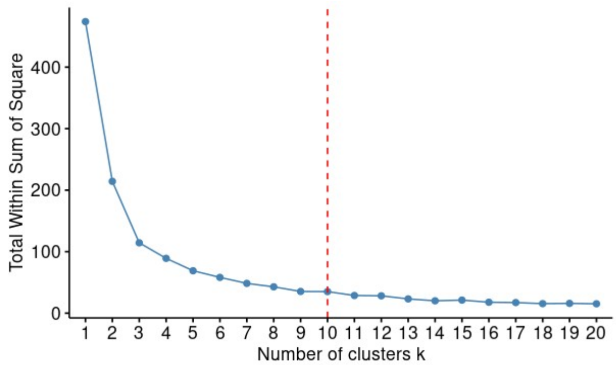
Based on the identified points, here called municipalities, we have their location represented based on latitude and longitude coordinates. (Figure 1) defines the reference for calculating Euclidean distances between municipalities and their respective centroids.

Figure 1. Map of the state of Ceará showing representative the points for calculating the Euclidean distance to the centroids. Development by the authors.



From the methodological approach presented, we have that the optimal number of clusters (k) represented by the Elbow method (Figure 2) identified the value of k equal to 10 for the set of municipalities used.

Figure 2. Optimal cluster number identified using the Elbow method. Development by the authors.



This value suggests that the total number of clusters should not exceed 10, since, as shown in the graph, there is no significant change that would support expanding this scope to reduce the Euclidean distance between municipalities and their respective centroids.

Based on the k value obtained, we have the distribution of municipalities in the state represented by 10 clusters, with their respective centroids, as shown in Table 1.

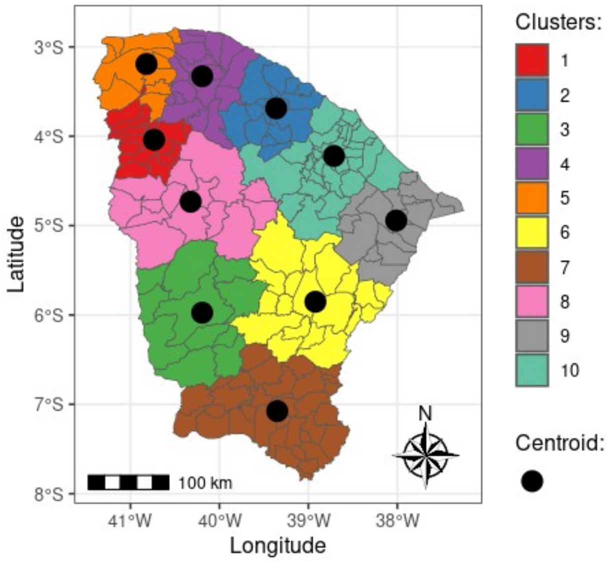
Table 1. Comparative data on the total number of municipalities in the states and their respective groups. Development by the authors.

Centroid	Latitude	Longitude	Total Municipalities
1	-40.73412	-4.040000	17
2	-39.36187	-3.688125	16
3	-40.19364	-5.974545	11
4	-40.19333	-3.328667	15
5	-40.82000	-3.192000	10
6	-38.92053	-5.852632	19
7	-39.34971	-7.076000	35
8	-40.32286	-4.733571	14
9	-38.01214	-4.943571	14
10	-38.71152	-4.220909	33

The final representation of these elements indicates where each centroid should be located to ensure the shortest distance between all municipalities in the clusters.

The distribution of these centroids among the municipalities of the state of Ceará (Figure 3) within their clusters suggests the implementation of micro or mini distributed power plants, with their energy source captured through the region's renewable energy potential, aiming to collaboratively power the municipalities and provide irrigation infrastructure for environmental conservation in the Caatinga.

Figure 3. Identification of Centroids on the clusters identified by the K-means Algorithm. Development by the authors.



4. Discussion

The sharing economy facilitates more economically viable investments. The potential integration between the caatinga vegetation and renewable energy generation technologies, such as solar energy, constitutes a solution capable of developing sustainable energy production for the Brazilian semiarid region, ensuring the implementation of irrigation infrastructure with democratic participation.

The integration of different data sources, as well as the analysis of multiple variables, such as road infrastructure, socioeconomic factors, legal dependency, environmental characteristics, energy networks and technology, among others, are also necessary to ensure that renewable energy projects are efficient, sustainable, and adapted to local realities.

The participation of microgrid-based infrastructures, characteristic of micro and mini distributed energy generation scenarios, although conceptually treated differently, constitutes an important enabling agent for scenarios with limited energy production, especially when collaborative energy production is necessary.

Cluster quantitative identification based on methods such as Elbow can be replaced by other methods, bringing the different specificities of each municipality into closer view.

Although the various scenarios highlighted translate into reality, the existence of optimal location points based on clustering systems opens up possibilities for optimization and efficient management of energy resources.

It is also noteworthy that clustering-based models aim for a decentralization process, providing greater autonomy over the grouped municipalities. They can be applied to different locations, not limited to a specific research locus, making the clustering algorithm a potential ally in constructing scenarios based on this set of characteristics.

5. Conclusion

The objective of this work was to propose a computacional model for low-carbon shared economy irrigation infrastructure projects focused on the development of the Caatinga region.

The use of machine learning-based methods constitutes a potential ally in research involving shared collaboration, especially in areas related to microgrid-based energy production.

These models emerge especially in decentralized settings far from large urban centers, where closer public policy engagement is necessary to promote positive changes in the current scenario, aiming to ensure a more sustainable future for present and future generations.

References

[1] Associação Caatinga. Sobre a Caatinga [Internet]. aCaatinga. Available at: https://www.acaatinga.org.br/sobre-a-caatinga/

[2] Teixeira CS. A economia política da transformação do nordeste: de Furtado a Unger. Cad CRH [Internet]. abril de 2014; 27:201–14. Available at: https://www.scielo.br/j/ccrh/a/Fd4psLkJYDtN4Rkg5Ps9jYk/?lang=pt

[3] Ministério da Integração e do Desenvolvimento Regional B. Irrigação — Ministério da Integração e do Desenvolvimento Regional [Internet]. 2023. Available at: https://www.gov.br/ mdr/pt-br/acesso-a-informacao/perguntas-frequentes/seguranca-hidrica/irrigacao

[4] BRASIL F. Atlas Brasileiro de Energia Solar, prepared by INPE, traça o mapa da produção de energia solar no território nacional(Junho 2017) [Internet]. FUNDAJ. 2021. Available at: https://www.gov.br/fundaj/pt-br/destaques/observa-fundaj-itens/observa-fundaj/a-questao-energetica/atlas-brasileiro-de-energia-solar-elaborado-pelo-inpe-traca-o-mapa-da-producao-de-energia-solar-no-territorio-nacional-junho-2017

[5] Filho ASN, Borges T, Salvador H, Ferreira P, Saba H. Renewable sources to promote well-being in poor regions of Brazil. Frontiers in Physics [Internet]. dezembro de 2022; 10:1048721. Available at: https://www.frontiersin.org/articles/10.3389/fphy.2022.1048721/full

[6] Borges TAR, Brito FC, Saba H, Nascimento Filho AS. RENEWABLE ENERGY PRODUCTION: A CLUSTERING APPROACH FOR DISTRIBUTED MICROGENERATION. In: Blucher Engineering Proceedings [Internet]. Salvador, BA: Editora Blucher; 2024. p. 693–703. Available at: http://www.proceedings.blucher.com.br/article-details/renewable-energy-production-a-clustering-approach-for-distributed-microgeneration-39902

[7] IBGE IBDGEE. Ceará | Cidades e Estados | IBGE [Internet]. 2024 [cited August 2, 2025]. Available at: https://www.ibge.gov.br/cidades-e-estados/ce.html

[8] R PROJECT. Installation [Internet]. Available at: https://cran.r-project.org/web /packages/geobr/vignettes/intro_to_geobr.html

[9] Lantz B. Machine learning with R: discover how to build machine learning algorithms, prepare data, and dig deep into data prediction techniques with R, second edition. 2nd ed. Place of publication not identified: Packt Publishing; 2015. 1 p. (Community Experience Distilled).